

21st Edition

# HARRISON'S® PRINCIPLES OF INTERNAL MEDICINE

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21st Edition

**HARRISON'S®**

PRINCIPLES OF

**INTERNAL  
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## Section 1 Pain

# 13

## Pain: Pathophysiology and Management

James P. Rathmell, Howard L. Fields



The province of medicine is to preserve and restore health and to relieve suffering. Understanding pain is essential to both of these goals. Because pain is universally understood as a signal of disease, it is the most common symptom that brings a patient to a physician's attention. The function of the pain sensory system is to protect the body and maintain homeostasis. It does this by detecting, localizing, and identifying potential or actual tissue-damaging processes. Because different diseases produce characteristic patterns of tissue damage, the quality, time course, and location of a patient's pain lend important diagnostic clues. It is the physician's responsibility to assess each patient promptly for any remediable cause underlying the pain and to provide rapid and effective pain relief whenever possible.

### THE PAIN SENSORY SYSTEM

Pain is an unpleasant sensation localized to a part of the body. It is often described in terms of a penetrating or tissue-destructive process (e.g., stabbing, burning, twisting, tearing, squeezing) and/or of a bodily or emotional reaction (e.g., terrifying, nauseating, sicken). Furthermore, any pain of moderate or higher intensity is accompanied by anxiety and the urge to escape or terminate the feeling. These properties illustrate the duality of pain: it is both sensation and emotion. When it is acute, pain is characteristically associated with behavioral arousal and a stress response consisting of increased blood pressure, heart rate, pupil diameter, and plasma cortisol levels. In addition, local muscle contraction (e.g., limb flexion, abdominal wall rigidity) is often present.

### PERIPHERAL MECHANISMS

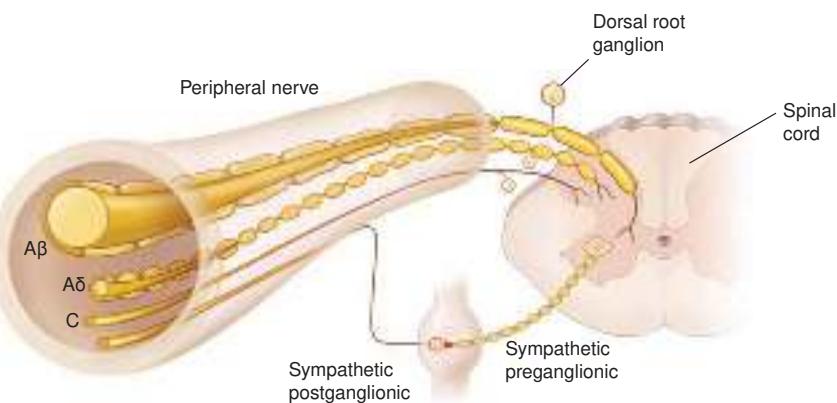
**The Primary Afferent Nociceptor** A peripheral nerve consists of the axons of three different types of neurons: primary sensory afferents, motor neurons, and sympathetic postganglionic neurons (Fig. 13-1). The cell bodies of primary sensory afferents are located in the dorsal root ganglia within the vertebral foramina. The primary afferent axon has two branches: one projects centrally into the spinal cord and the other projects peripherally to innervate tissues. Primary afferents are classified by their diameter, degree of myelination, and conduction velocity. The largest diameter afferent fibers, A-beta ( $A\beta$ ), respond maximally to light touch and/or moving stimuli; they are present primarily in nerves that innervate the skin. In normal individuals, the activity of these fibers does not produce pain. There are two other classes of primary afferent nerve fibers: the small diameter myelinated A-delta ( $A\delta$ ) and the unmyelinated (C) axons (Fig. 13-1). These fibers are present in nerves to the skin and to deep somatic and visceral structures. Some tissues, such as the cornea, are innervated only by  $A\delta$  and C fiber afferents.

Most  $A\delta$  and C fiber afferents respond maximally to intense (painful) stimuli and produce the subjective experience of pain when they are activated; this defines them as *primary afferent nociceptors (pain receptors)*. The ability to detect painful stimuli is completely abolished when conduction in  $A\delta$  and C fiber axons is blocked.

Individual primary afferent nociceptors can respond to several different types of noxious stimuli. For example, most nociceptors respond to heat; intense cold; intense mechanical distortion, such as a pinch; changes in pH, particularly an acidic environment; and application of chemical irritants including adenosine triphosphate (ATP), serotonin, bradykinin (BK), and histamine. The transient receptor potential cation channel subfamily V member 1 (TrpV1), also known as the vanilloid receptor, mediates perception of some noxious stimuli, especially heat sensations, by nociceptive neurons; it is activated by heat, acidic pH, endogenous mediators, and capsaicin, a component of hot chili peppers.

**Sensitization** When intense, repeated, or prolonged stimuli are applied to damaged or inflamed tissues, the threshold for activating primary afferent nociceptors is lowered, and the frequency of firing is higher for all stimulus intensities. Inflammatory mediators such as BK, nerve-growth factor, some prostaglandins (PGs), and leukotrienes contribute to this process, which is called *sensitization*. Sensitization occurs at the level of the peripheral nerve terminal (*peripheral sensitization*) as well as at the level of the dorsal horn of the spinal cord (*central sensitization*). Peripheral sensitization occurs in damaged or inflamed tissues, when inflammatory mediators activate intracellular signal transduction in nociceptors, prompting an increase in the production, transport, and membrane insertion of chemically gated and voltage-gated ion channels. These changes increase the excitability of nociceptor terminals and lower their threshold for activation by mechanical, thermal, and chemical stimuli. Central sensitization occurs when activity, generated by nociceptors during inflammation, enhances the excitability of nerve cells in the dorsal horn of the spinal cord. Following injury and resultant sensitization, normally innocuous stimuli can produce pain (termed *allodynia*). Sensitization is a clinically important process that contributes to tenderness, soreness, and *hyperalgesia* (increased pain intensity in response to the same noxious stimulus; e.g., pinprick causes severe pain). A striking example of sensitization is sunburned skin, in which severe pain can be produced by a gentle slap or a warm shower.

Sensitization is of particular importance for pain and tenderness in deep tissues. Viscera are normally relatively insensitive to noxious mechanical and thermal stimuli, although hollow viscera do generate



**FIGURE 13-1** Components of a typical cutaneous nerve. There are two distinct functional categories of axons: primary afferents with cell bodies in the dorsal root ganglion and sympathetic postganglionic fibers with cell bodies in the sympathetic ganglion. Primary afferents include those with large-diameter myelinated ( $A\beta$ ), small-diameter myelinated ( $A\delta$ ), and unmyelinated (C) axons. All sympathetic postganglionic fibers are unmyelinated.

significant discomfort when distended. In contrast, when affected by a disease process with an inflammatory component, deep structures such as joints or hollow viscera characteristically become exquisitely sensitive to mechanical stimulation.

A large proportion of A<sub>δ</sub> and C fiber afferents innervating viscera are completely insensitive in normal noninjured, noninflamed tissue. That is, they cannot be activated by known mechanical or thermal stimuli and are not spontaneously active. However, in the presence of inflammatory mediators, these afferents become sensitive to mechanical stimuli. Such afferents have been termed *silent nociceptors*, and their characteristic properties may explain how, under pathologic conditions, the relatively insensitive deep structures can become the source of severe and debilitating pain and tenderness. Low pH, PGs, leukotrienes, and other inflammatory mediators such as BK play a significant role in sensitization.

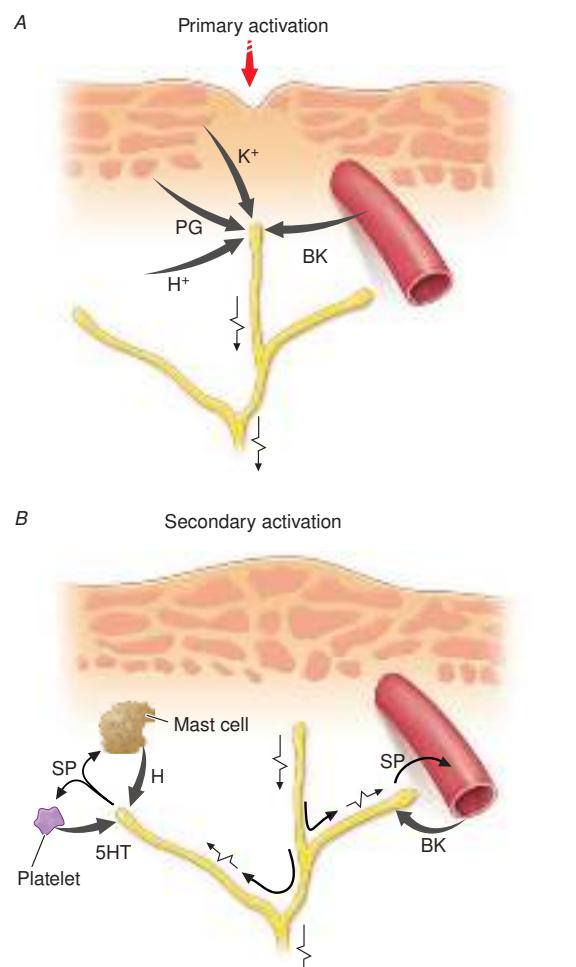
**Nociceptor-Induced Inflammation** Primary afferent nociceptors are not simply passive messengers of threats to tissue injury but also play an active role in tissue protection through a neuroeffector function. Most nociceptors contain polypeptide mediators, including substance P, calcitonin gene related peptide (CGRP), and cholecystokinin, that are released from their peripheral terminals when they are activated (Fig. 13-2). Substance P is an 11-amino-acid peptide that is released in peripheral tissues from primary afferent nociceptors and has multiple biologic activities. It is a potent vasodilator, causes mast cell degranulation, is a chemoattractant for leukocytes, and increases the production and release of inflammatory mediators. Interestingly, depletion of substance P from joints reduces the severity of experimental arthritis.

### CENTRAL MECHANISMS

**The Spinal Cord and Referred Pain** The axons of primary afferent nociceptors enter the spinal cord via the dorsal root. They terminate in the dorsal horn of the spinal gray matter (Fig. 13-3). The terminals of primary afferent axons contact spinal neurons that transmit the pain signal to brain sites involved in pain perception. When primary afferents are activated by noxious stimuli, they release neurotransmitters from their terminals that excite the spinal cord neurons. The major neurotransmitter released is glutamate, which rapidly excites the second-order dorsal horn neurons. Primary afferent nociceptor terminals also release substance P and CGRP, which produce a slower and longer-lasting excitation of the dorsal horn neurons. The axon of each primary afferent contacts many spinal neurons, and each spinal neuron receives convergent inputs from many primary afferents.

The convergence of sensory inputs to a single spinal pain-transmission neuron is of great importance because it underlies the phenomenon of referred pain. All spinal neurons that receive input from the viscera and deep musculoskeletal structures also receive input from the skin. The convergence patterns are determined by the spinal segment of the dorsal root ganglion that supplies the afferent innervation of a structure. For example, the afferents that supply the central diaphragm are derived from the third and fourth cervical dorsal root ganglia. Primary afferents with cell bodies in these same ganglia supply the skin of the shoulder and lower neck. Thus, sensory inputs from both the shoulder skin and the central diaphragm converge on pain-transmission neurons in the third and fourth cervical spinal segments. *Because of this convergence and the fact that the spinal neurons are most often activated by inputs from the skin, activity evoked in spinal neurons by input from deep structures is often mislocalized by the patient to a bodily location that roughly corresponds with the region of skin innervated by the same spinal segment.* Thus, inflammation near the central diaphragm is often reported as shoulder discomfort. This spatial displacement of pain sensation from the site of the injury that produces it is known as *referred pain*.

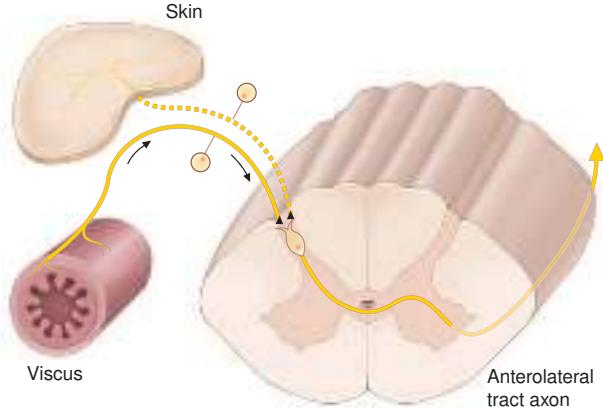
**Ascending Pathways for Pain** A majority of spinal neurons contacted by primary afferent nociceptors send their axons to the contralateral thalamus. These axons form the contralateral spinothalamic tract, which lies in the anterolateral white matter of the spinal cord,



**FIGURE 13-2** Events leading to activation, sensitization, and spread of sensitization of primary afferent nociceptor terminals. *A*. Direct activation by intense pressure and consequent cell damage. Cell damage induces lower pH ( $H^+$ ) and leads to release of potassium ( $K^+$ ) and to synthesis of prostaglandins (PGs) and bradykinin (BK). PGs increase the sensitivity of the terminal to BK and other pain-producing substances. *B*. Secondary activation. Impulses generated in the stimulated terminal propagate not only to the spinal cord but also into other terminal branches where they induce the release of peptides, including substance P (SP). Substance P causes vasodilation and neurogenic edema with further accumulation of BK. Substance P also causes the release of histamine (H) from mast cells and serotonin (5HT) from platelets.

the lateral edge of the medulla, and the lateral pons and midbrain. The spinothalamic pathway is crucial for pain sensation in humans. Interruption of this pathway produces permanent deficits in pain and temperature discrimination.

Spinothalamic tract axons ascend to several regions of the thalamus. There is tremendous divergence of the pain signal from these thalamic sites to several distinct areas of the cerebral cortex that subserve different aspects of the pain experience (Fig. 13-4). One of the thalamic projections is to the somatosensory cortex. This projection mediates the sensory discriminative aspects of pain, i.e., its location, intensity, and quality. Other thalamic neurons project to cortical regions that are linked to emotional responses, such as the cingulate and insular cortex. These pathways to the frontal cortex subserve the affective or unpleasant emotional dimension of pain. This affective dimension of pain produces suffering and exerts potent control of behavior. Because of this dimension, fear is a constant companion of pain. As a consequence, injury or surgical lesions to areas of the frontal cortex activated by painful stimuli can diminish the emotional impact of pain while

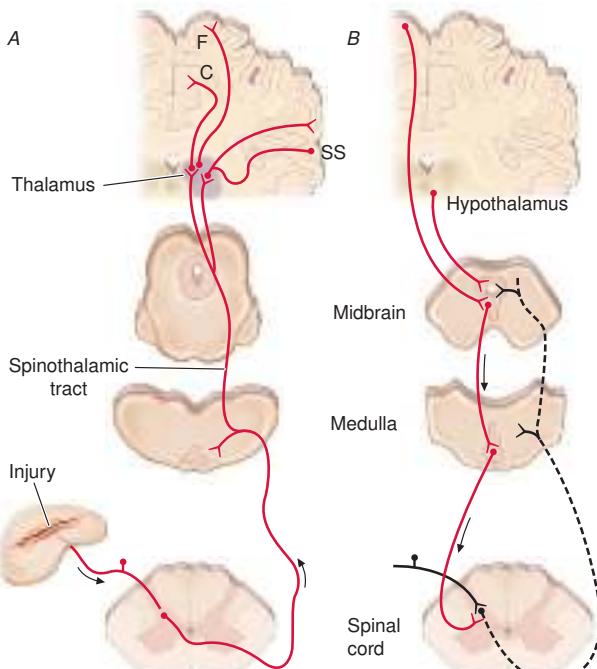


**FIGURE 13-3** The convergence-projection hypothesis of referred pain. According to this hypothesis, visceral afferent nociceptors converge on the same pain-projection neurons as the afferents from the somatic structures in which the pain is perceived. The brain has no way of knowing the actual source of input and mistakenly “projects” the sensation to the somatic structure.

largely preserving the individual's ability to recognize noxious stimuli as painful.

### PAIN MODULATION

The pain produced by injuries of similar magnitude is remarkably variable in different situations and in different individuals. For example, athletes have been known to sustain serious fractures with only minor pain, and Beecher's classic World War II survey revealed that many soldiers in battle were unbothered by injuries that would have produced agonizing pain in civilian patients. Furthermore, even the suggestion

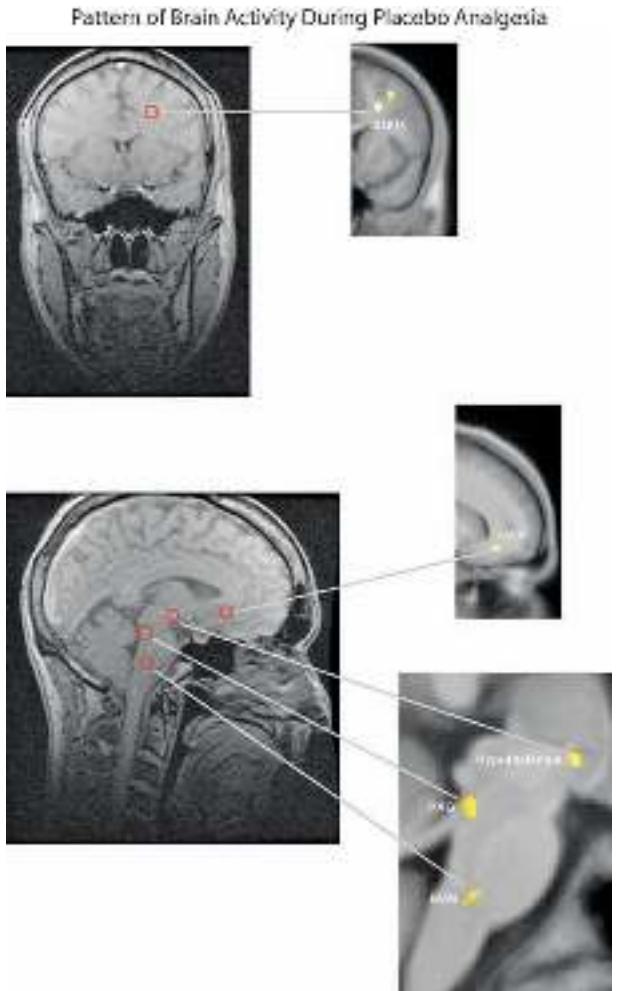


**FIGURE 13-4** Pain-transmission and modulatory pathways. *A*, Transmission system for nociceptive messages. Noxious stimuli activate the sensitive peripheral ending of the primary afferent nociceptor by the process of transduction. The message is then transmitted over the peripheral nerve to the spinal cord, where it synapses with cells of origin of the major ascending pain pathway, the spinothalamic tract. The message is relayed in the thalamus to the anterior cingulate (C), frontal insular (F), and somatosensory cortex (SS). *B*, Pain-modulation network. Inputs from frontal cortex and hypothalamus activate cells in the midbrain that control spinal pain-transmission cells via cells in the medulla.

that a treatment will relieve pain can have a significant analgesic effect (the *placebo effect*). On the other hand, many patients find even minor injuries such as venipuncture frightening and unbearable, and the expectation of pain can induce pain even without a noxious stimulus. The suggestion that pain will worsen following administration of an inert substance can increase its perceived intensity (the *nocebo effect*).

The powerful effect of expectation and other psychological variables on the perceived intensity of pain is explained by brain circuits that modulate the activity of the pain-transmission pathways. One of these circuits has links to the hypothalamus, midbrain, and medulla, and it selectively controls spinal pain-transmission neurons through a descending pathway (Fig. 13-4).

Human brain-imaging studies have implicated this pain-modulating circuit in the pain-relieving effect of attention, suggestion, and opioid analgesic medications (Fig. 13-5). Furthermore, each of the component structures of the pathway contains opioid receptors and is sensitive to the direct application of opioid drugs. In animals, lesions of this descending modulatory system reduce the analgesic effect of



**FIGURE 13-5** Functional magnetic resonance imaging (fMRI) demonstrates placebo-enhanced brain activity in anatomic regions correlating with the opioidergic descending pain control system. *Top panel:* Frontal fMRI image shows placebo-enhanced brain activity in the dorsal lateral prefrontal cortex (DLPFC). *Bottom panel:* Sagittal fMRI images show placebo-enhanced responses in the rostral anterior cingulate cortex (rACC), the rostral ventral medulla (RVM), the periaqueductal gray (PAG) area, and the hypothalamus. The placebo-enhanced activity in all areas was reduced by naloxone, demonstrating the link between the descending opioidergic system and the placebo analgesic response. (*F Eippert et al: Activation of the opioidergic descending pain control system underlies placebo analgesia. Neuron 63(4):533-543, 2009.*)

systemically administered opioids such as morphine. Along with the opioid receptor, the component nuclei of this pain-modulating circuit contain endogenous opioid peptides such as the enkephalins and  $\beta$ -endorphin.

The most reliable way to activate this endogenous opioid-mediated modulating system is by suggestion of pain relief or by intense emotion directed away from the pain-causing injury (e.g., during severe threat or an athletic competition). In fact, pain-relieving endogenous opioids are released following surgical procedures and in patients given a placebo for pain relief.

Pain-modulating circuits can enhance as well as suppress pain. Both pain-inhibiting and pain-facilitating neurons in the medulla project to and control spinal pain-transmission neurons. Because pain-transmission neurons can be activated by modulatory neurons, it is theoretically possible to generate a pain signal with no peripheral noxious stimulus. In fact, human functional imaging studies have demonstrated increased activity in this circuit during migraine headaches. A central circuit that facilitates pain could account for the finding that pain can be induced by suggestion or enhanced by expectation and provides a framework for understanding how psychological factors can contribute to chronic pain.

### ■ NEUROPATHIC PAIN

Lesions of the peripheral or central nociceptive pathways typically result in a loss or impairment of pain sensation. Paradoxically, damage to or dysfunction of these pathways can also produce pain. For example, damage to peripheral nerves, as occurs in diabetic neuropathy, or to primary afferents, as in herpes zoster infection, can result in pain that is referred to the body region innervated by the damaged nerves. Pain may also be produced by damage to the central nervous system (CNS), for example, in some patients following trauma or vascular injury to the spinal cord, brainstem, or thalamic areas that contain central nociceptive pathways. Such pains are termed *neuropathic* and are often severe and resistant to standard treatments for pain.

Neuropathic pain typically has an unusual burning, tingling, or electric shock-like quality and may occur spontaneously, without any stimulus, or be triggered by very light touch. These features are rare in other types of pain. On examination, a sensory deficit is characteristically co-extensive with the area of the patient's pain. *Hypersensitivity*, a greatly exaggerated pain response to innocuous or mild nociceptive stimuli, especially when applied repeatedly, is also characteristic of neuropathic pain; patients often complain that the very lightest moving stimulus evokes exquisite pain (allodynia). In this regard, it is of clinical interest that a topical preparation of 5% lidocaine in patch form is effective for patients with postherpetic neuralgia who have prominent allodynia.

A variety of mechanisms contribute to neuropathic pain. As with sensitized primary afferent nociceptors, damaged primary afferents, including nociceptors, become highly sensitive to mechanical stimulation and may generate impulses in the absence of stimulation. Increased sensitivity and spontaneous activity are due, in part, to an increased density of sodium channels in the damaged nerve fiber. Damaged primary afferents may also develop sensitivity to norepinephrine. Interestingly, spinal cord pain-transmission neurons cut off from their normal input may also become spontaneously active. Thus, both central and peripheral nervous system hyperactivity contribute to neuropathic pain.

**Sympathetically Maintained Pain** Patients with peripheral nerve injury occasionally develop spontaneous pain in or beyond the region innervated by the nerve. This pain is often described as having a burning quality. The pain typically begins after a delay of hours to days or even weeks and is accompanied by swelling of the extremity, periarticular bone loss, and arthritic changes in the distal joints. Early in the course of the condition, the pain may be relieved by a local anesthetic block of the sympathetic innervation to the affected extremity. Damaged primary afferent nociceptors acquire adrenergic sensitivity and can be activated by stimulation of the sympathetic outflow. This constellation of spontaneous pain and signs of sympathetic dysfunction following injury has been termed *complex regional pain*

*syndrome* (CRPS). When this occurs after an identifiable nerve injury, it is termed CRPS type II (also known as posttraumatic neuralgia or, if severe, *causalgia*). When a similar clinical picture appears without obvious nerve injury, it is termed CRPS type I (also known as *reflex sympathetic dystrophy*). CRPS can be produced by a variety of injuries, including fractures of bone, soft tissue trauma, myocardial infarction, and stroke. CRPS type I typically resolves with symptomatic treatment; however, when it persists, detailed examination often reveals evidence of peripheral nerve injury. Although the pathophysiology of CRPS is poorly understood, the pain and the signs of inflammation, when acute, can be rapidly relieved by blocking the sympathetic nervous system. This implies that sympathetic activity can activate undamaged nociceptors when inflammation is present. Signs of sympathetic hyperactivity should be sought in patients with posttraumatic pain and inflammation and no other obvious explanation.

## TREATMENT

### Acute Pain

The ideal treatment for any pain is to remove the cause; thus, while treatment can be initiated immediately, efforts to establish the underlying etiology should always proceed as treatment begins. Sometimes, treating the underlying condition does not immediately relieve pain. Furthermore, some conditions are so painful that rapid and effective analgesia is essential (e.g., the postoperative state, burns, trauma, cancer, or sickle cell crisis). Analgesic medications are a first line of treatment in these cases, and all practitioners should be familiar with their use.

### ASPIRIN, ACETAMINOPHEN, AND NONSTEROIDAL ANTI-INFLAMMATORY AGENTS (NSAIDS)

These drugs are considered together because they are used for similar problems and may have a similar mechanism of action (Table 13-1). All these compounds inhibit cyclooxygenase (COX), and except for acetaminophen, all have anti-inflammatory actions, especially at higher dosages. They are particularly effective for mild to moderate headache and for pain of musculoskeletal origin.

Because they are effective for these common types of pain and are available without prescription, COX inhibitors are by far the most commonly used analgesics. They are absorbed well from the gastrointestinal tract and, with occasional use, have only minimal side effects. With chronic use, gastric irritation is a common side effect of aspirin and NSAIDs and is the problem that most frequently limits the dose that can be given. Gastric irritation is most severe with aspirin, which may cause erosion and ulceration of the gastric mucosa leading to bleeding or perforation. Because aspirin irreversibly acetylates platelet COX and thereby interferes with coagulation of the blood, gastrointestinal bleeding is a particular risk. Older age and history of gastrointestinal disease increase the risks of aspirin and NSAIDs. In addition to the well-known gastrointestinal toxicity of NSAIDs, nephrotoxicity is a significant problem for patients using these drugs on a chronic basis. Patients at risk for renal insufficiency, particularly those with significant contraction of their intravascular volume as occurs with chronic diuretic use or acute hypovolemia, should avoid NSAIDs. NSAIDs can also increase blood pressure in some individuals. Long-term treatment with NSAIDs requires regular blood pressure monitoring and treatment if necessary. Although toxic to the liver when taken in high doses, acetaminophen rarely produces gastric irritation and does not interfere with platelet function.

The introduction of parenteral forms of NSAIDs, ketorolac and diclofenac, extends the usefulness of this class of compounds in the management of acute severe pain. Both agents are sufficiently potent and rapid in onset to supplant opioids as first-line treatment for many patients with acute severe headache and musculoskeletal pain.

There are two major classes of COX: COX-1 is constitutively expressed, and COX-2 is induced in the inflammatory state.

TABLE 13-1 Drugs for Relief of Pain

GENERIC NAME	DOSE, mg	INTERVAL	COMMENTS					
<b>Nonnarcotic Analgesics: Usual Doses and Intervals</b>								
Acetylsalicylic acid	650 PO	q4h	Enteric-coated preparations available					
Acetaminophen	650 PO	q4h	Side effects uncommon					
Ibuprofen	400 PO	q4–6h	Available without prescription					
Naproxen	250–500 PO	q12h	Naproxen is the common NSAID that poses the least cardiovascular risk, but it has a somewhat higher incidence of gastrointestinal bleeding					
Fenoprofen	200 PO	q4–6h	Contraindicated in renal disease					
Indomethacin	25–50 PO	q8h	Gastrointestinal side effects common					
Ketorolac	15–60 IM/IV	q4–6h	Available for parenteral use					
Celecoxib	100–200 PO	q12–24h	Useful for arthritis					
Valdecoxib	10–20 PO	q12–24h	Removed from U.S. market in 2005					
GENERIC NAME	PARENTERAL DOSE, mg	PO DOSE, mg	COMMENTS					
<b>Narcotic Analgesics: Usual Doses and Intervals</b>								
Codeine	30–60 q4h	30–60 q4h	Nausea common					
Oxycodone	—	5–10 q4–6h	Usually available with acetaminophen or aspirin					
Oxycodone extended-release	—	10–40 q12h	Oral extended-release tablet; high potential for misuse					
Morphine	5 q4h	30 q4h						
Morphine sustained release	—	15–60 bid to tid	Oral slow-release preparation					
Hydromorphone	1–2 q4h	2–4 q4h	Shorter acting than morphine sulfate					
Levorphanol	2 q6–8h	4 q6–8h	Longer acting than morphine sulfate; absorbed well PO					
Methadone	5–10 q6–8h	5–20 q6–8h	Due to long half-life, respiratory depression and sedation may persist after analgesic effect subsides; therapy should not be initiated with >40 mg/d, and dose escalation should be made no more frequently than every 3 days					
Meperidine	50–100 q3–4h	300 q4h	Poorly absorbed PO; normeperidine is a toxic metabolite; routine use of this agent is not recommended					
Butorphanol	—	1–2 q4h	Intranasal spray					
Fentanyl	25–100 µg/h	—	72-h transdermal patch					
Buprenorphine	5–20 µg/h		7-day transdermal patch					
Buprenorphine	0.3 q6–8h		Parenteral administration					
Tramadol	—	50–100 q4–6h	Mixed opioid/adrenergic action					
GENERIC NAME	UPTAKE BLOCKADE 5-HT	SEDATIVE NE	ANTICHOLINERGIC POTENCY	ORTHOSTATIC HYPOTENSION	CARDIAC ARRHYTHMIA	AVERAGE DOSE, mg/d	RANGE, mg/d	
<b>Antidepressants<sup>a</sup></b>								
Doxepin	++	+	High	Moderate	Moderate	Less	200	75–400
Amitriptyline	++++	++	High	Highest	Moderate	Yes	150	25–300
Imipramine	++++	++	Moderate	Moderate	High	Yes	200	75–400
Nortriptyline	+++	++	Moderate	Moderate	Low	Yes	100	40–150
Desipramine	+++	++++	Low	Low	Low	Yes	150	50–300
Venlafaxine	+++	++	Low	None	None	No	150	75–400
Duloxetine	+++	+++	Low	None	None	No	40	30–60
GENERIC NAME	PO DOSE, mg	INTERVAL	COMMENTS					
<b>Anticonvulsants and Antiarrhythmics<sup>a</sup></b>								
Carbamazepine	200–300	q6h	Rare aplastic anemia, GI irritation, hepatotoxicity					
Oxcarbamazepine	300	bid	Similar to carbamazepine					
Gabapentin <sup>b</sup>	600–1200	q8h	Dizziness, GI irritation; useful in trigeminal neuralgia					
Pregabalin	150–600	bid	Similar to gabapentin; dry mouth, edema					

<sup>a</sup>Antidepressants, anticonvulsants, and antiarrhythmics have not been approved by the U.S. Food and Drug Administration (FDA) for the treatment of pain. <sup>b</sup>Gabapentin in doses up to 1800 mg/d is FDA approved for postherpetic neuralgia.

Abbreviations: 5-HT, serotonin; NE, norepinephrine; NSAID, nonsteroidal anti-inflammatory agent.

COX-2-selective drugs have similar analgesic potency and produce less gastric irritation than the nonselective COX inhibitors. The use of COX-2-selective drugs does not appear to lower the risk of nephrotoxicity compared to nonselective NSAIDs. On the other hand, COX-2-selective drugs offer a significant benefit in the management of acute postoperative pain because they do not affect blood coagulation. Nonselective COX inhibitors (especially

aspirin) are usually contraindicated postoperatively because they impair platelet-mediated blood clotting and are thus associated with increased bleeding at the operative site. COX-2 inhibitors, including celecoxib (Celebrex), are associated with increased cardiovascular risk, including cardiovascular death, myocardial infarction, stroke, heart failure, or a thromboembolic event. It appears that this is a class effect of NSAIDs, excluding aspirin. These drugs

are contraindicated in patients in the immediate period after coronary artery bypass surgery and should be used with caution in elderly patients and those with a history of or significant risk factors for cardiovascular disease.

### OPIOID ANALGESICS

Opioids are the most potent pain-relieving drugs currently available. Of all analgesics, they have the broadest range of efficacy and provide the most reliable and effective treatment for rapid pain relief. Although side effects are common, most are reversible: nausea, vomiting, pruritus, sedation, and constipation are the most frequent and bothersome side effects. Respiratory depression is uncommon at standard analgesic doses but can be life-threatening. Opioid-related side effects can be reversed rapidly with the narcotic antagonist naloxone. Many physicians, nurses, and patients have a certain trepidation about using opioids that is based on a fear of initiating addiction in their patients. In fact, there is a very small chance of patients becoming addicted to narcotics as a result of their appropriate medical use. For chronic pain, particularly chronic noncancer pain, the risk of addiction in patients taking opioids on a chronic basis remains small, but the risk does appear to increase with dose escalation. The physician should not hesitate to use opioid analgesics in patients with acute severe pain. Table 13-1 lists the most commonly used opioid analgesics.

Opioids produce analgesia by actions in the CNS. They activate pain-inhibitory neurons and directly inhibit pain-transmission neurons. Most of the commercially available opioid analgesics act at the same opioid receptor ( $\mu$ -receptor), differing mainly in potency, speed of onset, duration of action, and optimal route of administration. Some side effects are due to accumulation of nonopioid metabolites that are unique to individual drugs. One striking example of this is normeperidine, a metabolite of meperidine. At higher doses of meperidine, typically  $>1$  g/d, accumulation of normeperidine can produce hyperexcitability and seizures that are not reversible with naloxone. Normeperidine accumulation is increased in patients with renal failure.

The most rapid pain relief is obtained by intravenous administration of opioids; relief with oral administration is significantly slower. Because of the potential for respiratory depression, patients with any form of respiratory compromise must be kept under close observation following opioid administration; an oxygen-saturation monitor may be useful, but only in a setting where the monitor is under constant surveillance. Opioid-induced respiratory depression is primarily manifest as a reduction in respiratory rate and is typically accompanied by sedation. A fall in oxygen saturation represents a critical level of respiratory depression and the need for immediate intervention to prevent life-threatening hypoxemia. Newer monitoring devices that incorporate capnography or pharyngeal air flow can detect apnea at the point of onset and should be used in hospitalized patients. Ventilatory assistance should be maintained until the opioid-induced respiratory depression has resolved. The opioid antagonist naloxone should be readily available whenever opioids are used at high doses or in patients with compromised pulmonary function. Opioid effects are dose-related, and there is great variability among patients in the doses that relieve pain and produce side effects. Synergistic respiratory depression is common when opioids are administered with other CNS depressants. Co-administration of benzodiazepines is particularly likely to produce respiratory depression and should be avoided, especially in outpatient pain management. Because of this variability in patient response, initiation of therapy requires titration to optimal dose and interval. The most important principle is to provide adequate pain relief. This requires determining whether the drug has adequately relieved the pain and timely reassessment to determine the optimal interval for dosing. *The most common error made by physicians in managing severe pain with opioids is to prescribe an inadequate dose. Because many patients are reluctant to complain, this practice leads to needless suffering.*

In the absence of sedation at the expected time of peak effect, a physician should not hesitate to repeat the initial dose to achieve satisfactory pain relief.

A now standard approach to the problem of achieving adequate pain relief is the use of patient-controlled analgesia (PCA). PCA uses a microprocessor-controlled infusion device that can deliver a baseline continuous dose of an opioid drug as well as preprogrammed additional doses whenever the patient pushes a button. The patient can then titrate the dose to the optimal level. This approach is used most extensively for the management of postoperative pain, but there is no reason why it should not be used for any hospitalized patient with persistent severe pain. PCA is also used for short-term home care of patients with intractable pain, such as that caused by metastatic cancer.

It is important to understand that the PCA device delivers small, repeated doses to maintain pain relief; in patients with severe pain, the pain must first be brought under control with a loading dose before transitioning to the PCA device. The bolus dose of the drug (typically 1 mg of morphine, 0.2 mg of hydromorphone, or 10  $\mu$ g of fentanyl) can then be delivered repeatedly as needed. To prevent overdosing, PCA devices are programmed with a lockout period after each demand dose is delivered (typically starting at 10 min) and a limit on the total dose delivered per hour. Although some have advocated the use of a simultaneous continuous or basal infusion of the PCA drug, this may increase the risk of respiratory depression and has not been shown to increase the overall efficacy of the technique.

The availability of new routes of administration has extended the usefulness of opioid analgesics. Most important is the availability of spinal administration. Opioids can be infused through a spinal catheter placed either intrathecally or epidurally. By applying opioids directly to the spinal or epidural space adjacent to the spinal cord, regional analgesia can be obtained using relatively low total doses. Indeed, the dose required to produce effective analgesia when using morphine intrathecally (0.1–0.3 mg) is a fraction of that required to produce similar analgesia when administered intravenously (5–10 mg). In this way, side effects such as sedation, nausea, and respiratory depression can be minimized. This approach has been used extensively during labor and delivery and for postoperative pain relief following surgical procedures. Continuous intrathecal delivery via implanted spinal drug-delivery systems is now commonly used, particularly for the treatment of cancer-related pain that would require sedating doses for adequate pain control if given systemically. Opioids can also be given intranasally (butorphanol), rectally, and transdermally (fentanyl and buprenorphine), or through the oral mucosa (fentanyl), thus avoiding the discomfort of frequent injections in patients who cannot be given oral medication. The fentanyl and buprenorphine transdermal patches have the advantage of providing fairly steady plasma levels, which may improve patient comfort.

Recent additions to the armamentarium for treating opioid-induced side effects are the peripherally acting opioid antagonists alvimopan (Entereg) and methylnaltrexone (Relistor). Alvimopan is available as an orally administered agent that is restricted to the intestinal lumen by limited absorption; methylnaltrexone is available in a subcutaneously administered form that has virtually no penetration into the CNS. Both agents act by binding to peripheral  $\mu$ -receptors, thereby inhibiting or reversing the effects of opioids at these peripheral sites. The action of both agents is restricted to receptor sites outside of the CNS; thus, these drugs can reverse the adverse effects of opioid analgesics that are mediated through their peripheral receptors without reversing their CNS-mediated analgesic effects. Alvimopan has proven effective in lowering the duration of persistent ileus following abdominal surgery in patients receiving opioid analgesics for postoperative pain control. Methylnaltrexone has proven effective for relief of opioid-induced constipation in patients taking opioid analgesics on a chronic basis.

**Opioid and COX Inhibitor Combinations** When used in combination, opioids and COX inhibitors have additive effects. Because a lower dose of each can be used to achieve the same degree of pain relief and their side effects are nonadditive, such combinations are used to lower the severity of dose-related side effects. However, fixed-ratio combinations of an opioid with acetaminophen carry an important risk. Dose escalation as a result of increased severity of pain or decreased opioid effect as a result of tolerance may lead to ingestion of levels of acetaminophen that are toxic to the liver. Although acetaminophen-related hepatotoxicity is uncommon, it remains a significant cause for liver failure. Thus, many practitioners have moved away from the use of opioid-acetaminophen combination analgesics to avoid the risk of excessive acetaminophen exposure as the dose of the analgesic is escalated.

## CHRONIC PAIN

Managing patients with chronic pain is intellectually and emotionally challenging. Sensitization of the nervous system can occur without an obvious precipitating cause, e.g., fibromyalgia, or chronic headache. In many patients, chronic pain becomes a distinct disease unto itself. The pain-generating mechanism is often difficult or impossible to determine with certainty; such patients are demanding of the physician's time and often appear emotionally distraught. The traditional medical approach of seeking an obscure organic pathology is often unhelpful. On the other hand, psychological evaluation and behaviorally based treatment paradigms are frequently helpful, particularly in the setting of a multidisciplinary pain-management center. Unfortunately, this approach, while effective, remains largely underused in current medical practice.

There are several factors that can cause, perpetuate, or exacerbate chronic pain. First, of course, the patient may simply have a disease that is characteristically painful for which there is presently no cure. Arthritis, cancer, chronic daily headaches, fibromyalgia, and diabetic neuropathy are examples of this. Second, there may be secondary perpetuating factors that are initiated by disease and persist after that disease has resolved. Examples include damaged sensory nerves, sympathetic efferent activity, and painful reflex muscle contraction (spasm). Finally, a variety of psychological conditions can exacerbate or even cause pain.

There are certain areas to which special attention should be paid in a patient's medical history. Because depression is the most common emotional disturbance in patients with chronic pain, patients should be questioned about their mood, appetite, sleep patterns, and daily activity. A simple standardized questionnaire, such as the Beck Depression Inventory, can be a useful screening device. It is important to remember that major depression is a common, treatable, and potentially fatal illness.

Other clues that a significant emotional disturbance is contributing to a patient's chronic pain complaint include pain that occurs in multiple, unrelated sites; a pattern of recurrent, but separate, pain problems beginning in childhood or adolescence; pain beginning at a time of emotional trauma, such as the loss of a parent or spouse; a history of physical or sexual abuse; and past or present substance abuse.

On examination, special attention should be paid to whether the patient guards the painful area and whether certain movements or postures are avoided because of pain. Discovering a mechanical component to the pain can be useful both diagnostically and therapeutically. Painful areas should be examined for deep tenderness, noting whether this is localized to muscle, ligamentous structures, or joints. Chronic myofascial pain is very common, and in these patients, deep palpation may reveal highly localized trigger points that are firm bands or knots in muscle. Relief of the pain following injection of local anesthetic into these trigger points supports the diagnosis. A neuropathic component to the pain is indicated by evidence of nerve damage, such as sensory impairment, exquisitely sensitive skin (allodynia), weakness, and muscle atrophy, or loss of deep tendon reflexes. Evidence suggesting sympathetic nervous system involvement includes the presence of diffuse

swelling, changes in skin color and temperature, and hypersensitive skin and joint tenderness compared with the normal side. Relief of the pain with a sympathetic block supports the diagnosis, but once the condition becomes chronic, the response to sympathetic blockade is of variable magnitude and duration; the role for repeated sympathetic blocks in the overall management of CRPS is unclear.

A guiding principle in evaluating patients with chronic pain is to assess both emotional and somatic causal and perpetuating factors before initiating therapy. Addressing these issues together, rather than waiting to address emotional issues after somatic causes of pain have been ruled out, improves compliance in part because it assures patients that a psychological evaluation does not mean that the physician is questioning the validity of their complaint. Even when a somatic cause for a patient's pain can be found, it is still wise to look for other factors. For example, a cancer patient with painful bony metastases may have additional pain due to nerve damage and may also be depressed. Optimal therapy requires that each of these factors be assessed and treated.

## TREATMENT

### Chronic Pain

Once the evaluation process has been completed and the likely causative and exacerbating factors identified, an explicit treatment plan should be developed. An important part of this process is to identify specific and realistic functional goals for therapy, such as getting a good night's sleep, being able to go shopping, or returning to work. A multidisciplinary approach that uses medications, counseling, physical therapy, nerve blocks, and even surgery may be required to improve the patient's quality of life. There are also some newer, minimally invasive procedures that can be helpful for some patients with intractable pain. These include image-guided interventions such as epidural injection of glucocorticoids for acute radicular pain and radiofrequency treatment of the facet joints for chronic facet-related back and neck pain. For patients with severe and persistent pain that is unresponsive to more conservative treatment, placement of electrodes on peripheral nerves or within the spinal canal on nerve roots or in the space overlying the dorsal columns of the spinal cord (spinal cord stimulation) or implantation of intrathecal drug-delivery systems has shown significant benefit. The criteria for predicting which patients will respond to these procedures continue to evolve. They are generally reserved for patients who have not responded to conventional pharmacologic approaches. Referral to a multidisciplinary pain clinic for a full evaluation should precede any invasive procedure. Such referrals are clearly not necessary for all chronic pain patients. For some, pharmacologic management alone can provide adequate relief.

## ANTIDEPRESSANT MEDICATIONS

The tricyclic antidepressants (TCAs), particularly nortriptyline and desipramine (Table 13-1), are useful for the management of chronic pain. Although developed for the treatment of depression, the TCAs have a spectrum of dose-related biologic activities that include analgesia in a variety of chronic clinical conditions. Although the mechanism is unknown, the analgesic effect of TCAs has a more rapid onset and occurs at a lower dose than is typically required for the treatment of depression. Furthermore, patients with chronic pain who are not depressed obtain pain relief with antidepressants. There is evidence that TCAs potentiate opioid analgesia, so they may be useful adjuncts for the treatment of severe persistent pain such as occurs with malignant tumors. Table 13-2 lists some of the painful conditions that respond to TCAs. TCAs are of particular value in the management of neuropathic pain such as occurs in diabetic neuropathy and postherpetic neuralgia, for which there are few other therapeutic options.

The TCAs that have been shown to relieve pain have significant side effects (Table 13-1; Chap. 452). Some of these side effects,

**TABLE 13-2** Painful Conditions That Respond to Tricyclic Antidepressants

Postherpetic neuralgia <sup>a</sup>
Diabetic neuropathy <sup>a</sup>
Fibromyalgia <sup>a</sup>
Tension headache <sup>a</sup>
Migraine headache <sup>a</sup>
Rheumatoid arthritis <sup>a,b</sup>
Chronic low back pain <sup>b</sup>
Cancer
Central poststroke pain

<sup>a</sup>Controlled trials demonstrate analgesia. <sup>b</sup>Controlled studies indicate benefit but not analgesia.

such as orthostatic hypotension, drowsiness, cardiac conduction delay, memory impairment, constipation, and urinary retention, are particularly problematic in elderly patients, and several are additive to the side effects of opioid analgesics. The selective serotonin reuptake inhibitors such as fluoxetine (Prozac) have fewer and less serious side effects than TCAs, but they are much less effective for relieving pain. It is of interest that venlafaxine (Effexor) and duloxetine (Cymbalta), which are nontricyclic antidepressants that block both serotonin and norepinephrine reuptake, appear to retain most of the pain-relieving effect of TCAs with a side effect profile more like that of the selective serotonin reuptake inhibitors. These drugs may be particularly useful in patients who cannot tolerate the side effects of TCAs.

### ANTICONVULSANTS AND ANTIARRHYTHMICS

These drugs are useful primarily for patients with neuropathic pain. Phenytoin (Dilantin) and carbamazepine (Tegretol) were first shown to relieve the pain of trigeminal neuralgia (*Chap. 441*). This pain has a characteristic brief, shooting, electric shock-like quality. In fact, anticonvulsants seem to be particularly helpful for pains that have such a lancinating quality. Newer anticonvulsants, the calcium channel alpha-2-delta subunit ligands gabapentin (Neurontin) and pregabalin (Lyrica), are effective for a broad range of neuropathic pains. Furthermore, because of their favorable side effect profile, these newer anticonvulsants are often used as first-line agents.

### CANNABINOIDS

These agents are widely used for their analgesic properties, although published evidence suggests that any effects are likely to be modest, with small increases in pain threshold reported and variable reductions in clinical pain intensity. Cannabis more consistently reduces the unpleasantness of the pain experience and, in cancer-related pain, can lessen the nausea and vomiting associated with chemotherapy use. *Marijuana and related compounds are discussed in Chap. 455.*

### CHRONIC OPIOID MEDICATION

The long-term use of opioids is accepted for patients with pain due to malignant disease. Although opioid use for chronic pain of nonmalignant origin is controversial, it is clear that, for many patients, opioids are the only option that produces meaningful pain relief. This is understandable because opioids are the most potent and have the broadest range of efficacy of any analgesic medications. Although addiction is rare in patients who first use opioids for pain relief, some degree of tolerance and physical dependence is likely with long-term use. Furthermore, studies suggest that long-term opioid therapy may worsen pain in some individuals, termed *opioid-induced hyperalgesia*. Therefore, before embarking on opioid therapy, other options should be explored, and the limitations and risks of opioids should be explained to the patient. It is also important to point out that some opioid analgesic medications have mixed agonist-antagonist properties (e.g., butorphanol and buprenorphine). From a practical standpoint, this means that they

may worsen pain by inducing an abstinence syndrome in patients who are actively being treated with other opioids and are physically dependent.

With long-term outpatient use of orally administered opioids, it may be desirable to use long-acting compounds such as levorphanol, methadone, extended-release morphine or oxycodone, or transdermal fentanyl (Table 13-1). The pharmacokinetic profiles of these drug preparations enable the maintenance of sustained analgesic blood levels, potentially minimizing side effects such as sedation that are associated with high peak plasma levels, and reducing the likelihood of rebound pain associated with a rapid fall in plasma opioid concentration. Extended-release opioid formulations are approved primarily for patients who are already taking other opioids and should not be used as first-line opioids for pain. Although long-acting opioid preparations may provide superior pain relief in patients with a continuous pattern of ongoing pain, others suffer from intermittent severe episodic pain and experience superior pain control and fewer side effects with the periodic use of short-acting opioid analgesics. Constipation is a virtually universal side effect of opioid use and should be treated expectantly. As noted earlier in the discussion of acute pain treatment, a recent advance for patients is the development of peripherally acting opioid antagonists that can reverse the constipation associated with opioid use without interfering with analgesia.

Soon after the introduction of an extended-release oxycodone formulation (OxyContin) in the late 1990s, a dramatic rise in emergency department visits and deaths associated with oxycodone ingestion appeared. This appears to be due primarily to individuals using a prescription opioid nonmedically. Drug-induced deaths have rapidly risen and are now the second leading cause of death in Americans, just behind motor vehicle fatalities. In 2011, the Office of National Drug Control Policy established a multifaceted approach to address prescription drug abuse, including prescription drug monitoring programs (PDMPs) that allow practitioners to determine if patients are receiving prescriptions from multiple providers and use of law enforcement to eliminate improper prescribing practices. In 2016, the Centers for Disease Control and Prevention (CDC) released the *CDC Guideline for Prescribing Opioids for Chronic Pain*, with recommendations for primary care clinicians who are prescribing opioids for chronic noncancer pain. A modified approach to opioid prescribing was published in 2019 by the Health and Human Services Task Force on chronic pain best medical practices. These guidelines address (1) when to initiate or continue opioids for chronic pain; (2) opioid selection, dosage, duration, follow-up, and discontinuation; and (3) assessing risk and addressing harms of opioid use. The recent increase in scrutiny leaves many practitioners hesitant to prescribe opioid analgesics, other than for brief periods to control pain associated with illness or injury. For now, the choice to begin chronic opioid therapy for a given patient is left to the individual practitioner. Pragmatic guidelines for properly selecting and monitoring patients receiving chronic opioid therapy are shown in Table 13-3; a checklist for primary care clinicians prescribing opioids for noncancer pain is shown in Table 13-4.

### TREATMENT OF NEUROPATHIC PAIN

It is important to individualize treatment for patients with neuropathic pain. Several general principles should guide therapy: the first is to move quickly to provide relief, and the second is to minimize drug side effects. For example, in patients with postherpetic neuralgia and significant cutaneous hypersensitivity, topical lidocaine (Lidoderm patches) can provide immediate relief without side effects. The anticonvulsants gabapentin or pregabalin (see above) or antidepressants (nortriptyline, desipramine, duloxetine, or venlafaxine) can be used as first-line drugs for patients with neuropathic pain. Systemically administered antiarrhythmic drugs such as lidocaine and mexiletine are less likely to be effective. Although intravenous infusion of lidocaine can provide analgesia for patients with different types of neuropathic pain, the relief is usually transient,

**TABLE 13-3 Guidelines for Selecting and Monitoring Patients Receiving Chronic Opioid Therapy (COT) for the Treatment of Chronic, Noncancer Pain**

#### Patient Selection

- Conduct a history, physical examination, and appropriate testing, including an assessment of risk of substance abuse, misuse, or addiction.
- Consider a trial of COT if pain is moderate or severe, pain is having an adverse impact on function or quality of life, and potential therapeutic benefits outweigh potential harms.
- A benefit-to-harm evaluation, including a history, physical examination, and appropriate diagnostic testing, should be performed and documented before and on an ongoing basis during COT.

#### Informed Consent and Use of Management Plans

- Informed consent should be obtained. A continuing discussion with the patient regarding COT should include goals, expectations, potential risks, and alternatives to COT.
- Consider using a written COT management plan to document patient and clinician responsibilities and expectations and assist in patient education.

#### Initiation and Titration

- Initial treatment with opioids should be considered as a therapeutic trial to determine whether COT is appropriate.
- Opioid selection, initial dosing, and titration should be individualized according to the patient's health status, previous exposure to opioids, attainment of therapeutic goals, and predicted or observed harms.

#### Monitoring

- Reassess patients on COT periodically and as warranted by changing circumstances. Monitoring should include documentation of pain intensity and level of functioning, assessments of progress toward achieving therapeutic goals, presence of adverse events, and adherence to prescribed therapies.
- In patients on COT who are at high risk or who have engaged in aberrant drug-related behaviors, clinicians should periodically obtain urine drug screens or other information to confirm adherence to the COT plan of care.
- In patients on COT not at high risk and not known to have engaged in aberrant drug-related behaviors, clinicians should consider periodically obtaining urine drug screens or other information to confirm adherence to the COT plan of care.

Source: Adapted with permission from R Chou et al: Clinical guidelines for the use of chronic opioid therapy in chronic noncancer pain. *J Pain* 10:113, 2009.

typically lasting just hours after the cessation of the infusion. The oral lidocaine congener mexiletine is poorly tolerated, producing frequent gastrointestinal adverse effects. There is no consensus on which class of drug should be used as a first-line treatment for any chronically painful condition. However, because relatively high doses of anticonvulsants are required for pain relief, sedation is not uncommon. Sedation is also a problem with TCAs but is much less of a problem with serotonin/norepinephrine reuptake inhibitors (SNRIs; e.g., venlafaxine and duloxetine). Thus, in the elderly or in patients whose daily activities require high-level mental activity, these drugs should be considered the first line. In contrast, opioid medications should be used as a second- or third-line drug class. Although highly effective for many painful conditions, opioids are sedating, and their effect tends to lessen over time, leading to dose escalation and, occasionally, a worsening of pain. A couple of interesting alternatives to pure opioids are two drugs with mixed opioid and norepinephrine reuptake action: tramadol and tapentadol. Tramadol is a relatively weak opioid but is sometimes effective for pain unresponsive to nonopioid analgesics. Tapentadol is a stronger opioid, but its analgesic action is apparently enhanced by the norepinephrine reuptake blockade. Similarly, drugs of different classes can be used in combination to optimize pain control. Repeated injection of botulinum toxin is an emerging approach that is showing some promise in treating focal neuropathic pain, particularly post-herpetic, trigeminal, and post-traumatic neuralgias.

It is worth emphasizing that many patients, especially those with chronic pain, seek medical attention primarily because they are

**TABLE 13-4 Centers for Disease Control and Prevention Checklist for Prescribing Opioids for Chronic Pain**

For Primary Care Providers Treating Adults (18+) with Chronic Pain ≥3 months, Excluding Cancer, Palliative, and End-of-Life Care

#### CHECKLIST

##### WHEN CONSIDERING LONG-TERM OPIOID THERAPY

- Set realistic goals for pain and function based on diagnosis (e.g., walk around the block).
- Check that nonopioid therapies tried and optimized.
- Discuss benefits and risks (e.g., addiction, overdose) with patient.
- Evaluate risk of harm or misuse.
  - Discuss risk factors with patient.
  - Check prescription drug monitoring program (PDMP) data.
  - Check urine drug screen.
- Set criteria for stopping or continuing opioids.
- Assess baseline pain and function (e.g., Pain, Enjoyment, General Activity [PEG] scale).
- Schedule initial reassessment within 1–4 weeks.
- Prescribe short-acting opioids using lowest dosage on product labeling; match duration to scheduled reassessment.

##### IF RENEWING WITHOUT A PATIENT VISIT

- Check that return visit is scheduled ≤3 months from last visit.

##### WHEN REASSESSING AT A PATIENT VISIT

- Continue opioids only after confirming clinically meaningful improvements in pain and function without significant risks or harm.
- Assess pain and function (e.g., PEG); compare results to baseline.
- Evaluate risk of harm or misuse:
  - Observe patient for signs of oversedation or overdose risk. If yes: Taper dose.
  - Check PDMP.
  - Check for opioid use disorder if indicated (e.g., difficulty controlling use). If yes: Refer for treatment.
- Check that nonopioid therapies optimized. Determine whether to continue, adjust, taper, or stop opioids.
- Calculate opioid dosage morphine milligram equivalent (MME).
  - If ≥50 MME/day total ( $\geq$ 50 mg hydrocodone;  $\geq$ 33 mg oxycodone), increase frequency of follow-up; consider offering naloxone.
  - Avoid  $\geq$ 90 MME/day total ( $\geq$ 90 mg hydrocodone;  $\geq$ 60 mg oxycodone), or carefully justify; consider specialist referral.
- Schedule reassessment at regular intervals ( $\leq$ 3 months).

Source: Centers for Disease Control and Prevention, available at: <https://stacks.cdc.gov/view/cdc/38025>. Accessed May 25, 2017 (Public Domain).

suffering and because only physicians can provide the medications required for pain relief. A primary responsibility of all physicians is to minimize the physical and emotional discomfort of their patients. Familiarity with pain mechanisms and analgesic medications is an important step toward accomplishing this aim.

#### ■ FURTHER READING

- D V MJ et al: Association of cannabinoid administration with experimental pain in healthy adults a systematic review and meta-analysis. *JAMA Psychiatry* 75:1118, 2018.
- D D et al: CDC guideline for prescribing opioids for chronic pain—United States, 2016. *JAMA* 315:1624, 2016.
- F NB et al: Pharmacotherapy for neuropathic pain in adults: A systematic review and meta-analysis. *Lancet Neurol* 14:162, 2015.
- S EC et al: Incidence of and risk factors for chronic opioid use among opioid-naïve patients in the postoperative period. *JAMA Intern Med* 176:1286, 2016.
- U.S. D H H S : Pain management best practices inter-agency task force report: Updates, gaps, inconsistencies, and recommendations. May 2019. <https://www.hhs.gov/ash/advisory-committees/pain/reports/index.html>.

Chest discomfort is among the most common reasons for which patients present for medical attention at either an emergency department (ED) or an outpatient clinic. The evaluation of nontraumatic chest discomfort is inherently challenging owing to the broad variety of possible causes, a minority of which are life-threatening conditions that should not be missed. It is helpful to frame the initial diagnostic assessment and triage of patients with acute chest discomfort around three categories: (1) myocardial ischemia; (2) other cardiopulmonary causes (myopericardial disease, aortic emergencies, and pulmonary conditions); and (3) noncardiopulmonary causes. Although rapid identification of high-risk conditions is a priority of the initial assessment, strategies that incorporate routine liberal use of testing carry the potential for adverse effects of unnecessary investigations.

## EPIDEMIOLOGY AND NATURAL HISTORY

Chest discomfort is one of the three most common reason for visits to the ED in the United States, resulting in 6 to 7 million emergency visits each year. More than 60% of patients with this presentation are hospitalized for further testing, and most of the remainder undergo additional investigation in the ED. Fewer than 15% of evaluated patients are eventually diagnosed with acute coronary syndrome (ACS), with rates of 10–20% in most series of unselected populations, and a rate as low as 5% in some studies. The most common diagnoses are gastrointestinal causes (Fig. 14-1), and as few as 5% are other life-threatening cardiopulmonary conditions. In a large proportion of patients with transient acute chest discomfort, ACS or another acute cardiopulmonary cause is excluded but the cause is not determined. Therefore, the resources and time devoted to the evaluation of chest discomfort *in the absence of a severe cause* are substantial. Nevertheless, historically, a disconcerting 2–6% of patients with chest discomfort of presumed nonischemic etiology who are discharged from the ED were later deemed to have had a missed myocardial infarction (MI). Patients with a missed diagnosis of MI have a 30-day risk of death that is double that of their counterparts who are hospitalized.

The natural histories of ACS, myocarditis, acute pericardial diseases, pulmonary embolism, and aortic emergencies are discussed in Chaps. 270, 273, 274, 275, 279, and 280, respectively. In a study of more than 350,000 patients with unspecified presumed noncardiopulmonary chest discomfort, the mortality rate 1 year after discharge was <2% and did not differ significantly from age-adjusted mortality in the general

population. The estimated rate of major cardiovascular events through 30 days in patients with acute chest pain who had been stratified as low risk was 2.5% in a large population-based study that excluded patients with ST-segment elevation or definite noncardiac chest pain.

## CAUSES OF CHEST DISCOMFORT

The major etiologies of chest discomfort are discussed in this section and summarized in Table 14-1. Additional elements of the history, physical examination, and diagnostic testing that aid in distinguishing these causes are discussed in a later section (see “Approach to the Patient”).

### ■ MYOCARDIAL ISCHEMIA/INJURY

Myocardial ischemia causing chest discomfort, termed *angina pectoris*, is a primary clinical concern in patients presenting with chest symptoms. Myocardial ischemia is precipitated by an imbalance between myocardial oxygen requirements and myocardial oxygen supply, resulting in insufficient delivery of oxygen to meet the heart's metabolic demands. Myocardial oxygen consumption may be elevated by increases in heart rate, ventricular wall stress, and myocardial contractility, whereas myocardial oxygen supply is determined by coronary blood flow and coronary arterial oxygen content. When myocardial ischemia is sufficiently severe and prolonged in duration (as little as 20 min), irreversible cellular injury occurs, resulting in MI.

Ischemic heart disease is most commonly caused by atherosomatous plaque that obstructs one or more of the epicardial coronary arteries. Stable ischemic heart disease (Chap. 273) usually results from the gradual atherosclerotic narrowing of the coronary arteries. *Stable angina* is characterized by ischemic episodes that are typically precipitated by a superimposed increase in oxygen demand during physical exertion and relieved upon resting. Ischemic heart disease becomes unstable, manifest by ischemia at rest or with an escalating pattern, most commonly when rupture or erosion of one or more atherosclerotic lesions triggers coronary thrombosis. Unstable ischemic heart disease is further classified clinically by the presence or absence of detectable acute myocardial injury and the presence or absence of ST-segment elevation on the patient's electrocardiogram (ECG). When acute coronary atherothrombosis occurs, the intracoronary thrombus may be partially obstructive, generally leading to myocardial ischemia in the absence of ST-segment elevation. Unstable ischemic heart disease is classified as *unstable angina* when there is no detectable acute myocardial injury and as *non-ST elevation MI* (NSTEMI) when there is evidence of acute myocardial necrosis (Chap. 274). When the coronary thrombus is acutely and completely occlusive, transmural myocardial ischemia usually ensues, with ST-segment elevation on the ECG and myocardial necrosis leading to a diagnosis of *ST elevation MI* (STEMI; see Chap. 275).

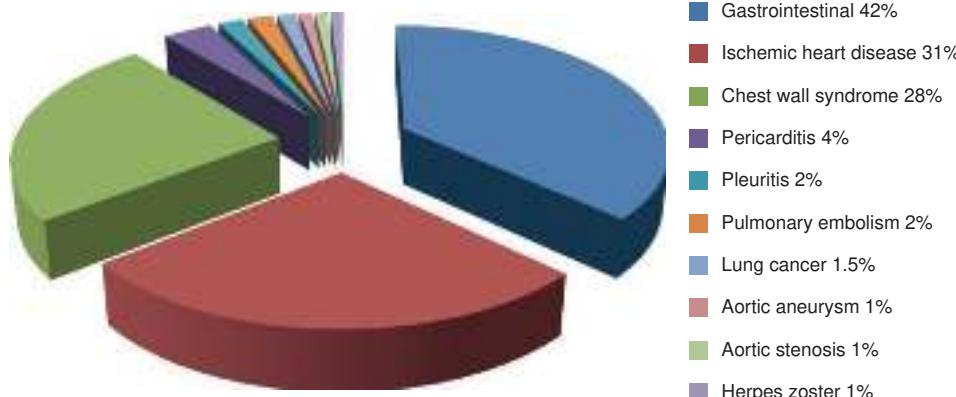


FIGURE 14-1 Distribution of final discharge diagnoses in patients with nontraumatic acute chest pain. (Figure prepared from data in P Fruergaard et al: Eur Heart J 17:1028, 1996.)

TABLE 14-1 Typical Clinical Features of Major Causes of Acute Chest Discomfort

SYSTEM	CONDITION	ONSET/DURATION	QUALITY	LOCATION	ASSOCIATED FEATURES
<b>Cardiopulmonary</b>					
Cardiac	Myocardial ischemia	<i>Stable angina:</i> Precipitated by exertion, cold, or stress; 2–10 min <i>Unstable angina:</i> Increasing pattern or at rest <i>Myocardial infarction:</i> Usually >30 min	Pressure, tightness, squeezing, heaviness, burning	Retrosternal; often radiation to neck, jaw, shoulders, or arms; sometimes epigastric	S <sub>1</sub> gallop or mitral regurgitation murmur (rare) during pain; S <sub>3</sub> or rales if severe ischemia or complication of myocardial infarction
	Pericarditis	Variable; hours to days; may be episodic	Pleuritic, sharp	Retrosternal or toward cardiac apex; may radiate to left shoulder	May be relieved by sitting up and leaning forward; pericardial friction rub
<b>Vascular</b>					
Vascular	Acute aortic syndrome	Sudden onset of unrelenting pain	Tearing or ripping; knifelike	Anterior chest, often radiating to back, between shoulder blades	Associated with hypertension and/or underlying connective tissue disorder; murmur of aortic insufficiency; loss of peripheral pulses
	Pulmonary embolism	Sudden onset	Pleuritic; may manifest as heaviness with massive pulmonary embolism	Often lateral, on the side of the embolism	Dyspnea, tachypnea, tachycardia, and hypotension
	Pulmonary hypertension	Variable; often exertional	Pressure	Substernal	Dyspnea, signs of increased venous pressure
<b>Pulmonary</b>					
Pulmonary	Pneumonia or pleuritis	Variable	Pleuritic	Unilateral, often localized	Dyspnea, cough, fever, rales, occasional rub
	Spontaneous pneumothorax	Sudden onset	Pleuritic	Lateral to side of pneumothorax	Dyspnea, decreased breath sounds on side of pneumothorax
<b>Noncardiopulmonary</b>					
Gastrointestinal	Esophageal reflux	10–60 min	Burning	Substernal, epigastric	Worsened by postprandial recumbency; relieved by antacids
	Esophageal spasm	2–30 min	Pressure, tightness, burning	Retrosternal	Can closely mimic angina
	Peptic ulcer	Prolonged; 60–90 min after meals	Burning	Epigastric, substernal	Relieved with food or antacids
	Gallbladder disease	Prolonged	Aching or colicky	Epigastric, right upper quadrant; sometimes to the back	May follow meal
Neuromuscular	Costochondritis	Variable	Aching	Sternal	Sometimes swollen, tender, warm over joint; may be reproduced by localized pressure on examination
	Cervical disk disease	Variable; may be sudden	Aching; may include numbness	Arms and shoulders	May be exacerbated by movement of neck
	Trauma or strain	Usually constant	Aching	Localized to area of strain	Reproduced by movement or palpation
	Herpes zoster	Usually prolonged	Sharp or burning	Dermatomal distribution	Vesicular rash in area of discomfort
Psychological	Emotional and psychiatric conditions	Variable; may be fleeting or prolonged	Variable; often manifests as tightness and dyspnea with feeling of panic or doom	Variable; may be retrosternal	Situational factors may precipitate symptoms; history of panic attacks, depression

Clinicians should be aware that unstable ischemic symptoms may also occur predominantly because of increased myocardial oxygen demand (e.g., during intense psychological stress or fever) or because of decreased oxygen delivery due to anemia, hypoxia, or hypotension. However, the term *acute coronary syndrome*, which encompasses unstable angina, NSTEMI, and STEMI, is in general reserved for ischemia precipitated by acute coronary atherothrombosis. In order to guide therapeutic strategies, a standardized system for classification of MI has been expanded to discriminate MI resulting from acute coronary thrombosis (type 1 MI) from MI occurring secondary to other imbalances of myocardial oxygen supply and demand (type 2 MI; see Chap. 274). These conditions are additionally distinguished from nonischemic causes of acute myocardial injury, such as myocarditis.

Other contributors to stable and unstable ischemic heart disease, such as endothelial dysfunction, microvascular disease, and vasoconstriction, may exist alone or in combination with coronary atherosclerosis and may be the dominant cause of myocardial ischemia in some patients. Moreover, nonatherosclerotic processes, including congenital abnormalities of the coronary vessels, myocardial bridging, coronary arteritis, and radiation-induced coronary disease, can lead to coronary obstruction. In addition, conditions associated with extreme myocardial oxygen demand and impaired endocardial blood flow, such as aortic valve disease (Chap. 280), hypertrophic cardiomyopathy, or idiopathic dilated cardiomyopathy (Chap. 259), can precipitate myocardial ischemia in patients with or without underlying obstructive atherosclerosis.

**Characteristics of Ischemic Chest Discomfort** The clinical characteristics of angina pectoris, often referred to simply as “angina,” are highly similar whether the ischemic discomfort is a manifestation of stable ischemic heart disease, unstable angina, or MI; the exceptions are differences in the pattern and duration of symptoms associated with these syndromes (Table 14-1). Heberden initially described angina as a sense of “strangling and anxiety.” Chest discomfort characteristic of myocardial ischemia is typically described as aching, heavy, squeezing, crushing, or constricting. However, in a substantial minority of patients, the quality of discomfort is extremely vague and may be described as a mild tightness, or merely an uncomfortable feeling, that sometimes is experienced as numbness or a burning sensation. The site of the discomfort is usually retrosternal, but radiation is common and generally occurs down the ulnar surface of the left arm; the right arm, both arms, neck, jaw, or shoulders may also be involved. These and other characteristics of ischemic chest discomfort pertinent to discrimination from other causes of chest pain are discussed later in this chapter (see “Approach to the Patient”).

Stable angina usually begins gradually and reaches its maximal intensity over a period of minutes before dissipating within several minutes with rest or with nitroglycerin. The discomfort typically occurs predictably at a characteristic level of exertion or psychological stress. By definition, unstable angina is manifest by anginal chest discomfort that occurs with progressively lower intensity of physical activity or even at rest. Chest discomfort associated with MI is commonly more severe, is prolonged (usually lasting  $\geq 30$  min), and is not relieved by rest.

**Mechanisms of Cardiac Pain** The neural pathways involved in ischemic cardiac pain are poorly understood. Ischemic episodes are thought to excite local chemosensitive and mechanoreceptive receptors that, in turn, stimulate release of adenosine, bradykinin, and other substances that activate the sensory ends of sympathetic and vagal afferent fibers. The afferent fibers traverse the nerves that connect to the upper five thoracic sympathetic ganglia and upper five distal thoracic roots of the spinal cord. From there, impulses are transmitted to the thalamus. Within the spinal cord, cardiac sympathetic afferent impulses may converge with impulses from somatic thoracic structures, and this convergence may be the basis for referred cardiac pain. In addition, cardiac vagal afferent fibers synapse in the nucleus tractus solitarius of the medulla and then descend to the upper cervical spinothalamic tract, and this route may contribute to anginal pain experienced in the neck and jaw.

## ■ OTHER CARDIOPULMONARY CAUSES

**Pericardial and Other Myocardial Diseases (See also Chap. 270)** Inflammation of the pericardium due to infectious or noninfectious causes can be responsible for acute or chronic chest discomfort. The visceral surface and most of the parietal surface of the pericardium are insensitive to pain. Therefore, the pain of pericarditis is thought to arise principally from associated pleural inflammation. Because of this pleural association, the discomfort of pericarditis is usually pleuritic pain that is exacerbated by breathing, coughing, or changes in position. Moreover, owing to the overlapping sensory supply of the central diaphragm via the phrenic nerve with somatic sensory fibers originating in the third to fifth cervical segments, the pain of pleural and pericardial inflammation is often referred to the shoulder and neck. Involvement of the pleural surface of the lateral diaphragm can lead to pain in the upper abdomen.

Acute inflammatory and other nonischemic myocardial diseases can also produce chest discomfort. The symptoms of acute myocarditis are highly varied. Chest discomfort may either originate with inflammatory injury of the myocardium or be due to severe increases in wall stress related to poor ventricular performance. The symptoms of *Takotsubo (stress-related) cardiomyopathy* often start abruptly with chest pain and shortness of breath. This form of cardiomyopathy, in its most recognizable form, is triggered by an emotionally or physically stressful event and may mimic acute MI because of its commonly

associated ECG abnormalities, including ST-segment elevation, and elevated biomarkers of myocardial injury. Observational studies support a predilection for women >50 years of age.

**Diseases of the Aorta (See also Chap. 280)** Acute aortic dissection (Fig. 14-1) is a less common cause of chest discomfort but is important because of the catastrophic natural history of certain subsets of cases when recognized late or left untreated. Acute aortic syndromes encompass a spectrum of acute aortic diseases related to disruption of the media of the aortic wall. *Aortic dissection* involves a tear in the aortic intima, resulting in separation of the media and creation of a separate “false” lumen. A *penetrating ulcer* has been described as ulceration of an aortic atheromatous plaque that extends through the intima and into the aortic media, with the potential to initiate an intramedial dissection or rupture into the adventitia. *Intramural hematoma* is an aortic wall hematoma with no demonstrable intimal flap, no radiologically apparent intimal tear, and no false lumen. Intramural hematoma can occur due to either rupture of the vasa vasorum or, less commonly, a penetrating ulcer.

Each of these subtypes of acute aortic syndrome typically presents with chest discomfort that is often severe, sudden in onset, and sometimes described as “tearing” in quality. Acute aortic syndromes involving the *ascending* aorta tend to cause pain in the midline of the anterior chest, whereas *descending* aortic syndromes most often present with pain in the back. Therefore, dissections that begin in the ascending aorta and extend to the descending aorta tend to cause pain in the front of the chest that extends toward the back, between the shoulder blades. Proximal aortic dissections that involve the ascending aorta (type A in the Stanford nomenclature) are at high risk for major complications that may influence the clinical presentation, including (1) compromise of the aortic ostia of the coronary arteries, resulting in MI; (2) disruption of the aortic valve, causing acute aortic insufficiency; and (3) rupture of the hematoma into the pericardial space, leading to pericardial tamponade.

Knowledge of the epidemiology of acute aortic syndromes can be helpful in maintaining awareness of this relatively uncommon group of disorders (estimated annual incidence, 3 cases per 100,000 population). Nontraumatic aortic dissections are very rare in the absence of hypertension or conditions associated with deterioration of the elastic or muscular components of the aortic media, including pregnancy, bicuspid aortic disease, or inherited connective tissue diseases, such as Marfan and Ehlers-Danlos syndromes.

Although aortic aneurysms are most often asymptomatic, thoracic aortic aneurysms can cause chest pain and other symptoms by compressing adjacent structures. This pain tends to be steady, deep, and occasionally severe. Aortitis, whether of noninfectious or infectious etiology, in the absence of aortic dissection is a rare cause of chest or back discomfort.

**Pulmonary Conditions** Pulmonary and pulmonary-vascular conditions that cause chest discomfort usually do so in conjunction with dyspnea and often produce symptoms that have a pleuritic nature.

**PULMONARY EMBOLISM (SEE ALSO CHAP. 279)** Pulmonary emboli (annual incidence, ~1 per 1000) can produce dyspnea and chest discomfort that is sudden in onset. Typically pleuritic in pattern, the chest discomfort associated with pulmonary embolism may result from (1) involvement of the pleural surface of the lung adjacent to a resultant pulmonary infarction; (2) distention of the pulmonary artery; or (3) possibly, right ventricular wall stress and/or subendocardial ischemia related to acute pulmonary hypertension. The pain associated with small pulmonary emboli is often lateral and pleuritic and is believed to be related to the first of these three possible mechanisms. In contrast, massive pulmonary emboli may cause severe substernal pain that may mimic an MI and that is plausibly attributed to the second and third of these potential mechanisms. Massive or submassive pulmonary embolism may also be associated with syncope, hypotension, and signs of right heart failure. Other typical characteristics that aid in the recognition of pulmonary embolism are discussed later in this chapter (see “Approach to the Patient”).

**PNEUMOTHORAX (SEE ALSO CHAP. 294)** Primary spontaneous pneumothorax is a rare cause of chest discomfort, with an estimated annual incidence in the United States of 7 per 100,000 among men and <2 per 100,000 among women. Risk factors include male sex, smoking, family history, and Marfan syndrome. The symptoms are usually sudden in onset, and dyspnea may be mild; thus, presentation to medical attention is sometimes delayed. Secondary spontaneous pneumothorax may occur in patients with underlying lung disorders, such as chronic obstructive pulmonary disease, asthma, or cystic fibrosis, and usually produces symptoms that are more severe. Tension pneumothorax is a medical emergency caused by trapped intrathoracic air that precipitates hemodynamic collapse.

**Other Pulmonary Parenchymal, Pleural, or Vascular Disease (See also Chaps. 283, 284, and 294)** Most pulmonary diseases that produce chest pain, including pneumonia and malignancy, do so because of involvement of the pleura or surrounding structures. Pleurisy is typically described as a knifelike pain that is worsened by inspiration or coughing. In contrast, chronic pulmonary hypertension can manifest as chest pain that may be very similar to angina in its characteristics, suggesting right ventricular myocardial ischemia in some cases. Reactive airways diseases similarly can cause chest tightness associated with breathlessness rather than pleurisy.

## ■ NONCARDIOPULMONARY CAUSES

**Gastrointestinal Conditions (See also Chap. 321)** Gastrointestinal disorders are the most common cause of nontraumatic chest discomfort and often produce symptoms that are difficult to discern from more serious causes of chest pain, including myocardial ischemia. Esophageal disorders, in particular, may simulate angina in the character and location of the pain. Gastroesophageal reflux and disorders of esophageal motility are common and should be considered in the differential diagnosis of chest pain (Fig. 14-1 and Table 14-1). The pain of esophageal spasm is commonly an intense, squeezing discomfort that is retrosternal in location and, like angina, may be relieved by nitroglycerin or dihydropyridine calcium channel antagonists. Chest pain can also result from injury to the esophagus, such as a Mallory-Weiss tear or even an esophageal rupture (Boerhaave's syndrome) caused by severe vomiting. Peptic ulcer disease is most commonly epigastric in location but can radiate into the chest (Table 14-1).

Hepatobiliary disorders, including cholecystitis and biliary colic, may mimic acute cardiopulmonary diseases. Although the pain arising from these disorders usually localizes to the right upper quadrant of the abdomen, it is variable and may be felt in the epigastrium and radiate to the back and lower chest. This discomfort is sometimes referred to the scapula or may in rare cases be felt in the shoulder, suggesting diaphragmatic irritation. The pain is steady, usually lasts several hours, and subsides spontaneously, without symptoms between attacks. Pain resulting from pancreatitis is typically aching epigastric pain that radiates to the back.

**Musculoskeletal and Other Causes (See also Chap. 360)** Chest discomfort can be produced by any musculoskeletal disorder involving the chest wall or the nerves of the chest wall, neck, or upper limbs. Costochondritis causing tenderness of the costochondral junctions (*Tietze's syndrome*) is relatively common. Cervical radiculitis may manifest as a prolonged or constant aching discomfort in the upper chest and limbs. The pain may be exacerbated by motion of the neck. Occasionally, chest pain can be caused by compression of the brachial plexus by the cervical ribs, and tendinitis or bursitis involving the left shoulder may mimic the radiation of angina. Pain in a dermatomal distribution can also be caused by cramping of intercostal muscles or by herpes zoster (Chap. 193).

**Emotional and Psychiatric Conditions** As many as 10% of patients who present to EDs with acute chest discomfort have a panic disorder or related condition (Table 14-1). The symptoms may include chest tightness or aching that is associated with a sense of anxiety and difficulty breathing. The symptoms may be prolonged or fleeting.

## APPROACH TO THE PATIENT

### Chest Discomfort

Given the broad set of potential causes and the heterogeneous risk of serious complications in patients who present with acute nontraumatic chest discomfort, the priorities of the initial clinical encounter include assessment of (1) the patient's clinical stability and (2) the probability that the patient has an underlying cause of the discomfort that may be life-threatening. The high-risk conditions of principal concern are acute cardiopulmonary processes, including ACS, acute aortic syndrome, pulmonary embolism, tension pneumothorax, and pericarditis with tamponade. Fulminant myocarditis also carries a poor prognosis but is usually also manifest by heart failure symptoms. Among noncardiopulmonary causes of chest pain, esophageal rupture likely holds the greatest urgency for diagnosis. Patients with these conditions may deteriorate rapidly despite initially appearing well. The remaining population with non-cardiopulmonary conditions has a more favorable prognosis during completion of the diagnostic workup. A rapid targeted assessment for a serious cardiopulmonary cause is of particular relevance for patients with acute ongoing pain who have presented for emergency evaluation. Among patients presenting in the outpatient setting with chronic pain or pain that has resolved, a general diagnostic assessment is reasonably undertaken (see "Outpatient Evaluation of Chest Discomfort," below). A series of questions that can be used to structure the clinical evaluation of patients with chest discomfort is shown in Table 14-2.

### HISTORY

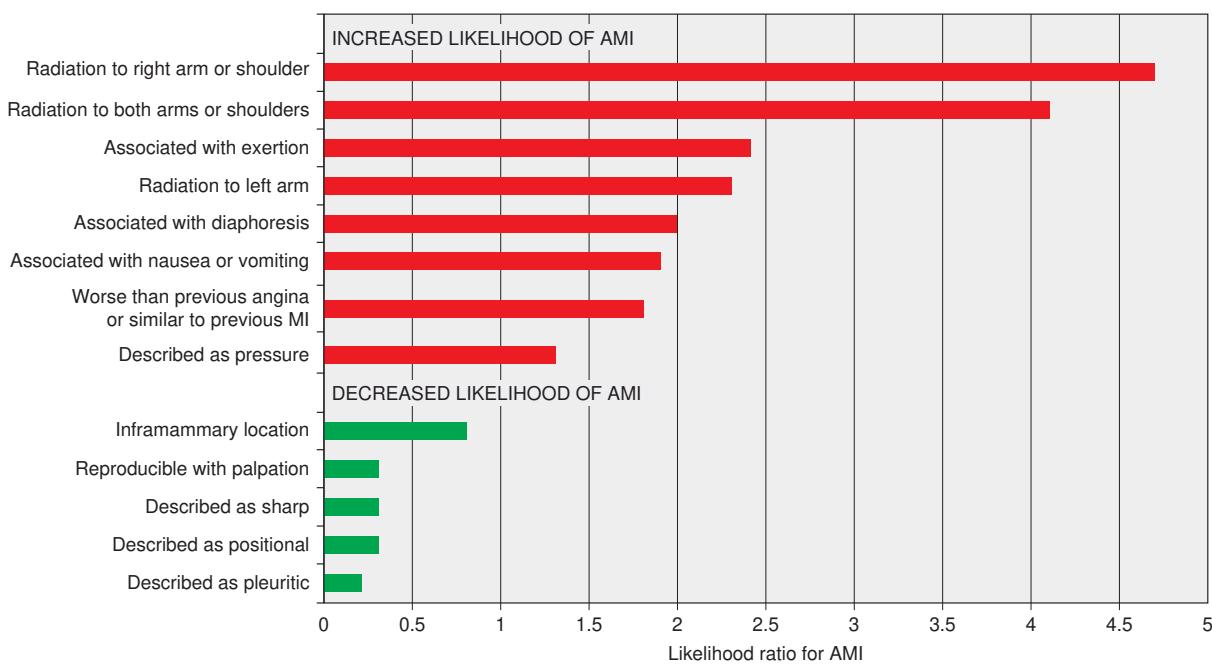
The evaluation of nontraumatic chest discomfort relies heavily on the clinical history and physical examination to direct subsequent diagnostic testing. The evaluating clinician should assess the quality, location (including radiation), and pattern (including onset and duration) of the pain as well as any provoking or alleviating factors. The presence of associated symptoms may also be useful in establishing a diagnosis.

**Quality of Pain** The quality of chest discomfort alone is never sufficient to establish a diagnosis. However, the characteristics of the pain are pivotal in formulating an initial clinical impression and assessing the likelihood of a serious cardiopulmonary process

TABLE 14-2 Considerations in the Assessment of the Patient with Chest Discomfort

1. Could the chest discomfort be due to an acute, potentially life-threatening condition that warrants urgent evaluation and management?	Unstable ischemic heart disease	Aortic dissection	Pneumothorax	Pulmonary embolism
2. If not, could the discomfort be due to a chronic condition likely to lead to serious complications?				
Stable angina	Aortic stenosis	Pulmonary hypertension		
3. If not, could the discomfort be due to an acute condition that warrants specific treatment?				
Pericarditis	Pneumonia/pleuritis	Herpes zoster		
4. If not, could the discomfort be due to another treatable chronic condition?				
Esophageal reflux		Cervical disk disease		
Esophageal spasm		Arthritis of the shoulder or spine		
Peptic ulcer disease		Costochondritis		
Gallbladder disease		Other musculoskeletal disorders		
Other gastrointestinal conditions		Anxiety state		

Source: Developed by Dr. Thomas H. Lee for the 18th edition of *Harrison's Principles of Internal Medicine*.



**FIGURE 14-2** Association of chest pain characteristics with the probability of acute myocardial infarction (AMI). Note that a subsequent larger study showed a nonsignificant association with radiation to the right arm. (Figure prepared from data in CJ Swap, JT Nagurney: JAMA 294:2623, 2005.)

(Table 14-1), including ACS in particular (Fig. 14-2). Pressure or tightness is consistent with a typical presentation of myocardial ischemic pain. Nevertheless, the clinician must remember that some patients with ischemic chest symptoms deny any “pain” but rather complain of dyspnea or a vague sense of anxiety. The severity of the discomfort has poor diagnostic accuracy. It is often helpful to ask about the similarity of the discomfort to previous definite ischemic symptoms. It is unusual for angina to be sharp, as in knifelike, stabbing, or pleuritic; however, patients sometimes use the word “sharp” to convey the intensity of discomfort rather than the quality. Pleuritic discomfort is suggestive of a process involving the pleura, including pericarditis, pulmonary embolism, or pulmonary parenchymal processes. Less frequently, the pain of pericarditis or massive pulmonary embolism is a steady severe pressure or aching that can be difficult to discriminate from myocardial ischemia. “Tearing” or “ripping” pain is often described by patients with acute aortic dissection. However, acute aortic emergencies also present commonly with knifelike pain. A burning quality can suggest acid reflux or peptic ulcer disease but may also occur with myocardial ischemia. Esophageal pain, particularly with spasm, can be a severe squeezing discomfort identical to angina.

**Location of Discomfort** A substernal location with radiation to the neck, jaw, shoulder, or arms is typical of myocardial ischemic discomfort. Radiation to both arms has a particularly high association with MI as the etiology. Some patients present with aching in sites of radiated pain as their only symptoms of ischemia. However, pain that is highly localized—e.g., that which can be demarcated by the tip of one finger—is highly unusual for angina. A retrosternal location should prompt consideration of esophageal pain; however, other gastrointestinal conditions usually present with pain that is most intense in the abdomen or epigastrium, with possible radiation into the chest. Angina may also occur in an epigastric location. Pain that occurs solely above the mandible or below the epigastrium is rarely angina. Severe pain radiating to the back, particularly between the shoulder blades, should prompt consideration of an acute aortic syndrome. Radiation to the trapezius ridge is characteristic of pericardial pain and does not usually occur with angina.

**Pattern** Myocardial ischemic discomfort usually builds over minutes and is exacerbated by activity and mitigated by rest. In contrast, pain that reaches its peak intensity immediately is more suggestive of aortic dissection, pulmonary embolism, or spontaneous pneumothorax. Pain that is fleeting (lasting only a few seconds) is rarely ischemic in origin. Similarly, pain that is constant in intensity for a prolonged period (many hours to days) is unlikely to represent myocardial ischemia if it occurs in the absence of other clinical consequences, such as abnormalities of the ECG, elevation of cardiac biomarkers, or clinical sequelae (e.g., heart failure or hypotension). Both myocardial ischemia and acid reflux may have their onset in the morning.

**Provoking and Alleviating Factors** Patients with myocardial ischemic pain usually prefer to rest, sit, or stop walking. However, clinicians should be aware of the phenomenon of “warm-up angina” in which some patients experience relief of angina as they continue at the same or even a greater level of exertion (Chap. 273). Alterations in the intensity of pain with changes in position or movement of the upper extremities and neck are less likely with myocardial ischemia and suggest a musculoskeletal etiology. The pain of pericarditis, however, often is worse in the supine position and relieved by sitting upright and leaning forward. Gastroesophageal reflux may be exacerbated by alcohol, some foods, or a reclined position. Relief can occur with sitting.

Exacerbation by eating suggests a gastrointestinal etiology such as peptic ulcer disease, cholecystitis, or pancreatitis. Peptic ulcer disease tends to become symptomatic 60–90 min after meals. However, in the setting of severe coronary atherosclerosis, redistribution of blood flow to the splanchnic vasculature after eating can trigger postprandial angina. The discomfort of acid reflux and peptic ulcer disease is usually diminished promptly by acid-reducing therapies. In contrast with its impact in some patients with angina, physical exertion is very unlikely to alter symptoms from gastrointestinal causes of chest pain. Relief of chest discomfort within minutes after administration of nitroglycerin is suggestive of but not sufficiently sensitive or specific for a definitive diagnosis of myocardial ischemia. Esophageal spasm may also be relieved promptly with

nitroglycerin. A delay of >10 min before relief is obtained after nitroglycerin suggests that the symptoms either are not caused by ischemia or are caused by severe ischemia, such as during acute MI.

**Associated Symptoms** Symptoms that accompany myocardial ischemia may include diaphoresis, dyspnea, nausea, fatigue, faintness, and eructations. In addition, these symptoms may exist in isolation as anginal equivalents (i.e., symptoms of myocardial ischemia other than typical angina), particularly in women and the elderly. Dyspnea may occur with multiple conditions considered in the differential diagnosis of chest pain and thus is not discriminative, but the presence of dyspnea is important because it suggests a cardio-pulmonary etiology. Sudden onset of significant respiratory distress should lead to consideration of pulmonary embolism and spontaneous pneumothorax. Hemoptysis may occur with pulmonary embolism or as blood-tinged frothy sputum in severe heart failure but usually points toward a pulmonary parenchymal etiology of chest symptoms. Presentation with syncope or presyncope should prompt consideration of hemodynamically significant pulmonary embolism or aortic dissection as well as ischemic arrhythmias. Although nausea and vomiting suggest a gastrointestinal disorder, these symptoms may occur in the setting of MI (more commonly inferior MI), presumably because of activation of the vagal reflex or stimulation of left ventricular receptors as part of the Bezold-Jarisch reflex.

**Past Medical History** The past medical history is useful in assessing the patient for risk factors for coronary atherosclerosis and venous thromboembolism (Chap. 279) as well as for conditions that may predispose the patient to specific disorders. For example, a history of connective tissue diseases such as Marfan syndrome should heighten the clinician's suspicion of an acute aortic syndrome or spontaneous pneumothorax. A careful history may elicit clues about depression or prior panic attacks.

#### PHYSICAL EXAMINATION

In addition to providing an initial assessment of the patient's clinical stability, the physical examination of patients with chest discomfort can provide direct evidence of specific etiologies of chest pain (e.g., unilateral absence of lung sounds) and can identify potential precipitants of acute cardiopulmonary causes of chest pain (e.g., uncontrolled hypertension), relevant comorbid conditions (e.g., obstructive pulmonary disease), and complications of the presenting syndrome (e.g., heart failure). However, because the findings on physical examination may be normal in patients with unstable ischemic heart disease, an unremarkable physical exam is not definitively reassuring.

**General** The patient's general appearance is helpful in establishing an initial impression of the severity of illness. Patients with acute MI or other acute cardiopulmonary disorders often appear anxious, uncomfortable, pale, cyanotic, or diaphoretic. Patients who are massaging or clutching their chests may describe their pain with a clenched fist held against the sternum (*Levine's sign*). Occasionally, body habitus is helpful—e.g., in patients with Marfan syndrome or the prototypical young, tall, thin man with spontaneous pneumothorax.

**Vital Signs** Significant tachycardia and hypotension are indicative of important hemodynamic consequences of the underlying cause of chest discomfort and should prompt a rapid survey for the most severe conditions, such as acute MI with cardiogenic shock, massive pulmonary embolism, pericarditis with tamponade, or tension pneumothorax. Acute aortic emergencies usually present with severe hypertension but may be associated with profound hypotension when there is coronary arterial compromise or dissection into the pericardium. Sinus tachycardia is an important manifestation of submassive pulmonary embolism. Tachypnea and hypoxemia point toward a pulmonary cause. The presence of low-grade fever is non-specific because it may occur with MI and with thromboembolism in addition to infection.

**Pulmonary** Examination of the lungs may localize a primary pulmonary cause of chest discomfort, as in cases of pneumonia, asthma, or pneumothorax. Left ventricular dysfunction from severe ischemia/infarction as well as acute valvular complications of MI or aortic dissection can lead to pulmonary edema, which is an indicator of high risk.

**Cardiac** The jugular venous pulse is often normal in patients with acute myocardial ischemia but may reveal characteristic patterns with pericardial tamponade or acute right ventricular dysfunction (Chaps. 239 and 270). Cardiac auscultation may reveal a third or, more commonly, a fourth heart sound, reflecting myocardial systolic or diastolic dysfunction. Murmurs of mitral regurgitation or a ventricular-septal defect may indicate mechanical complications of STEMI. A murmur of aortic insufficiency may be a complication of ascending aortic dissection. Other murmurs may reveal underlying cardiac disorders contributory to ischemia (e.g., aortic stenosis or hypertrophic cardiomyopathy). Pericardial friction rubs reflect pericardial inflammation.

**Abdominal** Localizing tenderness on the abdominal exam is useful in identifying a gastrointestinal cause of the presenting syndrome. Abdominal findings are infrequent with purely acute cardiopulmonary problems, except in the case of right-sided heart failure leading to hepatic congestion.

**Extremities** Vascular pulse deficits may reflect underlying chronic atherosclerosis, which increases the likelihood of coronary artery disease. However, evidence of acute limb ischemia with loss of the pulse and pallor, particularly in the upper extremities, can indicate catastrophic consequences of aortic dissection. Unilateral lower-extremity swelling should raise suspicion about venous thromboembolism.

**Musculoskeletal** Pain arising from the costochondral and chondrosternal articulations may be associated with localized swelling, redness, or marked localized tenderness. Pain on palpation of these joints is usually well localized and is a useful clinical sign, although deep palpation may elicit pain in the absence of costochondritis. Although palpation of the chest wall often elicits pain in patients with various musculoskeletal conditions, it should be appreciated that chest wall tenderness does not exclude myocardial ischemia. Sensory deficits in the upper extremities may be indicative of cervical disk disease.

#### ELECTROCARDIOGRAPHY

Electrocardiography is crucial in the evaluation of nontraumatic chest discomfort. The ECG is pivotal for identifying patients with ongoing ischemia as the principal reason for their presentation as well as secondary cardiac complications of other disorders. Professional society guidelines recommend that an ECG be obtained within 10 min of presentation, with the primary goal of identifying patients with ST-segment elevation diagnostic of MI who are candidates for immediate interventions to restore flow in the occluded coronary artery. ST-segment depression and symmetric T-wave inversions at least 0.2 mV in depth are useful for detecting myocardial ischemia in the absence of STEMI and are also indicative of higher risk of death or recurrent ischemia. Serial performance of ECGs (every 30–60 min) is recommended in the ED evaluation of suspected ACS. In addition, an ECG with right-sided lead placement should be considered in patients with clinically suspected ischemia and a nondiagnostic standard 12-lead ECG. Despite the value of the resting ECG, its sensitivity for ischemia is poor—as low as 20% in some studies.

Abnormalities of the ST segment and T wave may occur in a variety of conditions, including pulmonary embolism, ventricular hypertrophy, acute and chronic pericarditis, myocarditis, electrolyte imbalance, and metabolic disorders. Notably, hyperventilation associated with panic disorder can also lead to nonspecific ST and T-wave abnormalities. Pulmonary embolism is most often associated with sinus tachycardia but can also lead to rightward shift of the ECG axis, manifesting as an S-wave in lead I, with a Q-wave

and T-wave in lead III ([Chaps. 240 and 279](#)). In patients with ST-segment elevation, the presence of diffuse lead involvement not corresponding to a specific coronary anatomic distribution and PR-segment depression can aid in distinguishing pericarditis from acute MI.

### CHEST RADIOGRAPHY

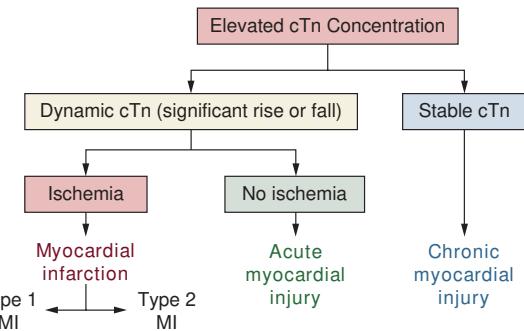
(See [Chap. A12](#)) Plain radiography of the chest is performed routinely when patients present with acute chest discomfort and selectively when individuals who are being evaluated as outpatients have subacute or chronic pain. The chest radiograph is most useful for identifying pulmonary processes, such as pneumonia or pneumothorax. Findings are often unremarkable in patients with ACS, but pulmonary edema may be evident. Other specific findings include widening of the mediastinum in some patients with aortic dissection, Hampton's hump or Westerman's sign in patients with pulmonary embolism ([Chaps. 279 and A12](#)), or pericardial calcification in chronic pericarditis.

### CARDIAC BIOMARKERS

Laboratory testing in patients with acute chest pain is focused on the detection of myocardial injury. Such injury can be detected by the presence of circulating proteins released from damaged cardiomyocytes. Owing to the time necessary for this release, initial biomarkers of injury may be in the normal range, even in patients with STEMI. Cardiac troponin is the preferred biomarker for the diagnosis of MI and should be measured in all patients with suspected ACS. It is not necessary or advisable to measure troponin in patients without suspicion of ACS unless this test is being used specifically for risk stratification (e.g., in pulmonary embolism or heart failure).

The development of cardiac troponin assays with progressively greater analytical sensitivity has facilitated detection of substantially lower blood concentrations of troponin than was previously possible. This evolution permits earlier detection of myocardial injury and more reliable discrimination of changing values, enhances the overall accuracy of a diagnosis of MI, and improves risk stratification in suspected ACS. For these reasons, high-sensitivity assays are generally preferred over prior generation troponin assays. The greater negative predictive value of a negative troponin result with high-sensitivity assays is an advantage in the evaluation of chest pain in the ED. Rapid rule-out protocols that use serial testing and changes in troponin concentration over as short a period as 1–2 h appear to perform well for diagnosis of ACS when using a high-sensitivity troponin assay. Troponin should be measured at presentation and repeated at 1–3 h using high-sensitivity troponin and 3–6 h using conventional troponin assays. Additional troponin measurements may be warranted beyond 3–6 h when the clinical condition still suggests possible ACS or if there is diagnostic uncertainty. In patients presenting more than 2–3 h after symptom onset, a concentration of cardiac troponin, at the time of hospital presentation, below the limit of detection using a high-sensitivity assay may be sufficient to exclude MI with a negative predictive value >99%.

With the use of high-sensitivity assays for troponin, myocardial injury is detected in a larger proportion of patients who have non-ACS cardiopulmonary conditions than with previous, less sensitive assays. Therefore, other aspects of the clinical evaluation are critical to the practitioner's determination of the probability that the symptoms represent ACS. In addition, observation of a change in cardiac troponin concentration between serial samples is necessary for discriminating acute causes of myocardial injury from chronic elevation due to underlying structural heart disease, end-stage renal disease, or the rare presence of interfering antibodies. The diagnosis of MI is reserved for acute myocardial injury that is marked by a rising and/or falling pattern—with at least one value exceeding the 99th percentile reference limit—and that is caused by ischemia. Other nonischemic insults, such as myocarditis, may result in acute myocardial injury but should not be labeled MI ([Fig. 14-3](#)).



**FIGURE 14-3** Clinical classification of patients with elevated cardiac troponin (cTn). MI, myocardial infarction.

Other laboratory assessments may include the D-dimer test to aid in exclusion of pulmonary embolism ([Chap. 279](#)). Measurement of a B-type natriuretic peptide is useful when considered in conjunction with the clinical history and exam for the diagnosis of heart failure. B-type natriuretic peptides also provide prognostic information among patients with ACS and those with pulmonary embolism.

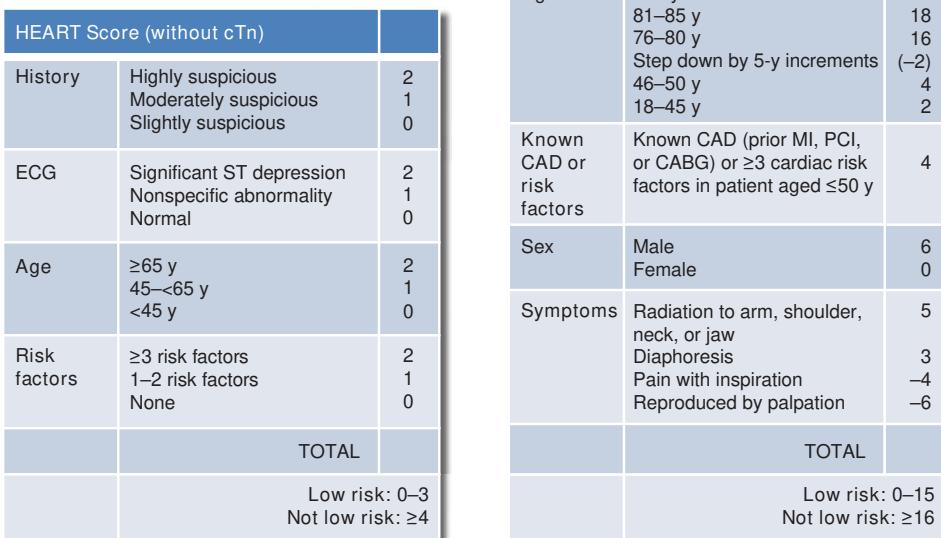
### INTEGRATIVE DECISION-AIDS

Multiple clinical algorithms have been developed to aid in decision-making during the evaluation and disposition of patients with acute nontraumatic chest pain. Such decision-aids estimate either of two closely related but not identical probabilities: (1) the probability of a final diagnosis of ACS and (2) the probability of major cardiac events during short-term follow-up. Such decision-aids are used most commonly to identify patients with a low clinical probability of ACS who are candidates for discharge from the ED, with or without additional noninvasive testing. Goldman and Lee developed one of the first such decision-aids, using only the ECG and risk indicators—hypotension, pulmonary rales, and known ischemic heart disease—to categorize patients into four risk categories ranging from a <1% to a >16% probability of a major cardiovascular complication. Decision-aids used more commonly in current practice are shown in [Fig. 14-4](#). Elements common across multiple risk stratification tools are (1) symptoms typical for ACS; (2) older age; (3) risk factors for or known atherosclerosis; (4) ischemic ECG abnormalities; and (5) elevated cardiac troponin level. Although, because of very low specificity, the overall diagnostic performance of such decision-aids is poor (area under the receiver operating curve, 0.55–0.65), in conjunction with the ECG and serial high-sensitivity cardiac troponin, they can help identify patients with a very low probability of ACS (e.g., <1%) or adverse cardiovascular events (<2% at 30 days). Clinical application of such integrated decision-aids or “accelerated diagnostic protocols” has been reported to achieve overall “miss rates” for ACS of <0.5% and may be useful for identifying patients who may be discharged without the need for additional cardiac testing.

Clinicians should differentiate between the algorithms discussed above and risk scores derived for stratification of prognosis (e.g., the TIMI and GRACE risk scores, [Chap. 275](#)) in patients who already have an established diagnosis of ACS. The latter risk scores were not designed to be used for diagnostic assessment.

### CORONARY AND MYOCARDIAL STRESS IMAGING

Among patients for whom other life-threatening causes of chest pain have been reasonably excluded and serial biomarker and clinical assessment have determined the patient to remain eligible for further testing because of intermediate or undetermined risk, diagnostic coronary imaging with coronary computed tomographic (CT) angiography or functional testing, preferably with nuclear or echocardiographic imaging, is recommended. Patient characteristics (e.g., body habitus and renal function), prior cardiac testing,



AND cardiac troponin < the limit of quantification.\*



**FIGURE 14-4** Examples of decision-aids used in conjunction with serial measurement of cardiac troponin (cTn) for evaluation of acute chest pain. The HEART score was modified by the authors in the presented study and omitting the assignment of 0, 1, or 2 points based on troponin. The negative predictive value (NPV) reported is for the composite endpoint of myocardial infarction (MI), cardiogenic shock, cardiac arrest, and all-cause mortality by 60 days. \*Limit of quantification is the lowest analyte concentration that can be quantitatively detected with a total imprecision of ≤20%. CABG, coronary artery bypass graft; CAD, coronary artery disease; ECG, electrocardiogram; PCI, percutaneous coronary intervention. (Figure prepared from data in DG Mark et al: *J Am Coll Cardiol* 13:606, 2018.)

history of known coronary artery disease, existing contraindications for a given test modality, and patient preferences are considerations when choosing among these diagnostic tests (Chaps. 241 and A9).

**CT Angiography (See Chap. 241)** CT angiography has emerged as a preferred modality for the evaluation of patients with acute chest discomfort who are candidates for further testing after biomarker and clinical risk assessment. Coronary CT angiography is a sensitive technique for detection of obstructive coronary disease. CT appears to enhance the speed to disposition of patients with a low-intermediate probability for ACS, with its major strength being the negative predictive value of a finding of no significant stenosis or coronary plaque. In addition, contrast-enhanced CT can detect focal areas of myocardial injury in the acute setting. At the same time, CT angiography can exclude aortic dissection, pericardial effusion, and pulmonary embolism.

**Stress Nuclear Perfusion Imaging or Stress Echocardiography (See Chaps. 241 and A9)** Functional testing with stress nuclear perfusion imaging and stress echocardiography are alternatives for the evaluation of patients with acute chest pain who are candidates for further testing and are preferred over coronary CT angiography in patients with known obstructive epicardial disease. The selection of stress test modality may depend on institutional availability and expertise. Stress testing with myocardial imaging, either with nuclear perfusion imaging or echocardiography, offers superior diagnostic performance over exercise ECG. In patients selected for stress myocardial imaging who are able to exercise, exercise stress is preferred over pharmacologic testing. When available, positron emission tomography offers advantages of improved diagnostic

performance and fewer nondiagnostic studies than single-photon emission CT.

Although functional testing is generally contraindicated in patients with ongoing chest pain, in selected patients with persistent pain and nondiagnostic ECG and biomarker data, resting myocardial perfusion images can be obtained; the absence of any perfusion abnormality substantially reduces the likelihood of coronary artery disease. In such a strategy, used in some centers, those with abnormal rest perfusion imaging, which cannot discriminate between old or new myocardial defects, usually must undergo additional evaluation.

#### EXERCISE ELECTROCARDIOGRAPHY

Exercise electrocardiography has historically been commonly employed for completion of risk stratification of patients who have undergone an initial evaluation that has not revealed a specific cause of chest discomfort and has identified a low risk of ACS. Early exercise testing is safe in patients without ongoing chest pain or high-risk findings and may assist in refining their prognostic assessment. However, for patients with chest pain for whom both cardiac troponin and clinical risk stratification have determined the patient to have low probability of ACS, there is insufficient evidence that stress testing or cardiac imaging improves their outcomes. This evolution in evidence supports a change from past practice in which outpatient stress testing within 72 hours was broadly used for patients with acute chest pain.

#### OTHER NONINVASIVE STUDIES

Other noninvasive imaging studies of the chest can be used selectively to provide additional diagnostic and prognostic information on patients with chest discomfort.

**Echocardiography** Echocardiography (nonstress) is not necessarily routine in patients with chest discomfort. However, in patients with an uncertain diagnosis, particularly those with nondiagnostic ST elevation, ongoing symptoms, or hemodynamic instability, detection of abnormal regional wall motion provides evidence of possible ischemic dysfunction. Echocardiography is diagnostic in patients with mechanical complications of MI or in patients with pericardial tamponade. Transthoracic echocardiography is poorly sensitive for aortic dissection, although an intimal flap may sometimes be detected in the ascending aorta.

**MRI (See Chap. 241)** Cardiac magnetic resonance (CMR) imaging is an evolving, versatile technique for structural and functional evaluation of the heart and the vasculature of the chest. CMR can be performed as a modality for pharmacologic stress perfusion imaging. Gadolinium-enhanced CMR can provide early detection of MI, defining areas of myocardial necrosis accurately, and can delineate patterns of myocardial disease that are often useful in discriminating ischemic from nonischemic myocardial injury. Although usually not practical for the urgent evaluation of acute chest discomfort, CMR can be a useful modality for cardiac structural evaluation of patients with elevated cardiac troponin levels in the absence of definite coronary artery disease. CMR coronary angiography is in its early stages. MRI also permits highly accurate assessment for aortic dissection but is infrequently used as the first test because CT and transesophageal echocardiography are usually more practical.

## ■ CRITICAL PATHWAYS FOR ACUTE CHEST DISCOMFORT

Because of the challenges inherent in reliably identifying the small proportion of patients with serious causes of acute chest discomfort while not exposing the larger number of low-risk patients to unnecessary testing and extended ED or hospital evaluations, many medical centers have adopted critical pathways to expedite the assessment and management of patients with nontraumatic chest pain, often in dedicated chest pain units. Such pathways are generally aimed at (1) rapid identification, triage, and treatment of high-risk cardiopulmonary conditions (e.g., STEMI); (2) accurate identification of low-risk patients who can be safely observed in units with less intensive monitoring, undergo early noninvasive testing, or be discharged home; and (3) through more efficient and systematic accelerated diagnostic protocols, safe reduction in costs associated with overuse of testing and unnecessary hospitalizations. In some studies, provision of protocol-driven care in chest pain units has decreased costs and overall duration of hospital evaluation with no detectable excess of adverse clinical outcomes.

## ■ OUTPATIENT EVALUATION OF CHEST DISCOMFORT

Chest pain is common in outpatient practice, with a lifetime prevalence of 20–40% in the general population. More than 25% of patients with MI have had a related visit with a primary care physician in the previous month. The diagnostic principles are the same as in the ED. However, the pretest probability of an acute cardiopulmonary cause is significantly lower. Therefore, testing paradigms are less intense, with an emphasis on the history, physical examination, and ECG. Moreover, decision-aids developed for settings with a high prevalence of significant cardiopulmonary disease have lower positive predictive value when applied in the practitioner's office. However, in general, if the level of clinical suspicion of ACS is sufficiently high to consider troponin testing, the patient should be referred to the ED for evaluation.

## ■ FURTHER READING

- A EA et al: Testing of low-risk patients presenting to the emergency department with chest pain: A scientific statement from the American Heart Association. *Circulation* 122:1756, 2010.
- C AR et al: Association of high-sensitivity cardiac troponin I concentration with cardiac outcomes in patients with suspected acute coronary syndrome. *JAMA* 318:1913, 2017.

- F AC et al: Does this patient with chest pain have acute coronary syndrome? *JAMA* 314:1955, 2015.
  - H RY et al: A national study of the prevalence of life-threatening diagnoses in patients with chest pain. *JAMA Intern Med* 176:1029, 2016.
  - M SA et al: Safely identifying emergency department patients with acute chest pain for early discharge: HEART pathway accelerated diagnostic protocol. *Circulation* 138:2456, 2018.
- Correctly diagnosing acute abdominal pain can be quite challenging. Few clinical situations require greater judgment, because the most catastrophic of events may be forecast by the subtlest of symptoms and signs. In every instance, the clinician must distinguish those conditions that require urgent intervention from those that do not and can best be managed nonoperatively. A meticulously executed, detailed history and physical examination are critically important for focusing the differential diagnosis and allowing the diagnostic evaluation to proceed expeditiously (**Table 15-1**).

The etiologic classification in **Table 15-2**, although not complete, provides a useful framework for evaluating patients with abdominal pain.

Any patient with abdominal pain of recent onset requires an early and thorough evaluation. The most common causes of abdominal pain on admission are nonspecific abdominal pain, acute appendicitis, pain of urologic origin, and intestinal obstruction. A diagnosis of "acute or surgical abdomen" is not acceptable because of its often misleading and erroneous connotations. Most patients who present with acute abdominal pain will have self-limited disease processes. However, it is important to remember that pain severity does not necessarily correlate with the severity of the underlying condition. And, the presence or absence of various degrees of "hunger" is unreliable as a sole indicator of the severity of intraabdominal disease. The most obvious of "acute abdomens" may not require operative intervention, and the mildest of abdominal pains may herald an urgently correctable disease.

## ■ SOME MECHANISMS OF PAIN ORIGINATING IN THE ABDOMEN

**Inflammation of the Parietal Peritoneum** The pain of parietal peritoneal inflammation is steady and aching in character and is located directly over the inflamed area, its exact reference being possible because it is transmitted by somatic nerves supplying the parietal peritoneum. The intensity of the pain is dependent on the type and amount of material to which the peritoneal surfaces are exposed in a given time period. For example, the sudden release of a small quantity

TABLE 15-1 Some Key Components of the Patient's History

Age
Time and mode of onset of the pain
Pain characteristics
Duration of symptoms
Location of pain and sites of radiation
Associated symptoms and their relationship to the pain
Nausea, emesis, and anorexia
Diarrhea, constipation, or other changes in bowel habits
Menstrual history

# 15 Abdominal Pain

Danny O. Jacobs



TABLE 15-2 Some Important Causes of Abdominal Pain

## Pain Originating in the Abdomen

Parietal peritoneal inflammation	Vascular disturbances
Bacterial contamination	Embolism or thrombosis
Perforated appendix or other perforated viscus	Vascular rupture
Pelvic inflammatory disease	Pressure or torsional occlusion
Chemical irritation	Sickle cell anemia
Perforated ulcer	Abdominal wall
Pancreatitis	Distortion or traction of mesentery
Mittelschmerz	Trauma or infection of muscles
Mechanical obstruction of hollow viscera	Distension of visceral surfaces, e.g., by hemorrhage
Obstruction of the small or large intestine	Hepatic or renal capsules
Obstruction of the biliary tree	Inflammation
Obstruction of the ureter	Appendicitis
	Typhoid fever
	Neutropenic enterocolitis or "typhlitis"

## Pain Referred from Extraabdominal Source

Cardiothoracic	Pleurodynia
Acute myocardial infarction	Pneumothorax
Myocarditis, endocarditis, pericarditis	Empyema
Congestive heart failure	Esophageal disease, including spasm, rupture, or inflammation
Pneumonia (especially lower lobes)	Genitalia
Pulmonary embolus	Torsion of the testis

## Metabolic Causes

Diabetes	Acute adrenal insufficiency
Uremia	Familial Mediterranean fever
Hyperlipidemia	Porphyria
Hyperparathyroidism	C1 esterase inhibitor deficiency (angioneurotic edema)

## Neurologic/Psychiatric Causes

Herpes zoster	Spinal cord or nerve root compression
Tabes dorsalis	Functional disorders
Causalgia	Psychiatric disorders
Radiculitis from infection or arthritis	

## Toxic Causes

Lead poisoning	
Insect or animal envenomation	
Black widow spider bites	
Snake bites	

## Uncertain Mechanisms

Narcotic withdrawal	
Heat stroke	

of *sterile* acidic gastric juice into the peritoneal cavity causes much more pain than the same amount of grossly contaminated neutral feces. Enzymatically active pancreatic juice incites more pain and inflammation than does the same amount of sterile bile containing no potent enzymes. Blood is normally only a mild irritant, and the response to urine is also typically bland, so exposure of blood and urine to the peritoneal cavity may go unnoticed unless it is sudden and massive. Bacterial contamination, such as may occur with pelvic inflammatory disease or perforated distal intestine, causes low-intensity pain until multiplication causes significant amounts of inflammatory mediators to be released. Patients with perforated upper gastrointestinal ulcers may present entirely differently depending on how quickly gastric juices enter the peritoneal cavity and their pH. Thus, the rate at which any inflammatory material irritates the peritoneum is important.

The pain of peritoneal inflammation is invariably accentuated by pressure or changes in tension of the peritoneum, whether produced

by palpation or by movement such as with coughing or sneezing. The patient with peritonitis characteristically lies quietly in bed, preferring to avoid motion, in contrast to the patient with colic, who may be thrashing in discomfort.

Another characteristic feature of peritoneal irritation is tonic reflex spasm of the abdominal musculature, localized to the involved body segment. Its intensity depends on the integrity of the nervous system, the location of the inflammatory process, and the rate at which it develops. Spasm over a perforated retrocecal appendix or perforation into the lesser peritoneal sac may be minimal or absent because of the protective effect of overlying viscera. Catastrophic abdominal emergencies may be associated with minimal or no detectable pain or muscle spasm in obtunded, seriously ill, debilitated, immunosuppressed, or psychotic patients. A slowly developing process also often greatly attenuates the degree of muscle spasm.

**Obstruction of Hollow Viscera** Intraluminal obstruction classically elicits intermittent or colicky abdominal pain that is not as well localized as the pain of parietal peritoneal irritation. However, the absence of cramping discomfort can be misleading because distention of a hollow viscus may also produce steady pain with only rare paroxysms.

Small-bowel obstruction often presents as poorly localized, intermittent periumbilical or supraumbilical pain. As the intestine progressively dilates and loses muscular tone, the colicky nature of the pain may diminish. With superimposed strangulating obstruction, pain may spread to the lower lumbar region if there is traction on the root of the mesentery. The colicky pain of colonic obstruction is of lesser intensity, is commonly located in the infraumbilical area, and may often radiate to the lumbar region.

*Sudden* distention of the biliary tree produces a steady rather than colicky type of pain; hence, the term *biliary colic* is misleading. Acute distention of the gallbladder typically causes pain in the right upper quadrant with radiation to the right posterior region of the thorax or to the tip of the right scapula, but discomfort is also not uncommonly found near the midline. Distention of the common bile duct often causes epigastric pain that may radiate to the upper lumbar region. Considerable variation is common, however, so that differentiation between gallbladder or common duct disease may be impossible.

Gradual dilatation of the biliary tree, as can occur with carcinoma of the head of the pancreas, may cause no pain or only a mild aching sensation in the epigastrium or right upper quadrant. The pain of distention of the pancreatic ducts is similar to that described for distention of the common bile duct but, in addition, is very frequently accentuated by recumbency and relieved by the upright position.

Obstruction of the urinary bladder usually causes dull, low-intensity pain in the suprapubic region. Restlessness, without specific complaint of pain, may be the only sign of a distended bladder in an obtunded patient. In contrast, acute obstruction of the intravesicular portion of the ureter is characterized by severe suprapubic and flank pain that radiates to the penis, scrotum, or inner aspect of the upper thigh. Obstruction of the ureteropelvic junction manifests as pain near the costovertebral angle, whereas obstruction of the remainder of the ureter is associated with flank pain that often extends into the same side of the abdomen.

**Vascular Disturbances** A frequent misconception is that pain due to intraabdominal vascular disturbances is sudden and catastrophic in nature. Certain disease processes, such as embolism or thrombosis of the superior mesenteric artery or impending rupture of an abdominal aortic aneurysm, can certainly be associated with diffuse, severe pain. Yet, just as frequently, the patient with occlusion of the superior mesenteric artery only has mild continuous or cramping diffuse pain for 2 or 3 days before vascular collapse or findings of peritoneal inflammation appear. The early, seemingly insignificant discomfort is caused by hyperperistalsis rather than peritoneal inflammation. Indeed, absence of tenderness and rigidity in the presence of continuous, diffuse pain (e.g., "pain out of proportion to physical findings") in a patient likely to have vascular disease is quite characteristic of occlusion of the superior mesenteric artery. Abdominal pain with radiation to the sacral region,

flank, or genitalia should always signal the possible presence of a rupturing abdominal aortic aneurysm. This pain may persist over a period of several days before rupture and collapse occur.

**Abdominal Wall** Pain arising from the abdominal wall is usually constant and aching. Movement, prolonged standing, and pressure accentuate the discomfort and associated muscle spasm. In the relatively rare case of hematoma of the rectus sheath, now most frequently encountered in association with anticoagulant therapy, a mass may be present in the lower quadrants of the abdomen. Simultaneous involvement of muscles in other parts of the body usually serves to differentiate myositis of the abdominal wall from other processes that might cause pain in the same region.

### ■ REFERRED PAIN IN ABDOMINAL DISEASE

Pain referred to the abdomen from the thorax, spine, or genitalia may present a diagnostic challenge because diseases of the upper part of the abdominal cavity such as acute cholecystitis or perforated ulcer may be associated with intrathoracic complications. A most important, yet often forgotten, dictum is that the possibility of intrathoracic disease must be considered in every patient with abdominal pain, especially if the pain is in the upper abdomen.

Systematic questioning and examination directed toward detecting myocardial or pulmonary infarction, pneumonia, pericarditis, or esophageal disease (the intrathoracic diseases that most often masquerade as abdominal emergencies) will often provide sufficient clues to establish the proper diagnosis. Diaphragmatic pleuritis resulting from pneumonia or pulmonary infarction may cause pain in the right upper quadrant and pain in the supraclavicular area, the latter radiation to be distinguished from the referred subscapular pain caused by acute distention of the extrahepatic biliary tree. The ultimate decision as to the origin of abdominal pain may require deliberate and planned observation over a period of several hours, during which repeated questioning and examination will provide the diagnosis or suggest the appropriate studies.

Referred pain of thoracic origin is often accompanied by splinting of the involved hemithorax with respiratory lag and a decrease in excursion more marked than that seen in the presence of intraabdominal disease. In addition, apparent abdominal muscle spasm caused by referred pain will diminish during the inspiratory phase of respiration, whereas it persists throughout both respiratory phases if it is of abdominal origin. Palpation over the area of referred pain in the abdomen also does not usually accentuate the pain and, in many instances, actually seems to relieve it.

Thoracic disease and abdominal disease frequently coexist and may be difficult or impossible to differentiate. For example, the patient with known biliary tract disease often has epigastric pain during myocardial infarction, or biliary colic may be referred to the precordium or left shoulder in a patient who has suffered previously from angina pectoris. **For an explanation of the radiation of pain to a previously diseased area, see Chap. 13.**

Referred pain from the spine, which usually involves compression or irritation of nerve roots, is characteristically intensified by certain motions such as cough, sneeze, or strain and is associated with hyperesthesia over the involved dermatomes. Pain referred to the abdomen from the testes or seminal vesicles is generally accentuated by the slightest pressure on either of these organs. The abdominal discomfort experienced is of dull, aching character and is poorly localized.

### ■ METABOLIC ABDOMINAL CRISES

Pain of metabolic origin may simulate almost any other type of intraabdominal disease. Several mechanisms may be at work. In certain instances, such as hyperlipidemia, the metabolic disease itself may be accompanied by an intraabdominal process such as pancreatitis, which can lead to unnecessary laparotomy unless recognized. C1 esterase deficiency associated with angioneurotic edema is often associated with episodes of severe abdominal pain. Whenever the cause of

abdominal pain is obscure, a metabolic origin always must be considered. Abdominal pain is also the hallmark of familial Mediterranean fever (Chap. 369).

The pain of porphyria and of lead colic is usually difficult to distinguish from that of intestinal obstruction, because severe hyperperistalsis is a prominent feature of both. The pain of uremia or diabetes is nonspecific, and the pain and tenderness frequently shift in location and intensity. Diabetic acidosis may be precipitated by acute appendicitis or intestinal obstruction, so if prompt resolution of the abdominal pain does not result from correction of the metabolic abnormalities, an underlying organic problem should be suspected. Black widow spider bites produce intense pain and rigidity of the abdominal muscles and back, an area infrequently involved in intraabdominal disease.

### ■ IMMUNOCOMPROMISE

Evaluating and diagnosing causes of abdominal pain in immunosuppressed or otherwise immunocompromised patients is very difficult. This includes those who have undergone organ transplantation; who are receiving immunosuppressive treatments for autoimmune diseases, chemotherapy, or glucocorticoids; who have AIDS; and who are very old. In these circumstances, normal physiologic responses may be absent or masked. In addition, unusual infections may cause abdominal pain where the etiologic agents include cytomegalovirus, mycobacteria, protozoa, and fungi. These pathogens may affect all gastrointestinal organs, including the gallbladder, liver, and pancreas, as well as the gastrointestinal tract, causing occult or overtly symptomatic perforations of the latter. Splenic abscesses due to *Candida* or *Salmonella* infection should also be considered, especially when evaluating patients with left upper quadrant or left flank pain. Acalculous cholecystitis may be observed in immunocompromised patients or those with AIDS, where it is often associated with cryptosporidiosis or cytomegalovirus infection.

Neutropenic enterocolitis (typhlitis) is often identified as a cause of abdominal pain and fever in some patients with bone marrow suppression due to chemotherapy. Acute graft-versus-host disease should be considered in this circumstance. Optimal management of these patients requires meticulous follow-up including serial examinations to assess the need for more surgical intervention, for example, to address perforation.

### ■ NEUROGENIC CAUSES

Diseases that injure sensory nerves may cause causalgic pain. This pain has a burning character and is usually limited to the distribution of a given peripheral nerve. Stimuli that are normally not painful such as touch or a change in temperature may be causalgic and are often present even at rest. The demonstration of irregularly spaced cutaneous "pain spots" may be the only indication that an old nerve injury exists. Even though the pain may be precipitated by gentle palpation, rigidity of the abdominal muscles is absent, and the respirations are not usually disturbed. Distention of the abdomen is uncommon, and the pain has no relationship to food intake.

Pain arising from spinal nerves or roots comes and goes suddenly and is of a lancinating type (Chap. 17). It may be caused by herpes zoster, impingement by arthritis, tumors, a herniated nucleus pulposus, diabetes, or syphilis. It is not associated with food intake, abdominal distention, or changes in respiration. Severe muscle spasms, when present, may be relieved by, but are certainly not accentuated by, abdominal palpation. The pain is made worse by movement of the spine and is usually confined to a few dermatomes. Hyperesthesia is very common.

Pain due to functional causes conforms to none of the aforementioned patterns. Mechanisms of disease are not clearly established. Irritable bowel syndrome (IBS) is a functional gastrointestinal disorder characterized by abdominal pain and altered bowel habits. The diagnosis is made on the basis of clinical criteria (Chap. 327) and after exclusion of demonstrable structural abnormalities. The episodes of abdominal pain may be brought on by stress, and the pain varies considerably in type and location. Nausea and vomiting are rare. Localized

tenderness and muscle spasm are inconsistent or absent. The causes of IBS or related functional disorders are not yet fully understood.

## APPROACH TO THE PATIENT

### Abdominal Pain

Few abdominal conditions require such urgent operative intervention that an orderly approach needs to be abandoned, no matter how ill the patient is. Only patients with exsanguinating intraabdominal hemorrhage (e.g., ruptured aneurysm) must be rushed to the operating room immediately, but in such instances, only a few minutes are required to assess the critical nature of the problem. Under these circumstances, all obstacles must be swept aside, adequate venous access for fluid replacement obtained, and the operation begun. Unfortunately, many of these patients may die in the radiology department or the emergency room while awaiting unnecessary examinations. *There are no absolute contraindications to operation when massive intraabdominal hemorrhage is present.* Fortunately, this situation is relatively rare. This statement does not necessarily apply to patients with intraluminal gastrointestinal hemorrhage, who can often be managed by other means (Chap. 48). In these patients, obtaining a *detailed history when possible* can be extremely helpful even though it can be laborious and time-consuming. Decision-making regarding next steps is facilitated and a reasonably accurate diagnosis can be made before any further diagnostic testing is undertaken.

In cases of *acute* abdominal pain, a diagnosis can be readily established in most instances, whereas success is not so frequent in patients with *chronic* pain. IBS is one of the most common causes of abdominal pain and must always be kept in mind (Chap. 327). The location of the pain can assist in narrowing the differential diagnosis (Table 15-3); however, the *chronological sequence of events* in the

patient's history is often more important than the pain's location. Careful attention should be paid to the extraabdominal regions. Narcotics or analgesics should *not* be withheld until a definitive diagnosis or a definitive plan has been formulated; obfuscation of the diagnosis by adequate analgesia is unlikely.

An accurate menstrual history in a female patient is essential. It is important to remember that normal anatomic relationships can be significantly altered by the gravid uterus. Abdominal and pelvic pain may occur during pregnancy due to conditions that do not require operation. Lastly, some otherwise noteworthy laboratory values (e.g., leukocytosis) may represent the normal physiologic changes of pregnancy.

In the examination, simple critical inspection of the patient, for example, of facies, position in bed, and respiratory activity, provides valuable clues. The amount of information to be gleaned is directly proportional to the *gentleness* and thoroughness of the examiner. Once a patient with peritoneal inflammation has been examined briskly, accurate assessment by the next examiner becomes almost impossible. Eliciting rebound tenderness by sudden release of a deeply palpating hand in a patient with suspected peritonitis is cruel and unnecessary. The same information can be obtained by gentle percussion of the abdomen (rebound tenderness on a miniature scale), a maneuver that can be far more precise and localizing. Asking the patient to cough will elicit true rebound tenderness without the need for placing a hand on the abdomen. Furthermore, the forceful demonstration of rebound tenderness will startle and induce protective spasm in a nervous or worried patient in whom true rebound tenderness is not present. A palpable gallbladder will be missed if palpation is so aggressive that voluntary muscle spasm becomes superimposed on involuntary muscular rigidity.

As with history taking, sufficient time should be spent in the examination. Abdominal signs may be minimal but, nevertheless, if accompanied by consistent symptoms, may be exceptionally meaningful. Abdominal signs may be virtually or totally absent in cases of pelvic peritonitis, so careful *pelvic and rectal examinations are mandatory in every patient with abdominal pain.* Tenderness on pelvic or rectal examination in the absence of other abdominal signs can be caused by operative indications such as perforated appendicitis, diverticulitis, twisted ovarian cyst, and many others. Much attention has been paid to the presence or absence of peristaltic sounds, their quality, and their frequency. Auscultation of the abdomen is one of the least revealing aspects of the physical examination of a patient with abdominal pain. Catastrophes such as a strangulating small-intestinal obstruction or perforated appendicitis may occur in the presence of normal peristaltic sounds. Conversely, when the proximal part of the intestine above obstruction becomes markedly distended and edematous, peristaltic sounds may lose the characteristics of borborygmi and become weak or absent, even when peritonitis is not present. It is usually the severe chemical peritonitis of sudden onset that is associated with the truly silent abdomen.

Laboratory examinations may be valuable in assessing the patient with abdominal pain, yet, with few exceptions, they rarely establish a diagnosis. Leukocytosis should never be the single deciding factor as to whether or not operation is indicated. A white blood cell count  $>20,000/\mu\text{L}$  may be observed with perforation of a viscus, but pancreatitis, acute cholecystitis, pelvic inflammatory disease, and intestinal infarction may also be associated with marked leukocytosis. A normal white blood cell count is not rare in cases of perforation of abdominal viscera. A diagnosis of anemia may be more helpful than the white blood cell count, especially when combined with the history.

The urinalysis may reveal the state of hydration or rule out severe renal disease, diabetes, or urinary infection. Blood urea nitrogen, glucose, and serum bilirubin levels and liver function tests may be

TABLE 15-3 Differential Diagnoses of Abdominal Pain by Location

Right Upper Quadrant	Epigastric	Left Upper Quadrant
Cholecystitis	Peptic ulcer disease	Splenic infarct
Cholangitis	Gastritis	Splenic rupture
Pancreatitis	GERD	Splenic abscess
Pneumonia/empyema	Pancreatitis	Gastritis
Pleurisy/pleurodynia	Myocardial infarction	Gastric ulcer
Subdiaphragmatic abscess	Pericarditis	Pancreatitis
Hepatitis	Ruptured aortic aneurysm	Subdiaphragmatic abscess
Budd-Chiari syndrome	Esophagitis	
Right Lower Quadrant	Perumbilical	Left Lower Quadrant
Appendicitis	Early appendicitis	Diverticulitis
Salpingitis	Gastroenteritis	Salpingitis
Inguinal hernia	Bowel obstruction	Inguinal hernia
Ectopic pregnancy	Ruptured aortic aneurysm	Ectopic pregnancy
Nephrolithiasis		Nephrolithiasis
Inflammatory bowel disease		Irritable bowel syndrome
Mesenteric lymphadenitis		Inflammatory bowel disease
Typhlitis		
Diffuse Nonlocalized Pain		
Gastroenteritis	Malaria	
Mesenteric ischemia	Familial Mediterranean fever	
Bowel obstruction	Metabolic diseases	
Irritable bowel syndrome	Psychiatric disease	
Peritonitis		
Diabetes		

Abbreviation: GERD, gastroesophageal reflux disease.

helpful. Serum amylase levels may be increased by many diseases other than pancreatitis, for example, perforated ulcer, strangulating intestinal obstruction, and acute cholecystitis; thus, elevations of serum amylase do not rule in or rule out the need for an operation.

Plain and upright or lateral decubitus radiographs of the abdomen have limited utility and may be unnecessary in some patients who have substantial evidence of some diseases such as acute appendicitis or strangulated external hernia. Where the indications for surgical or medical intervention are not clear, low-dose computed tomography is preferred to abdominal radiography when evaluating nontraumatic acute abdominal pain.

Very rarely, barium or water-soluble contrast study of the upper part of the gastrointestinal tract is an appropriate radiographic investigation and may demonstrate partial intestinal obstruction that may elude diagnosis by other means. If there is any question of obstruction of the colon, oral administration of barium sulfate should be avoided. On the other hand, in cases of suspected colonic obstruction (without perforation), a contrast enema may be diagnostic.

In the absence of trauma, peritoneal lavage has been replaced as a diagnostic tool by CT scanning and laparoscopy. Ultrasonography has proved to be useful in detecting an enlarged gallbladder or pancreas, the presence of gallstones, an enlarged ovary, or a tubal pregnancy. Laparoscopy is especially helpful in diagnosing pelvic conditions, such as ovarian cysts, tubal pregnancies, salpingitis, acute appendicitis, and other disease processes. Laparoscopy has a particular advantage over imaging in that the underlying etiologic condition can often be definitively addressed.

Radioisotopic hepatobiliary iminodiacetic acid scans (HIDAs) may help differentiate acute cholecystitis or biliary colic from acute pancreatitis. A CT scan may demonstrate an enlarged pancreas, ruptured spleen, or thickened colonic or appendiceal wall and streaking of the mesocolon or mesoappendix characteristic of diverticulitis or appendicitis.

Sometimes, even under the best circumstances with all available aids and with the greatest of clinical skill, a definitive diagnosis cannot be established at the time of the initial examination. And, in some cases, operation may be indicated based on clinical grounds alone. Should that decision be questionable, watchful waiting with repeated questioning and examination will often elucidate the true nature of the illness and indicate the proper course of action.

## A

The author gratefully acknowledges the enormous contribution to this chapter and the approach it espouses of William Silen, who wrote this chapter for many editions.

## FURTHER READING

- B A et al: Acute appendicitis: Modern understanding of pathogenesis, diagnosis and management. *Lancet* 386:1278, 2015.
- C SL, K MP: Diagnostic imaging of acute abdominal pain in adults. *Am Fam Phys* 91:452, 2015.
- H DS et al: Diagnostic performance of a biomarker panel as a negative predictor for acute appendicitis in acute emergency department patients with abdominal pain. *Am J Emerg Med* 35:418, 2017.
- N J et al: Tracing the cause of abdominal pain. *N Engl J Med* 375:e8, 2016.
- P MT: Clinical yield of computed tomography scans in the emergency department for abdominal pain. *J Invest Med* 64:542, 2016.
- S W, C Z: *Cope's Early Diagnosis of the Acute Abdomen*, 22nd ed. New York, Oxford University Press, 2010.

# 16

## Headache

Peter J. Goadsby



Headache is among the most common reasons patients seek medical attention and is responsible, on a global basis, for more disability than any other neurologic problem. Diagnosis and management are based on a careful clinical approach augmented by an understanding of the anatomy, physiology, and pharmacology of the nervous system pathways mediating the various headache syndromes. This chapter will focus on the general approach to a patient with headache; migraine and other primary headache disorders are discussed in Chap. 430.

### GENERAL PRINCIPLES

A classification system developed by the International Headache Society ([www.ihhs-headache.org/en/resources/guidelines/](http://www.ihhs-headache.org/en/resources/guidelines/)) characterizes headache as primary or secondary (Table 16-1). Primary headaches are those in which headache and its associated features are the disorder itself, whereas secondary headaches are those caused by exogenous disorders (Headache Classification Committee of the International Headache Society, 2018). Primary headache often results in considerable disability and a decrease in the patient's quality of life. Mild secondary headache, such as that seen in association with upper respiratory tract infections, is common but rarely worrisome. Life-threatening headache is relatively uncommon, but vigilance is required in order to recognize and appropriately treat such patients.

### ANATOMY AND PHYSIOLOGY OF HEADACHE

Pain usually occurs when peripheral nociceptors are stimulated in response to tissue injury, visceral distension, or other factors (Chap. 13). In such situations, pain perception is a normal physiologic response mediated by a healthy nervous system. Pain can also result when pain-producing pathways of the peripheral or central nervous system (CNS) are damaged or activated inappropriately. Headache may originate from either or both mechanisms. Relatively few cranial structures are pain producing; these include the scalp, meningeal arteries, dural sinuses, falx cerebri, and proximal segments of the large pial arteries. The ventricular ependyma, choroid plexus, pial veins, and much of the brain parenchyma are not pain producing.

The key structures involved in primary headache are the following:

- The large intracranial vessels and dura mater, and the peripheral terminals of the trigeminal nerve that innervate these structures
- The caudal portion of the trigeminal nucleus, which extends into the dorsal horns of the upper cervical spinal cord and receives input from the first and second cervical nerve roots (the trigeminocervical complex)
- Rostral pain-processing regions, such as the ventroposteromedial thalamus and the cortex
- The pain-modulatory systems in the brain that modulate input from the trigeminal nociceptors at all levels of the pain-processing pathways and influence vegetative functions, such as the hypothalamus and brainstem

TABLE 16-1 Common Causes of Headache

PRIMARY HEADACHE		SECONDARY HEADACHE	
TYPE	%	TYPE	%
Tension-type	69	Systemic infection	63
Migraine	16	Head injury	4
Idiopathic stabbing	2	Vascular disorders	1
Exertional	1	Subarachnoid hemorrhage	<1
Cluster	0.1	Brain tumor	0.1

Source: After J Olesen et al: *The Headaches*. Philadelphia, Lippincott Williams & Wilkins, 2005.

The *trigeminovascular system* innervates the large intracranial vessels and dura mater via the trigeminal nerve. Cranial autonomic symptoms, such as lacrimation, conjunctival injection, nasal congestion, rhinorrhea, periorbital swelling, aural fullness, and ptosis, are prominent in the trigeminal autonomic cephalgias (TACs), including cluster headache and paroxysmal hemicrania, and may also be seen in migraine, even in children. These autonomic symptoms reflect activation of cranial parasympathetic pathways, and functional imaging studies indicate that vascular changes in migraine and cluster headache, when present, are similarly driven by these cranial autonomic systems. Thus, they are secondary, and not causative, events in the headache cascade. Moreover, they can often be mistaken for symptoms or signs of cranial sinus inflammation, which is then overdiagnosed and inappropriately managed. Migraine and other primary headache types are not “vascular headaches”; these disorders do not reliably manifest vascular changes, and treatment outcomes cannot be predicted by vascular effects. Migraine is a brain disorder and is best understood and managed as such.

### ■ CLINICAL EVALUATION OF ACUTE, NEW ONSET HEADACHE

The patient who presents with a new, severe headache has a differential diagnosis that is quite different from the patient with recurrent headaches over many years. In new-onset and severe headache, the probability of finding a potentially serious cause is considerably greater than in recurrent headache. Patients with recent onset of pain require prompt evaluation and appropriate treatment. Serious causes to be considered include meningitis, subarachnoid hemorrhage, epidural or subdural hematoma, glaucoma, tumor, and purulent sinusitis. When worrisome symptoms and signs are present ([Table 16-2](#)), rapid diagnosis and management are critical.

A careful neurologic examination is an essential first step in the evaluation. In most cases, patients with an abnormal examination or a history of recent-onset headache should be evaluated by a computed tomography (CT) or magnetic resonance imaging (MRI) study of the brain. As an initial screening procedure for intracranial pathology in this setting, CT and MRI methods appear to be equally sensitive. In some circumstances, a lumbar puncture (LP) is also required, unless a benign etiology can be otherwise established. A general evaluation of acute headache might include cranial arteries by palpation; cervical spine by the effect of passive movement of the head and by imaging; the investigation of cardiovascular and renal status by blood pressure monitoring and urine examination; and eyes by funduscopic, intraocular pressure measurement, and refraction.

The patient's psychological state should also be evaluated because a relationship exists between head pain, depression, and anxiety. This is intended to identify comorbidity rather than provide an explanation for the headache, because troublesome headache is seldom simply caused by mood change. Although it is notable that medicines with antidepressant actions are also effective in the preventive treatment

of both tension-type headache and migraine, each symptom must be treated optimally.

Underlying recurrent headache disorders may be activated by pain that follows otologic or endodontic surgical procedures. Thus, pain about the head as the result of diseased tissue or trauma may reawaken an otherwise quiescent migraine syndrome. Treatment of the headache is largely ineffective until the cause of the primary problem is addressed.

Serious underlying conditions that are associated with headache are described below. Brain tumor is a rare cause of headache and even less commonly a cause of severe pain. The vast majority of patients presenting with severe headache have a benign cause.

## SECONDARY HEADACHE

The management of secondary headache focuses on diagnosis and treatment of the underlying condition.

### ■ MENINGITIS

Acute, severe headache with stiff neck and fever suggests meningitis. LP is mandatory. Often there is striking accentuation of pain with eye movement. Meningitis can be easily mistaken for migraine in that the cardinal symptoms of pounding headache, photophobia, nausea, and vomiting are frequently present, perhaps reflecting the underlying biology of some of the patients.

[Meningitis is discussed in Chaps. 138 and 139.](#)

### ■ INTRACRANIAL HEMORRHAGE

Acute, maximal in <5 min, severe headache lasting >5 min with stiff neck but without fever suggests subarachnoid hemorrhage. A ruptured aneurysm, arteriovenous malformation, or intraparenchymal hemorrhage may also present with headache alone. Rarely, if the hemorrhage is small or below the foramen magnum, the head CT scan can be normal. Therefore, LP may be required to diagnose definitively subarachnoid hemorrhage.

[Subarachnoid hemorrhage is discussed in Chap. 429, and intracranial hemorrhage in Chap. 428.](#)

### ■ BRAIN TUMOR

Approximately 30% of patients with brain tumors consider headache to be their chief complaint. The head pain is usually nondescript—an intermittent deep, dull aching of moderate intensity, which may worsen with exertion or change in position and may be associated with nausea and vomiting. This pattern of symptoms results from migraine far more often than from brain tumor. The headache of brain tumor disturbs sleep in about 10% of patients. Vomiting that precedes the appearance of headache by weeks is highly characteristic of posterior fossa brain tumors. A history of amenorrhea or galactorrhea should lead one to question whether a prolactin-secreting pituitary adenoma (or polycystic ovary syndrome) is the source of headache. Headache arising de novo in a patient with known malignancy suggests either cerebral metastases or carcinomatous meningitis. Head pain appearing abruptly after bending, lifting, or coughing can be due to a posterior fossa mass, a Chiari malformation, or low cerebrospinal fluid (CSF) volume.

[Brain tumors are discussed in Chap. 90.](#)

### ■ TEMPORAL ARTERITIS SEE ALSO CHAPS. 32 AND 363

Temporal (giant cell) arteritis is an inflammatory disorder of arteries that frequently involves the extracranial carotid circulation. It is a common disorder of the elderly; its annual incidence is 77 per 100,000 individuals aged ≥50. The average age of onset is 70 years, and women account for 65% of cases. About half of patients with untreated temporal arteritis develop blindness due to involvement of the ophthalmic artery and its branches; indeed, the ischemic optic neuropathy induced by giant cell arteritis is the major cause of rapidly developing bilateral blindness in patients >60 years. Because treatment with glucocorticoids is effective in preventing this complication, prompt recognition of the disorder is important.

Typical presenting symptoms include headache, polymyalgia rheumatica ([Chap. 363](#)), jaw claudication, fever, and weight loss. Headache

**TABLE 16-2** Headache Symptoms That Suggest a Serious Underlying Disorder

Sudden-onset headache
First severe headache
“Worst” headache ever
Vomiting that precedes headache
Subacute worsening over days or weeks
Pain induced by bending, lifting, coughing
Pain that disturbs sleep or presents immediately upon awakening
Known systemic illness
Onset after age 55
Fever or unexplained systemic signs
Abnormal neurologic examination
Pain associated with local tenderness, e.g., region of temporal artery

is the dominant symptom and often appears in association with malaise and muscle aches. Head pain may be unilateral or bilateral and is located temporally in 50% of patients but may involve any and all aspects of the cranium. Pain usually appears gradually over a few hours before peak intensity is reached; occasionally, it is explosive in onset. The quality of pain is infrequently throbbing; it is almost invariably described as dull and boring, with superimposed episodic stabbing pains similar to the sharp pains that appear in migraine. Most patients can recognize that the origin of their head pain is superficial, external to the skull, rather than originating deep within the cranium (the pain site usually identified by migraineurs). Scalp tenderness is present, often to a marked degree; brushing the hair or resting the head on a pillow may be impossible because of pain. Headache is usually worse at night and often aggravated by exposure to cold. Additional findings may include reddened, tender nodules or red streaking of the skin overlying the temporal arteries, and tenderness of the temporal or, less commonly, the occipital arteries.

The erythrocyte sedimentation rate (ESR) is often, although not always, elevated; a normal ESR does not exclude giant cell arteritis. A temporal artery biopsy followed by immediate treatment with prednisone 80 mg daily for the first 4–6 weeks should be initiated when clinical suspicion is high; treatment should not be unreasonably delayed to obtain a biopsy. The prevalence of migraine among the elderly is substantial, considerably higher than that of giant cell arteritis. Migraineurs often report amelioration of their headache with prednisone; thus, caution must be used when interpreting the therapeutic response.

### ■ GLAUCOMA

Glaucoma may present with a prostrating headache associated with nausea and vomiting. The headache often starts with severe eye pain. On physical examination, the eye is often red with a fixed, moderately dilated pupil.

*Glaucoma is discussed in Chap. 32.*

## PRIMARY HEADACHE DISORDERS

Primary headaches are disorders in which headache and associated features occur in the absence of any exogenous cause. The most common are migraine, tension-type headache, and the TACs, notably cluster headache. These entities are discussed in detail in *Chap. 430*.

### ■ CHRONIC DAILY OR NEAR DAILY HEADACHE

The broad description of chronic daily headache (CDH) can be applied when a patient experiences headache on 15 days or more per month. CDH is neither a single entity nor a diagnosis; it encompasses a number of different headache syndromes, both primary and secondary (*Table 16-3*). In aggregate, this group presents considerable

disability and is thus specially mentioned here. Population-based estimates suggest that about 4% of adults have daily or near-daily headache.

## APPROACH TO THE PATIENT

### Chronic Daily Headache

The first step in the management of patients with CDH is to diagnose any secondary headache and treat that problem (*Table 16-3*). This can sometimes be a challenge when the underlying cause triggers worsening of a primary headache. For patients with primary headaches, diagnosis of the headache type will guide therapy. Preventive treatments such as tricyclics, either amitriptyline or nortriptyline, at doses up to 1 mg/kg, are very useful in patients with CDH arising from migraine or tension-type headache or where the secondary cause has activated the underlying primary headache. Tricyclics are started in low doses (10–25 mg daily) and may be given 12 h before the expected time of awakening in order to avoid excessive morning sleepiness. Medicines including topiramate, valproate, propranolol, flunarizine (not available in the United States), candesartan, and the newer calcitonin gene-related peptide (CGRP) pathway monoclonal antibodies, or gepants-CGRP receptor antagonists (see *Chap. 430*) are also useful when the underlying issue is migraine.

### MANAGEMENT OF MEDICALLY INTRACTABLE DISABLING PRIMARY HEADACHE

The management of medically intractable headache is difficult, although recent developments in therapy are at hand. Monoclonal antibodies to CGRP or its receptor have been reported to be effective and well tolerated in chronic migraine and are now licensed for use in clinical practice. Noninvasive neuromodulatory approaches, such as single-pulse transcranial magnetic stimulation and noninvasive vagal nerve stimulation, which appear to modulate thalamic processing or brainstem mechanisms, respectively, in migraine have been used in clinical practice with success. Noninvasive vagal nerve stimulation has also shown promise particularly in chronic cluster headache, chronic paroxysmal hemicrania, and hemicrania continua, and possibly in short-lasting unilateral neuralgiform headache attacks with cranial autonomic symptoms (SUNA) and short-lasting unilateral neuralgiform headache attacks with conjunctival injection and tearing (SUNCT) (*Chap. 430*). Other modalities are discussed in *Chap. 430*.

### MEDICATION-RELATED AND MEDICATION-OVERUSE HEADACHE

Overuse of analgesic medication for headache can aggravate headache frequency, markedly impair the effect of preventive medicines, and induce a state of refractory daily or near-daily headache called *medication-overuse headache*. A proportion of patients who stop taking analgesics will experience substantial improvement in the severity and frequency of their headache. However, even after cessation of analgesic use, many patients continue to have headache, although they may feel clinically improved in some way, especially if they have been using opioids or barbiturates regularly. The residual symptoms probably represent the underlying primary headache disorder, and most commonly this issue occurs in patients prone to migraine.

*Management of Medication Overuse: Outpatients* For patients who overuse analgesic medications, it is often helpful to reduce and eliminate the medications, although this approach is far from universally effective. One approach is to reduce the medication dose by 10% every 1–2 weeks. Immediate cessation of analgesic use is possible for some patients, provided there is no contraindication. Both approaches are facilitated by use of a medication diary maintained during the month or two before cessation; this helps to identify the scope of the problem. A small dose of a nonsteroidal anti-inflammatory drug (NSAID) such as naproxen, 500 mg bid, if tolerated, will help relieve residual pain as analgesic use is reduced.

TABLE 16-3 Classification of Daily or Near-Daily Headache

Primary		
>4 H DAILY	<4 H DAILY	SECONDARY
Chronic migraine <sup>a</sup>	Chronic cluster headache <sup>b</sup>	Posttraumatic Head injury Iatrogenic Postinfectious
Chronic tension-type headache <sup>a</sup>	Chronic paroxysmal hemicrania	Inflammatory, such as Giant cell arteritis Sarcoidosis Behcet's syndrome
Hemicrania continua <sup>a</sup>	SUNCT/SUNA	Chronic CNS infection
New daily persistent headache <sup>a</sup>	Hypnic headache	Medication-overuse headache <sup>a</sup>

<sup>a</sup>May be complicated by medication overuse. <sup>b</sup>Some patients may have headache >4 h/d.

Abbreviations: CNS, central nervous system; SUNA, short-lasting unilateral neuralgiform headache attacks with cranial autonomic symptoms; SUNCT, short-lasting unilateral neuralgiform headache attacks with conjunctival injection and tearing.

NSAID overuse is not usually a problem for patients with daily headache when an NSAID with a longer half-life is taken once or twice daily; however, overuse problems may develop with shorter-acting NSAIDs. Once the patient has substantially reduced analgesic use, a preventive medication should be introduced. Another widely used approach is to commence the preventive at the same time the analgesic reduction is started. It must be emphasized that *preventives may not work in the presence of analgesic overuse, particularly with opioids*. The most common cause of unresponsiveness to treatment is the use of a preventive when analgesics continue to be used regularly. For some patients, discontinuing analgesics is very difficult; often the best approach is to inform the patient that some degree of headache is inevitable during this initial period.

**Management of Medication Overuse: Inpatients** Some patients will require hospitalization for detoxification. Such patients have typically failed efforts at outpatient withdrawal or have a significant medical condition, such as diabetes mellitus or epilepsy, which would complicate withdrawal as an outpatient. Following admission to the hospital, medications are withdrawn completely on the first day, in the absence of a contraindication. Antiemetics and fluids are administered as required; clonidine is used for opioid withdrawal symptoms. For acute intolerable pain during the waking hours, aspirin, 1 g IV (not approved in the United States), is useful. IM chlorpromazine can be helpful at night; patients must be adequately hydrated. Three to five days into the admission, as the effect of the withdrawn substance wears off, a course of IV dihydroergotamine (DHE) can be used. DHE, administered every 8 h for 5 consecutive days, a treatment that is not stopped short if headache settles, can induce a significant remission that allows a preventive treatment to be established. Serotonin 5-HT<sub>3</sub> receptor antagonists, such as ondansetron or granisetron, or the neurokinin receptor antagonist, aprepitant, may be required with DHE to prevent significant nausea, and domperidone (not approved in the United States) orally or by suppository can be very helpful. Avoiding sedating or otherwise side effect–prone antiemetics is helpful.

#### NEW DAILY PERSISTENT HEADACHE

New daily persistent headache (NDPH) is a clinically distinct syndrome with important secondary causes; these are listed in Table 16-4.

**Clinical Presentation** NDPH presents with headache on most if not all days, and the patient can clearly, and often vividly, recall the moment of onset. The headache usually begins abruptly, but onset may be more gradual; evolution over 3 days has been proposed as the upper limit for this syndrome. Patients typically recall the exact day and circumstances of the onset of headache; the new, persistent head pain does not remit. The first priority is to distinguish between a primary and a secondary cause of this syndrome. Subarachnoid hemorrhage is the most serious of the secondary causes and must be excluded either by history or appropriate investigation (Chap. 429).

**Secondary NDPH • Low CSF Volume Headache** In these syndromes, head pain is positional: it begins when the patient sits or stands upright and resolves upon reclining. The pain, which is occipitofrontal, is usually a dull ache but may be throbbing. Patients with chronic low CSF volume headache typically present with a

history of headache from one day to the next that is generally not present on waking but worsens during the day. Recumbency usually improves the headache within minutes, and it can take only minutes to an hour for the pain to return when the patient resumes an upright position.

The most common cause of headache due to persistent low CSF volume is CSF leak following LP (Chap. S9). Post-LP headache usually begins within 48 h but may be delayed for up to 12 days. Its incidence is between 10% and 30%. Beverages with caffeine may provide temporary relief. Besides LP, index events may include epidural injection or a vigorous Valsalva maneuver, such as from lifting, straining, coughing, clearing the eustachian tubes in an airplane, or multiple orgasms. Spontaneous CSF leaks are well recognized, and the diagnosis should be considered whenever the headache history is typical, even when there is no obvious index event. As time passes from the index event, the postural nature may become less apparent; cases in which the index event occurred several years before the eventual diagnosis have been recognized. Symptoms appear to result from low volume rather than low pressure: although low CSF pressures, typically 0–50 mm CSF, are usually identified, a pressure as high as 140 mm CSF has been noted with a documented leak.

Postural orthostatic tachycardia syndrome (POTS; Chap. 440) can present with orthostatic headache similar to low CSF volume headache and is a diagnosis that needs consideration in this setting.

When imaging is indicated to identify the source of a presumed leak, an MRI with gadolinium is the initial study of choice (Fig. 16-1). A striking pattern of diffuse meningeal enhancement is so typical that in the appropriate clinical context the diagnosis is established. Chiari malformations may sometimes be noted on MRI; in such cases, surgery to decompress the posterior fossa is *not* indicated and usually worsens the headache. Spinal MRI with T2 weighting may reveal a leak, and spinal MRI may demonstrate spinal meningeal cysts whose role in these syndromes is yet to be elucidated. The source of CSF leakage may be identified by spinal MRI with appropriate sequences, or by CT, preferably digital subtraction, myelography. In the absence of a directly identified site of leakage, <sup>113</sup>In-DTPA CSF studies may demonstrate early emptying of the tracer into the bladder or slow progress of tracer across the brain suggesting a CSF leak; this procedure is now only rarely employed.

TABLE 16-4 Differential Diagnosis of New Daily Persistent Headache

PRIMARY	SECONDARY
Migrainous-type	Subarachnoid hemorrhage
Featureless (tension-type)	Low cerebrospinal fluid (CSF) volume headache Raised CSF pressure headache Posttraumatic headache <sup>a</sup> Chronic meningitis

<sup>a</sup>Includes postinfectious forms.

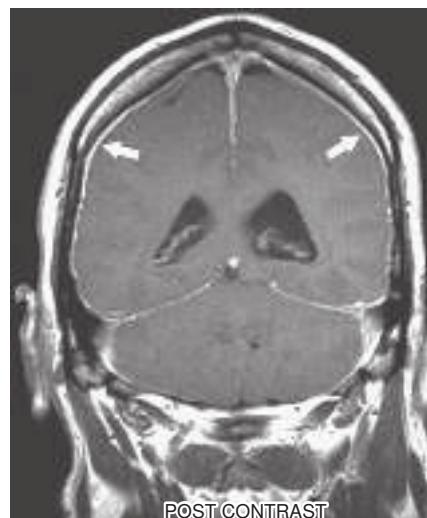


FIGURE 16-1 Magnetic resonance image showing diffuse meningeal enhancement after gadolinium administration in a patient with low cerebrospinal fluid (CSF) volume headache.

Initial treatment for low CSF volume headache is bed rest. For patients with persistent pain, IV caffeine (500 mg in 500 mL of saline administered over 2 h) can be very effective. An electrocardiogram (ECG) to screen for arrhythmia should be performed before administration. It is reasonable to administer at least two infusions of caffeine before embarking on additional tests to identify the source of the CSF leak. Because IV caffeine is safe and can be curative, it spares many patients the need for further investigations. If unsuccessful, an abdominal binder may be helpful. If a leak can be identified, an autologous blood patch is usually curative. A blood patch is also effective for post-LP headache; in this setting, the location is empirically determined to be the site of the LP. In patients with intractable headache, oral theophylline is a useful alternative that can take some months to be effective.

**Raised CSF Pressure Headache** Raised CSF pressure is well recognized as a cause of headache. Brain imaging can often reveal the cause, such as a space-occupying lesion.

**Idiopathic intracranial hypertension (pseudotumor cerebri)** NDPH due to raised CSF pressure can be the presenting symptom for patients with idiopathic intracranial hypertension, a disorder associated with obesity, female gender, and, on occasion, pregnancy. The syndrome can also occur without visual problems, particularly when the fundi are normal. These patients typically present with a history of generalized headache that is present on waking and improves as the day goes on. It is generally present on awakening in the morning and is worse with recumbency. Transient visual obscurations are frequent and may occur when the headaches are most severe. The diagnosis is relatively straightforward when papilledema is present, but the possibility must be considered even in patients without funduscopic changes. Formal visual field testing should be performed even in the absence of overt ophthalmic involvement. Partial obstructions of the cerebral venous sinuses are found in a small number of cases. In addition, persistently raised intracranial pressure can trigger a syndrome of chronic migraine. Other conditions that characteristically produce headache on rising in the morning or nocturnal headache are obstructive sleep apnea or poorly controlled hypertension.

Evaluation of patients suspected to have raised CSF pressure requires brain imaging. It is most efficient to obtain an MRI, including an MR venogram, as the initial study. If there are no contraindications, the CSF pressure should be measured by LP; this should be done when the patient is symptomatic so that both the pressure and the response to removal of 20–30 mL of CSF can be determined. An elevated opening pressure and improvement in headache following removal of CSF are diagnostic in the absence of fundal changes.

Initial treatment is with acetazolamide (250–500 mg bid); the headache may improve within weeks. If ineffective, topiramate is the next treatment of choice; it has many actions that may be useful in this setting, including carbonic anhydrase inhibition, weight loss, and neuronal membrane stabilization, likely mediated via effects on phosphorylation pathways. Severely disabled patients who do not respond to medical treatment require intracranial pressure monitoring and may require shunting. If appropriate, weight loss should be encouraged.

**Posttraumatic Headache** A traumatic event can trigger a headache process that lasts for many months or years after the event. The term *trauma* is used here in a very broad sense: headache can develop following an injury to the head, but it can also develop after an infectious episode, typically viral meningitis; a flulike illness; or a parasitic infection. Complaints of dizziness, vertigo, and impaired memory can accompany the headache. Symptoms may remit after several weeks or persist for months and even years after the injury. Typically, the neurologic examination is normal and CT or MRI studies are unrevealing. Chronic subdural hematoma may

on occasion mimic this disorder. Posttraumatic headache may also be seen after carotid dissection and subarachnoid hemorrhage and after intracranial surgery. The underlying theme appears to be that a traumatic event involving the pain-producing meninges can trigger a headache process that lasts for many years.

**Other Causes** In one series, one-third of patients with NDPH reported headache beginning after a transient flulike illness characterized by fever, neck stiffness, photophobia, and marked malaise. Evaluation typically reveals no apparent cause for the headache. There is no convincing evidence that persistent Epstein-Barr virus infection plays a role in NDPH. A complicating factor is that many patients undergo LP during the acute illness; iatrogenic low CSF volume headache must be considered in these cases.

**Treatment** Treatment is largely empirical and directed at the headache phenotype. Tricyclic antidepressants, notably amitriptyline, and anticonvulsants, such as topiramate, valproate, candesartan, and gabapentin, have been used with reported benefit. The monoamine oxidase inhibitor phenelzine may also be useful in carefully selected patients. The headache usually resolves within 3–5 years, but it can be quite disabling.

## PRIMARY CARE AND HEADACHE MANAGEMENT

Most patients with headache will be seen first in a primary care setting. The challenging task of the primary care physician is to identify the very few worrisome secondary headaches from the very great majority of primary and less dangerous secondary headaches (Table 16-2).

Absent any warning signs, a reasonable approach is to treat when a diagnosis is established. As a general rule, the investigation should focus on identifying worrisome causes of headache or on helping the patient to gain confidence if no primary headache diagnosis can be made.

After treatment has been initiated, follow-up care is essential to identify whether progress has been made against the headache complaint. Not all headaches will respond to treatment, but, in general, worrisome headaches will progress and will be easier to identify.

When a primary care physician feels the diagnosis is a primary headache disorder, it is worth noting that >90% of patients who present to primary care with a complaint of headache will have migraine (Chap. 430).

In general, patients who do not have a clear diagnosis, have a primary headache disorder other than migraine or tension-type headache, or are unresponsive to two or more standard therapies for the considered headache type, should be considered for referral to a specialist. In a practical sense, the threshold for referral is also determined by the experience of the primary care physician in headache medicine and the availability of secondary care options.

### A

The editors acknowledge the contributions of Neil H. Raskin to earlier editions of this chapter.

## FURTHER READING

- | H | C        | C   | I  |
|---|----------|---|--|
| H | S        | : The International Classification of Headache Disorders, 3rd ed. Cephalalgia 33:629, 2018. |  |
| K | D, G     | PJ:   | Headache: A Practical Manual. Oxford: Oxford University Press, 2008.                       |
| L | JW, G    | PJ:   | Mechanism and Management of Headache, 7th ed. New York, Elsevier, 2005.                    |
| O | J et al: | The Headaches. Philadelphia, Lippincott, Williams & Wilkins, 2005.                          |  |
| S | SD, L    | RB, D   | DW: Wolff's Headache and Other Head Pain, 9th ed. New York, Oxford University Press, 2021. |

## 17

## Back and Neck Pain

John W. Engstrom



The importance of back and neck pain in our society is underscored by the following: (1) the cost of chronic back pain in the United States is estimated at more than \$200 billion annually; approximately one-third of this cost is due to direct health care expenses and two-thirds are indirect costs resulting from loss of wages and productivity; (2) back symptoms are the most common cause of disability in individuals <45 years of age; (3) low back pain (LBP) is the second most common reason for visiting a physician in the United States; and (4) more than four out of five people will experience significant back pain at some point in their lives.

## ANATOMY OF THE SPINE

The anterior spine consists of cylindrical vertebral bodies separated by intervertebral disks and stabilized by the anterior and posterior longitudinal ligaments. The intervertebral disks are composed of a central gelatinous nucleus pulposus surrounded by a tough cartilaginous ring, the annulus fibrosis. Disks are responsible for 25% of spinal column length and allow the bony vertebrae to move easily upon each other (Figs. 17-1 and 17-2). Desiccation of the nucleus pulposus and degeneration of the annulus fibrosus worsen with age, resulting in loss of disk height. The disks are largest in the cervical and lumbar regions where movements of the spine are greatest. The anterior spine absorbs the shock of bodily movements such as walking and running, and with the posterior spine protects the spinal cord and nerve roots in the spinal canal.

The posterior spine consists of the vertebral arches and processes. Each arch consists of paired cylindrical pedicles anteriorly and paired lamina posteriorly. The vertebral arch also gives rise to two transverse processes laterally, one spinous process posteriorly, plus two superior and two inferior articular facets. The apposition of a superior and inferior facet constitutes a *facet joint*. The posterior spine provides an anchor for the attachment of muscles and ligaments. The contraction of muscles attached to the spinous and transverse processes and lamina works like a system of pulleys and levers producing flexion, extension, rotation, and lateral bending movements of the spine.

Nerve root injury (*radiculopathy*) is a common cause of pain in the neck and arm, or low back and buttock, or leg (see *dermatomes* in Figs. 25-2 and 25-3). Each nerve root exits just above its corresponding vertebral body in the cervical region (e.g., the C7 nerve root exits

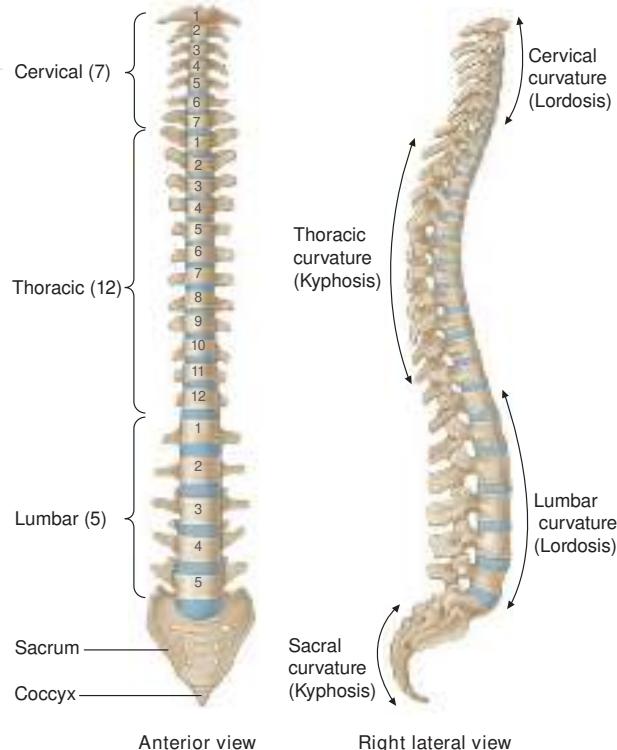


FIGURE 17-2 Spinal column. (Reproduced with permission from AG Cornuelle, DH Gronefeld: *Radiographic Anatomy Positioning*. New York, McGraw-Hill, 1998.)

at the C6-C7 level), and just below the vertebral body in the thoracic and lumbar spine (e.g., the T1 nerve root exits at the T1-T2 level). The cervical nerve roots follow a short intraspinal course before exiting. In contrast, because the spinal cord ends at the L1 or L2 vertebral level, the lumbar nerve roots follow a long intraspinal course and can be injured anywhere along its path. For example, disk herniation at the L4-L5 level can produce L4 root compression laterally, but more often compression of the traversing L5 nerve root occurs (Fig. 17-3). The lumbar nerve roots are mobile in the spinal canal, but eventually pass through the narrow *lateral recess* of the spinal canal and *intervertebral*

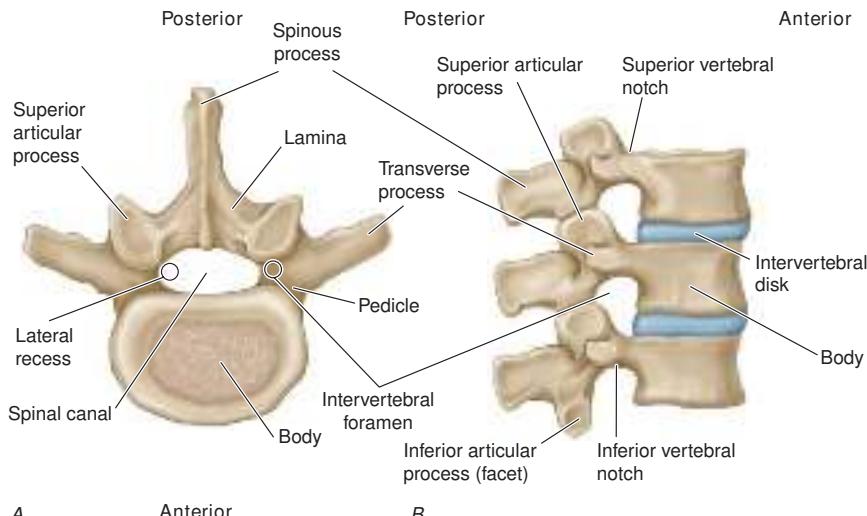
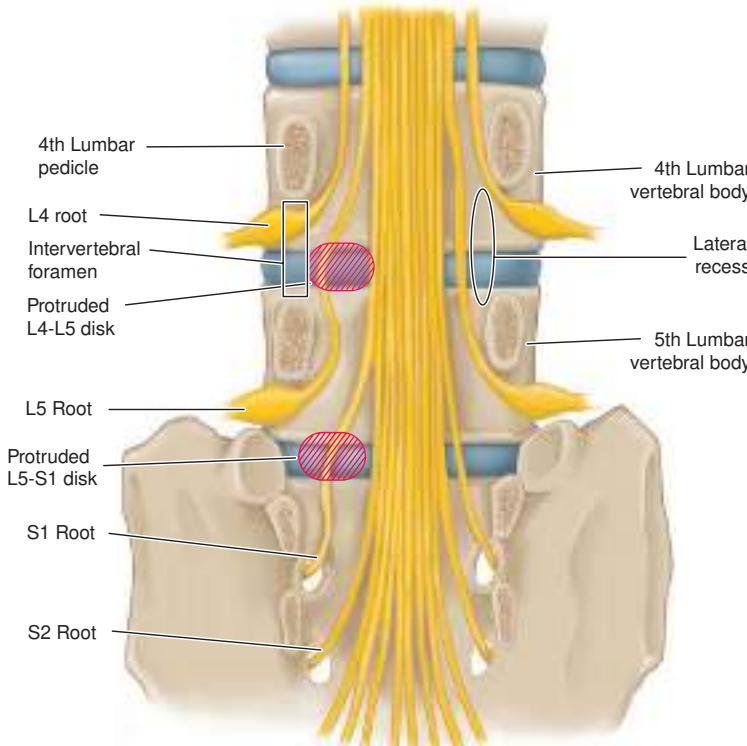


FIGURE 17-1 Vertebral anatomy. A. Vertebral body—axial view; B. vertebral column—sagittal view. (Reproduced with permission from AG Cornuelle, DH Gronefeld: *Radiographic Anatomy Positioning*. New York, McGraw-Hill, 1998.)



**FIGURE 17-3** Compression of L5 and S1 roots by herniated disks. (Reproduced with permission from AH Ropper, MA Samuels: Adams and Victor's Principles of Neurology, 9th ed. New York, McGraw-Hill, 2009.)

foramen (Figs. 17-2 and 17-3). When imaging the spine, both sagittal and axial views are needed to assess possible compression at these sites.

Beginning at the C3 level, each cervical (and the first thoracic) vertebral body projects a lateral bony process upward—the uncinate process. The uncinate process articulates with the cervical vertebral body above via the uncovertebral joint. The uncovertebral joint can hypertrophy with age and contribute to neural foraminal narrowing and cervical radiculopathy.

Pain-sensitive structures of the spine include the periosteum of the vertebrae, dura, facet joints, annulus fibrosus of the intervertebral disk, epidural veins and arteries, and the longitudinal ligaments. Disease of these diverse structures may explain many cases of back pain without nerve root compression. Under normal circumstances, the nucleus pulposus of the intervertebral disk is not pain sensitive.

*Pain of spine origin* may be located in the back or referred to the buttocks or legs. Diseases affecting the upper lumbar spine tend to refer pain to the lumbar region, groin, or anterior thighs. Diseases affecting the lower lumbar spine tend to produce pain referred to the buttocks, posterior thighs, calves, or feet. Referred pain often explains pain syndromes that cross multiple dermatomes without evidence of nerve or nerve root injury.

## APPROACH TO THE PATIENT

### Back Pain

#### TYPES OF BACK PAIN

Delineating the type of pain reported by the patient is the essential first step. Attention is also focused on identifying risk factors for a serious underlying etiology. The most frequent serious causes of back pain are radiculopathy, fracture, tumor, infection, or referred pain from visceral structures (Table 17-1).

*Local pain* is caused by injury to pain-sensitive structures that compress or irritate sensory nerve endings. The site of the pain is near the affected part of the back.

*Pain referred to the back* may arise from abdominal or pelvic viscera. The pain is usually described as primarily abdominal or pelvic, accompanied by back pain, and usually unaffected by posture. The patient may occasionally complain of back pain only.

**TABLE 17-1** Acute Low Back Pain: Risk Factors for an Important Structural Cause

#### History

Pain worse at rest or at night

Prior history of cancer

History of chronic infection (especially lung, urinary tract, skin, poor dentition)

History of trauma

Incontinence

Age >70 years

Intravenous drug use

Glucocorticoid use

History of a rapidly progressive neurologic deficit

#### Examination

Unexplained fever

Unexplained weight loss

Focal palpation/percussion tenderness over the midline spine

Abdominal, rectal, or pelvic mass

Internal/external rotation of the leg at the hip

Straight-leg or reverse straight-leg raising signs

Progressive focal neurologic deficit

**Radicular pain** is typically sharp and radiates from the low back to a leg within the territory of a nerve root (see “Lumbar Disk Disease,” below). Coughing, sneezing, or voluntary contraction of abdominal muscles (lifting heavy objects or straining at stool) may elicit or worsen the radiating pain. The pain may also increase in postures that stretch the nerves and nerve roots. Sitting with the leg outstretched places traction on the sciatic nerve and L5 and S1 roots because the sciatic nerve passes posterior to the hip. The femoral nerve (L2, L3, and L4 roots) passes anterior to the hip and is not stretched by sitting. The description of the pain alone often fails to distinguish between referred pain and radiculopathy, although a burning or electric quality favors radiculopathy.

**Pain associated with muscle spasm** is commonly associated with many spine disorders. The spasms may be accompanied by an abnormal posture, tense paraspinal muscles, and dull or achy pain in the paraspinal region.

Knowledge of the circumstances associated with the onset of back pain is important when weighing possible serious underlying causes for the pain. Some patients involved in accidents or work-related injuries may exaggerate their pain for the purpose of compensation or for psychological reasons.

#### EXAMINATION

A complete physical examination including vital signs, heart and lungs, abdomen and rectum, and limbs is advisable. Back pain referred from visceral organs may be reproduced during palpation of the abdomen (pancreatitis, abdominal aortic aneurysm [AAA]) or percussion over the costovertebral angles (pyelonephritis).

The normal spine has a cervical and lumbar lordosis and a thoracic kyphosis. Exaggeration of these normal alignments may result in hyperkyphosis of the thoracic spine or hyperlordosis of the lumbar spine. Inspection of the back may reveal a lateral curvature of the spine (scoliosis). A midline hair tuft, skin dimpling or pigmentation, or a sinus tract may indicate a congenital spine anomaly. Asymmetry in the prominence of the paraspinal muscles suggests muscle spasm. Palpation over the spinous process transmits force to the entire vertebrae and suggests vertebral pathology.

Flexion at the hips is normal in patients with lumbar spine disease, but flexion of the lumbar spine is limited and sometimes painful. Lateral bending to the side opposite the injured spinal element may stretch the damaged tissues, worsen pain, and limit motion. Hyperextension of the spine (with the patient prone or standing) is limited when nerve root compression, facet joint pathology, or other bony spine disease is present.

Pain from hip disease may mimic the pain of lumbar spine disease. Hip pain can be reproduced by passive internal and external rotation at the hip with the knee and hip in flexion or by percussing the heel with the examiner’s palm with the leg extended (heel percussion sign).

The *straight-leg raising (SLR)* maneuver is a simple bedside test for nerve root disease. With the patient supine, passive straight-leg flexion at the hip stretches the L5 and S1 nerve roots and the sciatic nerve; dorsiflexion of the foot during the maneuver adds to the stretch. In healthy individuals, flexion to at least 80° is normally possible without causing pain, although a tight, stretching sensation in the hamstring muscles is common. The SLR test is positive if the maneuver reproduces the patient’s usual back or limb pain. Eliciting the SLR sign in both the supine and sitting positions can help determine if the finding is reproducible. The patient may describe pain in the low back, buttocks, posterior thigh, or lower leg, but the *key feature is reproduction of the patient’s usual pain*. The *crossed SLR sign* is present when flexion of one leg reproduces the usual pain in the opposite leg or buttocks. In disk herniation, the crossed SLR sign is less sensitive but more specific than the SLR sign. The *reverse SLR sign* is elicited by standing the patient next to the examination table and passively extending each leg with the knee fully extended. This maneuver, which stretches the L2-L4 nerve roots, lumbosacral plexus, and femoral nerve, is considered positive if the patient’s usual back or limb pain is reproduced. For all of these tests, the nerve or nerve root lesion is always on the side of the pain. Examination of the unaffected leg first provides a control test, ensures mutual understanding of test parameters, and enhances test utility.

The neurologic examination includes a search for focal weakness or muscle atrophy, localized reflex changes, diminished sensation in the legs, or signs of spinal cord injury. The examiner should be alert to the possibility of breakaway weakness, defined as fluctuations in the maximum power generated during muscle testing. Breakaway weakness may be due to pain, inattention, or a combination of pain and underlying true weakness. Breakaway weakness without pain is usually due to a lack of effort. In uncertain cases, electromyography (EMG) can determine if true weakness due to nerve tissue injury is present. Findings with specific lumbosacral nerve root lesions are shown in Table 17-2 and are discussed below.

#### LABORATORY, IMAGING, AND EMG STUDIES

Laboratory studies are rarely needed for the initial evaluation of nonspecific acute (<3 months duration) low back pain (ALBP).

TABLE 17-2 Lumbosacral Radiculopathy: Neurologic Features

LUMBOSACRAL NERVE ROOT	EXAMINATION FINDINGS			PAIN DISTRIBUTION
	REFLEX	SENSORY	MOTOR	
L2 <sup>a</sup>	—	Upper anterior thigh	Psoas (hip flexors)	Anterior thigh
L3 <sup>a</sup>	—	Lower anterior thigh Anterior knee	Psoas (hip flexors) Quadriceps (knee extensors) Thigh adductors	Anterior thigh, knee
L4 <sup>a</sup>	Quadriceps (knee)	Medial calf	Quadriceps (knee extensors) <sup>b</sup> Thigh adductors	Knee, medial calf Anterolateral thigh
L5 <sup>c</sup>	—	Dorsal surface—foot Lateral calf	Peronei (foot evertors) <sup>b</sup> Tibialis anterior (foot dorsiflexors) Gluteus medius (leg abductors) Toe dorsiflexors	Lateral calf, dorsal foot, posterior lateral thigh, buttocks
S1 <sup>c</sup>	Gastrocnemius/ soleus (ankle)	Plantar surface—foot Lateral aspect—foot	Gastrocnemius/soleus (foot plantar flexors) <sup>b</sup> Abductor hallucis (toe flexors) <sup>b</sup> Gluteus maximus (leg extensors)	Bottom foot, posterior calf, posterior thigh, buttocks

<sup>a</sup>Reverse straight-leg raising sign may be present—see “Examination of the Back.” <sup>b</sup>These muscles receive the majority of innervation from this root. <sup>c</sup>Straight-leg raising sign may be present—see “Examination of the Back.”

Risk factors for a serious underlying cause and for infection, tumor, or fracture in particular should be sought by history and examination. If risk factors are present (Table 17-1), then laboratory studies (complete blood count [CBC], erythrocyte sedimentation rate [ESR], urinalysis) are indicated. If risk factors are absent, then management is conservative (see "Treatment," below).

CT scanning is used as a primary screening modality for acute trauma that is moderate to severe. CT is superior to x-rays for detection of fractures involving posterior spine structures, craniocervical and cervicothoracic junctions, C1 and C2 vertebrae, bone fragments in the spinal canal, or misalignment. MRI or CT myelography is the radiologic test of choice for evaluation of most serious diseases involving the spine. MRI is superior for the definition of soft tissue structures, whereas CT myelography provides optimal imaging of the lateral recess of the spinal canal, defines bony abnormalities, and is tolerated by claustrophobic patients.

Population surveys in the United States suggest that patients with back pain report greater functional limitations in recent years, despite rapid increases in spine imaging, opioid prescribing, injections, and spine surgery. This suggests that more selective use of diagnostic and treatment modalities may be reasonable for many patients. One prospective case-control study found that older adults with back pain of less than 6 weeks duration who received spine imaging as part of a primary care visit had no better outcomes than the control group.

Spine imaging often reveals abnormalities of dubious clinical relevance that may alarm clinicians and patients alike and prompt further testing and unnecessary therapy. When imaging tests are reviewed, it is important to remember that degenerative findings are common in normal, pain-free individuals. Randomized trials and observational studies have suggested that imaging can have a "cascade effect," creating a gateway to other unnecessary care. Interventions have included physician education and computerized decision support within the electronic medical record to require specific indications for approval of imaging tests. Other strategies have included audit and feedback of individual practitioners' rates of ordering, more rapid access to physical therapy, or consultation with spine experts for patients without imaging indications.

Educational tools created by the American College of Physicians for patients and the public have included "Five Things Physicians and Patients Should Question": (1) Do not recommend advanced imaging (e.g., MRI) of the spine within the first 6 weeks in patients with nonspecific ALBP in the absence of red flags. (2) Do not perform elective spinal injections without imaging guidance, unless contraindicated. (3) Do not use bone morphogenetic protein (BMP) for routine anterior cervical spine fusion surgery. (4) Do not use EMG and nerve conduction studies (NCSs) to determine the cause of purely midline lumbar, thoracic, or cervical spine pain. (5) Do not recommend bed rest for >48 h when treating LBP. In an observational study, application of this strategy was associated with lower rates of repeat imaging, opioid use, and referrals for physical therapy.

Electrodiagnostic studies can be used to assess the functional integrity of the peripheral nervous system (Chap. 446). Sensory NCSs are normal when focal sensory loss confirmed by examination is due to nerve root damage because the nerve roots are proximal to the nerve cell bodies in the dorsal root ganglia. Injury to nerve tissue distal to the dorsal root ganglion (e.g., plexus or peripheral nerve) results in reduced sensory nerve signals. Needle EMG complements NCSs by detecting denervation or reinnervation changes in a myotomal (segmental) distribution. Multiple muscles supplied by different nerve roots and nerves are sampled; the pattern of muscle involvement indicates the nerve root(s) responsible for the injury. Needle EMG provides objective information about motor nerve fiber injury when clinical evaluation of weakness is limited by pain or poor effort. EMG and NCSs will be normal when sensory nerve root injury or irritation is the pain source.

The COVID-19 pandemic has disrupted and complicated the care of patients with LBP. Paraspinal myalgias may result in LBP. The sedentary lifestyle resulting from quarantine is associated with an increased frequency or severity of LBP. Fear of infection risk has also prevented many patients from seeking needed care. Video-telemedicine visits can help identify patients with underlying risks for a serious cause and inform appropriate next steps in management.

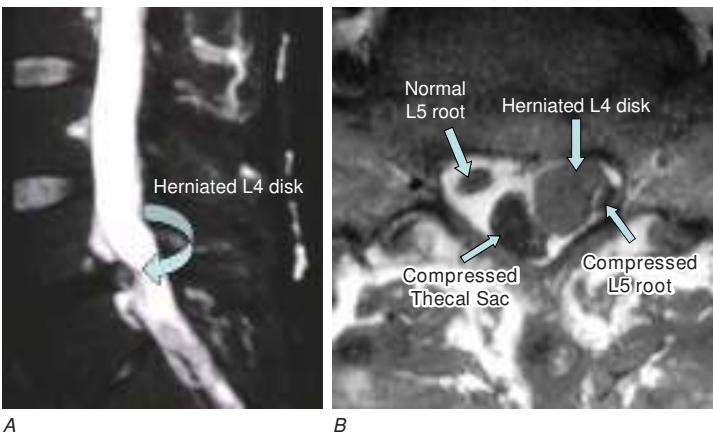
## CAUSES OF BACK PAIN TABLE 17 3

### LUMBAR DISK DISEASE

Lumbar disk disease is a common cause of acute, chronic, or recurrent low back and leg pain (Figs. 17-3 and 17-4). Disk disease is most likely to occur at the L4-L5 or L5-S1 levels, but upper lumbar levels can also be involved. The cause is often unknown, but the risk is increased in overweight individuals. Disk herniation is unusual prior to age 20 years and is rare in the fibrotic disks of the elderly. Complex genetic factors may play a role in predisposition. The pain may be located in the low back only or referred to a leg, buttock, or hip. A sneeze, cough, or trivial movement may cause the nucleus pulposus to prolapse, pushing the frayed and weakened annulus posteriorly. With severe disk disease, the nucleus can protrude through the annulus (herniation) or become extruded to lie as a free fragment in the spinal canal.

TABLE 17-3 Causes of Back or Neck Pain

Lumbar or Cervical Disk Disease
Degenerative Spine Disease
Lumbar spinal stenosis without or with neurogenic claudication Intervertebral foraminal or lateral recess narrowing Disk-osteophyte complex Facet or uncovertebral joint hypertrophy Lateral disk protrusion Spondylosis (osteoarthritis), spondylolisthesis, or spondylolysis
Spine Infection
Vertebral osteomyelitis Spinal epidural abscess Septic disk (diskitis) Meningitis Lumbar arachnoiditis
Neoplasms
Metastatic with/without pathologic fracture Primary Nervous System: Meningioma, neurofibroma, schwannoma Primary Bone: chordoma, osteoma
Trauma
Strain or sprain Whiplash injury Trauma/falls, motor vehicle accidents
Metabolic Spine Disease
Osteoporosis with/without pathologic fracture—hyperparathyroidism, immobility Osteosclerosis (e.g., Paget's disease)
Congenital/Developmental
Spondylolysis Kyphoscoliosis Spina bifida occulta Tethered spinal cord
Autoimmune Inflammatory Arthritis
Other Causes of Back Pain
Referred pain from visceral disease (e.g., abdominal aortic aneurysm) Postural Psychiatric, malingering, chronic pain syndromes



**FIGURE 17-4** Disk herniation. *A*, Sagittal T2-weighted image on the left side of the spinal canal reveals disk herniation at the L4-L5 level. *B*, Axial T1-weighted image shows paracentral disk herniation with displacement of the thecal sac medially and the left L5 nerve root posteriorly in the left lateral recess.

The mechanism by which intervertebral disk injury causes back pain is uncertain. The inner annulus fibrosus and nucleus pulposus are normally devoid of innervation. Inflammation and production of proinflammatory cytokines within a ruptured nucleus pulposus may trigger or perpetuate back pain. Ingrowth of nociceptive (pain) nerve fibers into the nucleus pulposus of a diseased disk may be responsible for some cases of chronic “diskogenic” pain. Nerve root injury (radiculopathy) from disk herniation is usually due to inflammation, but lateral herniation may produce compression in the lateral recess or intervertebral foramen.

A ruptured disk may be asymptomatic or cause back pain, limited spine motion (particularly flexion), a focal neurologic deficit, or radicular pain. A dermatomal pattern of sensory loss or a reduced or absent deep tendon reflex is more suggestive of a specific root lesion than is the pattern of pain. Motor findings (focal weakness, muscle atrophy, or fasciculations) occur less frequently than focal sensory or reflex changes. Symptoms and signs are usually unilateral, but bilateral involvement does occur with large central disk herniations that involve roots bilaterally or cause inflammation of nerve roots within the spinal canal. Clinical manifestations of specific nerve root lesions are summarized in Table 17-2.

The differential diagnosis covers a variety of serious and treatable conditions, including epidural abscess, hematoma, fracture, or tumor. Fever, constant pain uninfluenced by position, sphincter abnormalities, or signs of myelopathy suggest an etiology other than lumbar disk disease. Absent ankle reflexes can be a normal finding in persons >60 years or a sign of bilateral S1 radiculopathies. An absent deep tendon reflex or focal sensory loss may indicate injury to a nerve root, but other sites of injury along the nerve must also be considered. As examples, an absent knee reflex may be due to a femoral neuropathy or an L4 nerve root injury; loss of sensation over the foot and lateral lower calf may result from a peroneal or lateral sciatic neuropathy, or an L5 nerve root injury. Focal muscle atrophy may reflect injury to the anterior horn cells of the spinal cord, a nerve root, peripheral nerve, or disuse.

A lumbar spine MRI scan or CT myelogram can often confirm the location and type of pathology. Spine MRIs yield exquisite views of intraspinal and adjacent soft tissue anatomy, whereas bony lesions of the lateral recess or intervertebral foramen are optimally visualized by CT myelography. The correlation of neuroradiologic findings to clinical symptoms, particularly pain, is not simple. Contrast-enhancing tears in the annulus fibrosus or disk protrusions are widely accepted as common sources of back pain; however, studies have found that many asymptomatic adults have similar radiologic findings. Entirely asymptomatic disk protrusions are also common, occurring in up to one-third of adults, and these may also enhance with contrast. Furthermore,

in patients with known disk herniation treated either medically or surgically, persistence of the herniation 10 years later had no relationship to the clinical outcome. In summary, MRI findings of disk protrusion, tears in the annulus fibrosus, or hypertrophic facet joints are common incidental findings that, by themselves, should not dictate management decisions for patients with back pain.

The diagnosis of nerve root injury is most secure when the history, examination, results of imaging studies, and the EMG are concordant. There is often good correlation between CT and EMG findings for localization of nerve root injury.

Management of lumbar disk disease is discussed below.

*Cauda equina syndrome (CES)* signifies an injury of multiple lumbosacral nerve roots within the spinal canal distal to the termination of the spinal cord at L1-L2. LBP, weakness and areflexia in the legs, saddle anesthesia, or loss of bladder function may occur. The problem must be distinguished from disorders of the lower spinal cord (conus medullaris syndrome), acute transverse myelitis (Chap. 442), and Guillain-Barré syndrome (Chap. 447).

Combined involvement of the conus medullaris and cauda equina can occur. CES is most commonly due to a large ruptured lumbosacral intervertebral disk, but other causes include lumbosacral spine fracture, hematoma within the spinal canal (sometimes following lumbar puncture in patients with coagulopathy), and tumor or other compressive mass lesions. Treatment is usually surgical decompression, sometimes on an urgent basis in an attempt to restore or preserve motor or sphincter function, or radiotherapy for metastatic tumors (Chap. 90).

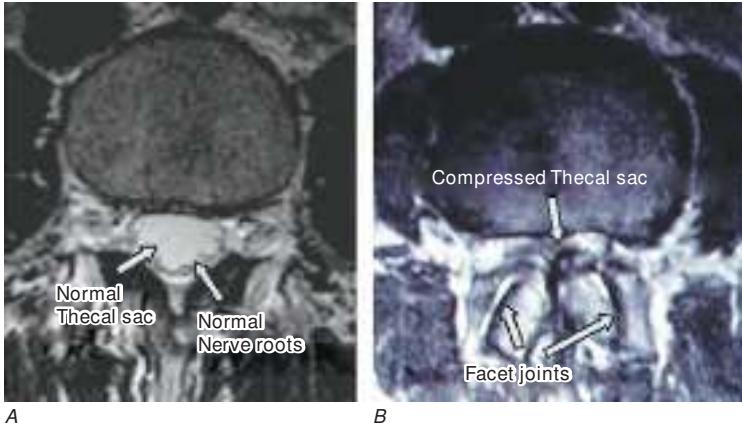
## ■ DEGENERATIVE CONDITIONS

*Lumbar spinal stenosis (LSS)* describes a narrowed lumbar spinal canal. *Neurogenic claudication* consists of pain, typically in the back and buttocks or legs, that is brought on by walking or standing and relieved by sitting. Unlike vascular claudication, symptoms are often provoked by standing without walking. Unlike lumbar disk disease, symptoms are usually relieved by sitting. Patients with neurogenic claudication can often walk much farther when leaning over a shopping cart and can pedal a stationary bike with ease while sitting. These flexed positions increase the anteroposterior spinal canal diameter and reduce intraspinal venous hypertension, producing pain relief. Focal weakness, sensory loss, or reflex changes may occur when spinal stenosis is associated with neural foraminal narrowing and radiculopathy. Severe neurologic deficits, including paralysis and urinary incontinence, occur only rarely.

LSS by itself is common (6–7% of adults) and is usually asymptomatic. Symptoms are correlated with severe spinal canal stenosis. LSS is most often acquired (75%) but can also be congenital or due to a mixture of both etiologies. Congenital forms (achondroplasia and idiopathic) are characterized by short, thick pedicles that produce both spinal canal and lateral recess stenosis. Acquired factors that contribute to spinal stenosis include degenerative diseases (spondylosis, spondylolisthesis, and scoliosis), trauma, spine surgery, metabolic or endocrine disorders (epidural lipomatosis, osteoporosis, acromegaly, renal osteodystrophy, and hypoparathyroidism), and Paget’s disease. MRI provides the best definition of the abnormal anatomy (Fig. 17-5).

LSS accompanied by neurogenic claudication responds to surgical decompression of the stenotic segments. The same processes leading to LSS may cause lumbar foraminal or lateral recess narrowing resulting in coincident lumbar radiculopathy that may require treatment as well.

Conservative treatment of symptomatic LSS can include nonsteroidal anti-inflammatory drugs (NSAIDs), acetaminophen, exercise programs, and symptomatic treatment of acute pain episodes. There is insufficient evidence to support the routine use of epidural glucocorticoid injections. Surgery is considered when medical therapy does not relieve symptoms sufficiently to allow for resumption of activities of



**FIGURE 17-5** Spinal stenosis. *A*, An axial T2-weighted image of the normal lumbar spine shows a normal thecal sac within the lumbar spinal canal. The thecal sac is bright. The lumbar roots are seen as dark punctate dots located posteriorly in the thecal sac. *B*, The thecal sac is not well visualized due to severe lumbar spinal canal stenosis, partially the result of hypertrophic facet joints.

daily living or when focal neurologic signs are present. Most patients with neurogenic claudication who are treated medically do not improve over time. Surgical management with laminectomy, which increases the spinal canal diameter and reduces venous hypertension, can produce significant relief of exertional back and leg pain, leading to less disability and improved functional outcomes. Laminectomy and fusion is usually reserved for patients with LSS and spondylolisthesis. Predictors of a poor surgical outcome include impaired walking preoperatively, depression, cardiovascular disease, and scoliosis. Up to one-quarter of surgically treated patients develop recurrent stenosis at the same or an adjacent spinal level within 7–10 years; recurrent symptoms usually respond to a second surgical decompression.

*Neural foraminal narrowing or lateral recess stenosis with radiculopathy* is a common consequence of osteoarthritic processes that cause LSS (Figs. 17-1 and 17-6), including osteophytes, lateral disk protrusion, calcified disk-osteophytes, facet joint hypertrophy, uncovertebral

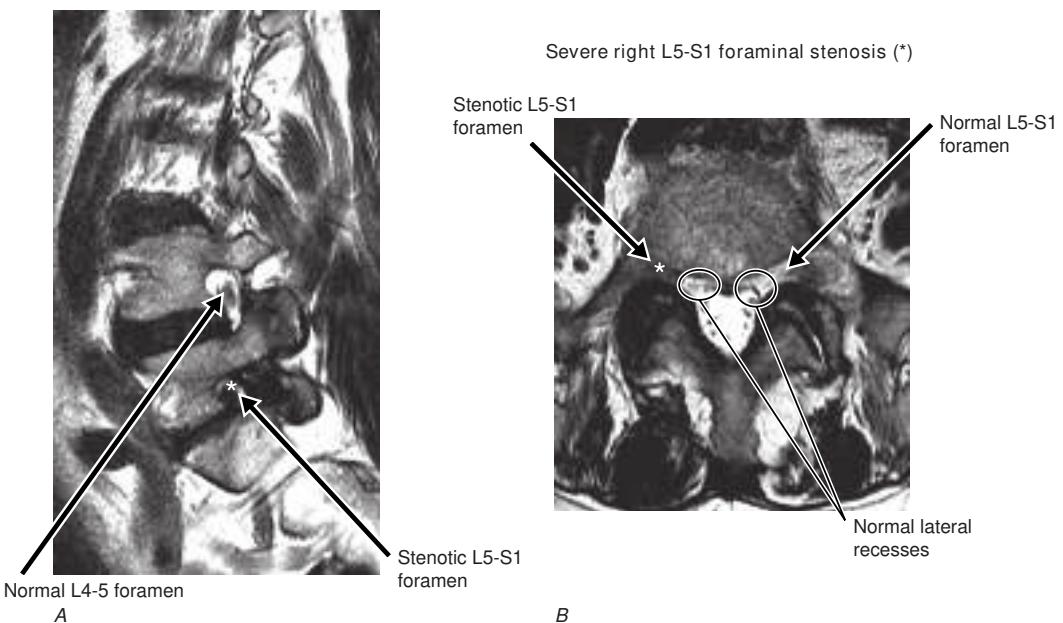
joint hypertrophy (in the cervical spine), congenitally shortened pedicles, or, frequently, a combination of these processes. Neoplasms (primary or metastatic), fractures, infections (epidural abscess), or hematomas are less frequent causes. Most common is bony foraminal narrowing leading to nerve root ischemia and persistent symptoms, in contrast to inflammation that is associated with a paracentral herniated disk and radiculopathy. These conditions can produce unilateral nerve root symptoms or signs due to compression at the intervertebral foramen or in the lateral recess; symptoms are indistinguishable from disk-related radiculopathy, but treatment may differ depending on the etiology. The history and neurologic examination alone cannot distinguish between these possibilities. Neuroimaging (CT or MRI) is required to identify the anatomic cause. Neurologic findings from the examination and EMG can help direct the attention of the radiologist to specific nerve roots, especially on axial images. For *facet joint hypertrophy with foraminal stenosis*, surgical foraminotomy produces long-term relief of leg and back pain in 80–90% of patients.

Facet joint or medial branch blocks for back or neck

pain are sometimes used to help determine the anatomic origin of back pain or for treatment, but there is a lack of clinical data to support their utility. Medical causes of lumbar or cervical radiculopathy unrelated to primary spine disease include infections (e.g., herpes zoster and Lyme disease), carcinomatous meningitis, diabetes, and root avulsion or traction (trauma).

### ■ SPONDYLOYSIS AND SPONDYLOLISTHESIS

*Spondylosis*, or osteoarthritic spine disease, typically occurs in later life and primarily involves the cervical and lumbosacral spine. Patients often complain of back pain that increases with movement, is associated with stiffness, and is better with inactivity. The relationship between clinical symptoms and radiologic findings is usually not straightforward. Pain may be prominent when MRI, CT, or x-ray findings are minimal, and prominent degenerative spine disease can be seen in asymptomatic patients. Osteophytes, combined



**FIGURE 17-6** Foraminal stenosis. *A*, Sagittal T2-weighted image reveals normal high signal around the exiting right L4 nerve root in the right neural foramen at L4-L5; effacement of the high signal is noted one level below at L5-S1, due to severe foraminal stenosis. *B*, Axial T2-weighted image at the L5-S1 level demonstrates normal lateral recesses bilaterally, a normal intervertebral foramen on the left, but a severely stenotic foramen (\*) on the right.

disk-osteophytes, or a thickened ligamentum flavum may cause or contribute to central spinal canal stenosis, lateral recess stenosis, or neural foraminal narrowing.

*Spondylolisthesis* is the anterior slippage of the vertebral body, pedicles, and superior articular facets, leaving the posterior elements behind. Spondylolisthesis can be associated with spondylolysis, congenital anomalies, degenerative spine disease, or other causes of mechanical weakness of the pars interarticularis (e.g., infection, osteoporosis, tumor, trauma, earlier surgery). The slippage may be asymptomatic or may cause LBP, nerve root injury (the L5 root most frequently), symptomatic spinal stenosis, or CES in rare severe cases. A “step-off” on palpation or tenderness may be elicited near the segment that has “slipped” (most often L4 on L5 or occasionally L5 on S1). Focal anterolisthesis or retrolisthesis can occur at any cervical or lumbar level and be the source of neck or LBP. Plain x-rays of the low back or neck in flexion and extension will reveal movement at the abnormal spinal segment. Surgery is performed for spinal instability (slippage 5–8 mm) and considered for pain symptoms that do not respond to conservative measures (e.g., rest, physical therapy), cases with a progressive neurologic deficit, or scoliosis.

## ■ NEOPLASMS

Back pain is the most common neurologic symptom in patients with systemic cancer and is the presenting symptom in 20%. The cause is usually vertebral body metastasis (85–90%) but can also result from spread of cancer through the intervertebral foramen (especially with lymphoma), carcinomatous meningitis, or metastasis to the spinal cord. The thoracic spine is most often affected. Cancer-related back pain tends to be constant, dull, unrelieved by rest, and worse at night. By contrast, mechanical causes of LBP usually improve with rest. MRI, CT, and CT myelography are the studies of choice when spinal metastasis is suspected. Once a metastasis is found, imaging of the entire spine is essential, as it reveals additional tumor deposits in one-third of patients. MRI is preferred for soft tissue definition, but the most rapidly available imaging modality is best because the patient's condition may worsen quickly without intervention. Early diagnosis is crucial. A strong predictor of outcome is baseline neurologic function prior to diagnosis. Half to three-quarters of patients are nonambulatory at the time of diagnosis and few regain the ability to walk. [The management of spinal metastasis is discussed in detail in Chap. 90.](#)

## ■ INFECTIONS/INFLAMMATION

*Vertebral osteomyelitis* is most often caused by hematogenous seeding of staphylococci, but other bacteria or tuberculosis (Pott's disease) may be responsible. The primary source of infection is usually the skin or urinary tract. Other common sources of bacteremia are IV drug use, poor dentition, endocarditis, lung abscess, IV catheters, or postoperative wound sites. Back pain at rest, tenderness over the involved vertebra, and an elevated erythrocyte sedimentation rate (ESR) or C-reactive protein (CRP) are the most common findings in vertebral osteomyelitis. Fever or an elevated white blood cell count is found in a minority of patients. MRI and CT are sensitive and specific for early detection of osteomyelitis. The intervertebral disk can also be affected by infection (diskitis) and almost never by tumor. Extension of the infection posteriorly from the vertebral body can produce a spinal epidural abscess.

*Spinal epidural abscess* ([Chap. 442](#)) presents with back pain (aggravated by movement or palpation of the spinous process), fever, radiculopathy, or signs of spinal cord compression. The subacute development of two or more of these findings should increase suspicion for spinal epidural abscess. The abscess is best delineated by spine MRI and may track over multiple spinal levels.

*Lumbar adhesive arachnoiditis* with radiculopathy is due to fibrosis following inflammation within the subarachnoid space. The fibrosis results in nerve root adhesions and presents as back and leg pain associated with multifocal motor, sensory, or reflex changes. Causes of arachnoiditis include multiple lumbar operations (most common in the United States), chronic spinal infections (especially tuberculosis in the developing world), spinal cord injury, intrathecal hemorrhage, myelography (rare), intrathecal injections (glucocorticoids, anesthetics, or

other agents), and foreign bodies. The MRI shows clumped nerve roots on axial views or loculations of cerebrospinal fluid within the thecal sac. Clumped nerve roots should be distinguished from enlarged nerve roots seen with demyelinating polyneuropathy or neoplastic infiltration. Treatment is usually unsatisfactory. Microsurgical lysis of adhesions, dorsal rhizotomy, dorsal root ganglionectomy, and epidural glucocorticoids have been tried, but outcomes have been poor. Dorsal column stimulation for pain relief has produced varying results.

## ■ TRAUMA

A patient complaining of back pain and an inability to move the legs may have a spine fracture or dislocation; fractures above L1 place the spinal cord at risk for compression. Care must be taken to avoid further damage to the spinal cord or nerve roots by immobilizing the back or neck pending the results of radiologic studies. Vertebral fractures frequently occur in the absence of trauma in association with osteoporosis, glucocorticoid use, osteomyelitis, or neoplastic infiltration.

**Sprains and Strains** The terms *low back sprain*, *strain*, and *mechanically induced muscle spasm* refer to minor, self-limited injuries associated with lifting a heavy object, a fall, or a sudden deceleration such as in an automobile accident. These terms are used loosely and do not correlate with specific underlying pathologies. The pain is usually confined to the lower back. Patients with paraspinal muscle spasm often assume unusual postures.

**Traumatic Vertebral Fractures** Most traumatic fractures of the lumbar vertebral bodies result from injuries producing anterior wedging or compression. With severe trauma, the patient may sustain a fracture-dislocation or a “burst” fracture involving the vertebral body and posterior elements. Traumatic vertebral fractures are caused by falls from a height, sudden deceleration in an automobile accident, or direct injury. Neurologic impairment is common, and early surgical treatment is indicated. In victims of blunt trauma, CT scans of the chest, abdomen, or pelvis can be reformatted to detect associated vertebral fractures. Rules have been developed to avoid unnecessary spine imaging associated with low-risk trauma, but these studies typically exclude patients aged >65 years—a group that can sustain fractures with minor trauma.

## ■ METABOLIC CAUSES

**Osteoporosis and Osteosclerosis** Immobilization, osteomalacia, the postmenopausal state, renal disease, multiple myeloma, hyperparathyroidism, hyperthyroidism, metastatic carcinoma, or glucocorticoid use may accelerate osteoporosis and weaken the vertebral body, leading to compression fractures and pain. Up to two-thirds of compression fractures seen on radiologic imaging are asymptomatic. The most common nontraumatic vertebral body fractures are due to a postmenopausal cause, or to osteoporosis in adults >75 years old ([Chap. 411](#)). The risk of an additional vertebral fracture 1 year following a first vertebral fracture is 20%. The presence of fever, weight loss, fracture at a level above T4, any fracture in a young adult, or the predisposing conditions described above should increase suspicion for a cause other than typical osteoporosis. The sole manifestations of a compression fracture may be localized back or radicular pain exacerbated by movement and often reproduced by palpation over the spinous process of the affected vertebra.

Relief of acute pain can often be achieved with acetaminophen, NSAIDs, opioids, or a combination of these medications. Both pain and disability are improved with bracing. Antiresorptive drugs are not recommended in the setting of acute pain but are the preferred treatment to prevent additional fractures. Less than one-third of patients with prior compression fractures are adequately treated for osteoporosis despite the increased risk for future fractures; even fewer at-risk patients without a history of fracture are adequately treated. The literature for percutaneous vertebroplasty (PVP) or kyphoplasty for osteoporotic compression fractures associated with debilitating pain does not support their use.

Osteosclerosis, an abnormally increased bone density often due to Paget's disease, is readily identifiable on routine x-ray studies and can sometimes be a source of back pain. It may be associated with an isolated increase in alkaline phosphatase in an otherwise healthy older person. Spinal cord or nerve root compression can result from bony encroachment. The diagnosis of Paget's disease as the cause of a patient's back pain is a diagnosis of exclusion.

For further discussion of these bone disorders, see Chaps. 410, 411, and 412.

### AUTOIMMUNE INFLAMMATORY ARTHRITIS

Autoimmune inflammatory disease of the spine can present with the insidious onset of low back, buttock, or neck pain. Examples include rheumatoid arthritis (RA) (Chap. 358), ankylosing spondylitis, reactive arthritis and psoriatic arthritis (Chap. 355), or inflammatory bowel disease (Chap. 326).

### CONGENITAL ANOMALIES OF THE LUMBAR SPINE

*Spondylosis* is a bony defect in the vertebral pars interarticularis (a segment near the junction of the pedicle with the lamina), a finding present in up to 6% of adolescents. The cause is usually a stress microfracture in a congenitally abnormal segment. Multislice CT with multiplanar reformation is the most accurate modality for detecting spondylosis in adults. Symptoms may occur in the setting of a single injury, repeated minor injuries, or during a growth spurt. Spondylosis is the most common cause of persistent LBP in adolescents and is often associated with sports-related activities.

*Scoliosis* refers to an abnormal curvature in the coronal (lateral) plane of the spine. With *kyphoscoliosis*, there is, in addition, a forward curvature of the spine. The abnormal curvature may be congenital, due to abnormal spine development, acquired in adulthood due to degenerative spine disease, or progressive due to paraspinal neuromuscular disease. The deformity can progress until ambulation or pulmonary function is compromised.

*Spina bifida occulta* (closed spinal dysraphism) is a failure of closure of one or several vertebral arches posteriorly; the meninges and spinal cord are normal. A dimple or small lipoma may overlie the defect, but the skin is intact. Most cases are asymptomatic and discovered incidentally during a physical examination for back pain.

*Tethered cord syndrome* usually presents as a progressive cauda equina disorder (see below), although myelopathy may also be the initial manifestation. The patient is often a child or young adult who complains of perineal or perianal pain, sometimes following minor trauma. MRI studies typically reveal a low-lying conus (below L1 and L2) and a short and thickened filum terminale. The MRI findings also occur as incidental findings, sometimes during evaluation of unrelated LBP in adults.

### REFERRED PAIN FROM VISCERAL DISEASE

Diseases of the thorax, abdomen, or pelvis may refer pain to the spinal segment that innervates the diseased organ. Occasionally, back pain may be the first and only manifestation. Upper abdominal diseases generally refer pain to the lower thoracic or upper lumbar region (eighth thoracic to the first and second lumbar vertebrae), lower abdominal diseases to the midlumbar region (second to fourth lumbar vertebrae), and pelvic diseases to the sacral region. Local signs (pain with spine palpation, paraspinal muscle spasm) are absent, and little or no pain accompanies routine movements.

**Low Thoracic or Lumbar Pain with Abdominal Disease** Tumors of the posterior wall of the stomach or duodenum typically produce epigastric pain (Chaps. 80 and 324), but back pain may occur if retroperitoneal extension is present. Fatty foods occasionally induce back pain associated with biliary or pancreatic disease. Pathology in retroperitoneal structures (hemorrhage, tumors, and pyelonephritis) can produce paraspinal pain that radiates to the lower abdomen, groin, or anterior thighs. A mass in the iliopsoas region can produce unilateral lumbar pain with radiation toward the groin, labia, or testicle. The sudden appearance of lumbar

pain in a patient receiving anticoagulants should prompt consideration of retroperitoneal hemorrhage.

Isolated LBP occurs in some patients with a contained rupture of an AAA. The classic clinical triad of abdominal pain, shock, and back pain occurs in <20% of patients. The diagnosis may be missed because the symptoms and signs can be nonspecific. Misdiagnoses include nonspecific back pain, diverticulitis, renal colic, sepsis, and myocardial infarction. A careful abdominal examination revealing a pulsatile mass (present in 50–75% of patients) is an important physical finding. Patients with suspected AAA should be evaluated with abdominal ultrasound, CT, or MRI (Chap. 280).

**Sacral Pain with Gynecologic and Urologic Disease** Pelvic organs rarely cause isolated LBP. Uterine malposition (retroversion, descensus, and prolapse) may cause traction on the uterosacral ligament. The pain is referred to the sacral region, sometimes appearing after prolonged standing. Endometriosis or uterine cancers can invade the uterosacral ligaments. Pain associated with endometriosis is typically premenstrual and often continues until it merges with menstrual pain.

Menstrual pain with poorly localized, cramping pain can radiate down the legs. LBP that radiates into one or both thighs is common in the last weeks of pregnancy. Continuous and worsening pain unrelieved by rest or at night may be due to neoplastic infiltration of nerves or nerve roots.

Urologic sources of lumbosacral back pain include chronic prostatitis, prostate cancer with spinal metastasis (Chap. 87), and diseases of the kidney or ureter. Infectious, inflammatory, or neoplastic renal diseases may produce ipsilateral lumbosacral pain, as can renal artery or vein thrombosis. Paraspinal lumbar pain may be a symptom of ureteral obstruction due to nephrolithiasis.

### OTHER CAUSES OF BACK PAIN

**Postural Back Pain** There is a group of patients with nonspecific chronic low back pain (CLBP) in whom no specific anatomic lesion can be found despite exhaustive investigation. Exercises to strengthen the paraspinal and abdominal muscles are sometimes helpful. CLBP may be encountered in patients who seek financial compensation; in malingerers; or in those with concurrent substance abuse. Many patients with CLBP have a history of psychiatric illness (depression, anxiety states) or childhood trauma (physical or sexual abuse) that antedates the onset of back pain. Preoperative psychological assessment has been used to exclude patients with marked psychological impairments that predict a poor surgical outcome from spine surgery.

**Idiopathic** The cause of LBP occasionally remains unclear. Some patients have had multiple operations for disk disease. The original indications for surgery may have been questionable, with back pain only, no definite neurologic signs, or a minor disk bulge noted on CT or MRI. Scoring systems based on neurologic signs, psychological factors, physiologic studies, and imaging studies have been devised to minimize the likelihood of unsuccessful surgery.

### GLOBAL CONSIDERATIONS

While many of the history and examination features described in this chapter apply to all patients, information regarding the global epidemiology and prevalence of LBP is limited. The Global Burden of Diseases Study 2019 reported that LBP represented the #1 cause overall for total years lived with disability (YLD), and #9 overall as a cause of disability-related life years (DALYs). These numbers increased substantially from 1990 estimates, and with the aging of the population worldwide, the numbers of individuals suffering from LBP are expected to increase further in the future. Although rankings for LBP generally were higher in developed regions, a high burden exists in every part of the world. An area of uncertainty is the degree to which regional differences exist in terms of the specific etiologies of LBP and how these are managed. For example, the most common cause of arachnoiditis in developing countries is a prior spinal infection, but in developed countries the most frequent cause is multiple lumbar spine surgeries.

## TREATMENT

### Back Pain

Management is considered separately for acute and chronic low back pain syndromes without radiculopathy, and for back pain with radiculopathy.

#### ACUTE LOW BACK PAIN WITHOUT RADICULOPATHY

This is defined as pain of <12 weeks duration. Full recovery can be expected in >85% of adults with ALBP without leg pain. Most have purely “mechanical” symptoms (i.e., pain that is aggravated by motion and relieved by rest).

The initial assessment is focused on excluding serious causes of spine pathology that require urgent intervention, including infection, cancer, or trauma. Risk factors for a serious cause of ALBP are shown in Table 17-1. Laboratory and imaging studies are unnecessary if risk factors are absent. CT, MRI, or plain spine films are rarely indicated in the first month of symptoms unless a spine fracture, tumor, or infection is suspected.

The prognosis of ALBP is generally excellent; however, episodes tend to recur, and as many as two-thirds of patients will experience a second episode within 1 year. Most patients do not seek medical care and improve on their own. Even among those seen in primary care, two-thirds report substantial improvement after 7 weeks. This high likelihood of spontaneous improvement can mislead clinicians and patients about the efficacy of treatment interventions, highlighting the importance of rigorous prospective trials. Many treatments commonly used in the past are now known to be ineffective, including bed rest and lumbar traction.

Clinicians should reassure and educate patients that improvement is very likely and instruct them in self-care. Satisfaction and the likelihood of follow-up increase when patients are educated about prognosis, evidence-based treatments, appropriate activity modifications, and strategies to prevent future exacerbations. Counseling patients about the risks of overtreatment is another important part of the discussion. Patients who report that they did not receive an adequate explanation for their symptoms are likely to request further diagnostic tests.

In general, bed rest should be avoided for relief of severe symptoms or limited to a day or two at most. Several randomized trials suggest that bed rest does not hasten the pace of recovery. In general, early resumption of normal daily physical activity should be encouraged, avoiding only strenuous manual labor. Advantages of early ambulation for ALBP also include maintenance of cardiovascular conditioning; improved bone, cartilage, and muscle strength; and increased endorphin levels. Specific back exercises or early vigorous exercise have not shown benefits for acute back pain. Empiric use of heating pads or blankets is sometimes helpful.

**NSAIDs and Acetaminophen** Evidence-based guidelines recommend over-the-counter medicines such as NSAIDs and acetaminophen as first-line options for treatment of ALBP. In otherwise healthy patients, a trial of NSAIDs can be followed by acetaminophen for time-limited periods. In theory, the anti-inflammatory effects of NSAIDs might provide an advantage over acetaminophen to suppress inflammation that accompanies many causes of ALBP, but in practice there is no clinical evidence to support the superiority of NSAIDs. The risk of renal and gastrointestinal toxicity with NSAIDs is increased in patients with preexisting medical comorbidities (e.g., renal insufficiency, cirrhosis, prior gastrointestinal hemorrhage, use of anticoagulants or glucocorticoids, heart failure). Some patients elect to take acetaminophen and an NSAID together in hopes of a more rapid benefit.

**Muscle Relaxants** Skeletal muscle relaxants, such as cyclobenzaprine or methocarbamol, may be useful, but sedation is a common side effect. Limiting the use of muscle relaxants to nighttime only may be an option for patients with back pain that interferes with sleep.

**Opioids** There is no good evidence to support the use of opioid analgesics or tramadol as first-line therapy for ALBP. Their use is best reserved for patients who cannot tolerate acetaminophen or NSAIDs and for those with severe refractory pain. Also, the duration of opioid treatment for ALBP should be strictly limited to 3–7 days. As with muscle relaxants, these drugs are often sedating, so it may be useful to prescribe them at nighttime only. Side effects of short-term opioid use include nausea, constipation, and pruritus; risks of long-term opioid use include hypersensitivity to pain, hypogonadism, and dependency. Falls, fractures, driving accidents, and fecal impaction are other risks. The clinical efficacy of opioids for chronic pain beyond 16 weeks of use is unproven.

Mounting evidence of morbidity from long-term opioid therapy (including overdose, dependency, addiction, falls, fractures, accident risk, and sexual dysfunction) has prompted efforts to reduce its use for chronic pain, including back pain (Chap. 13). When used, safety may be improved with automated notices for high doses, early refills, prescriptions from multiple pharmacies, overlapping opioid and benzodiazepine prescriptions, and in the United States by state-based prescription drug monitoring programs (PDMPs). A recent study indicated that most patients with opioid use disorder presenting to emergency departments had no prescriptions recorded in the PDMP, reflecting other methods used to obtain opioids. Greater access to alternative treatments for chronic pain, such as tailored exercise programs and cognitive behavioral therapy (CBT), may also reduce opioid prescribing.

**Other Approaches** There is no evidence to support use of oral or injected glucocorticoids, antiepileptics, antidepressants, or therapies for neuropathic pain such as gabapentin or herbal therapies. Commonly used nonpharmacologic treatments for ALBP are also of unproven benefit, including spinal manipulation, physical therapy, massage, acupuncture, laser therapy, therapeutic ultrasound, corsets, transcutaneous electrical nerve stimulation (TENS), special mattresses, or lumbar traction. Although important for chronic pain, use of back exercises for ALBP are generally not supported by clinical evidence. There is no convincing evidence regarding the value of ice or heat applications for ABLP; however, many patients report temporary symptomatic relief from ice or frozen gel packs just before sleep, and heat may produce a short-term reduction in pain after the first week. Patients often report improved satisfaction with the care that they receive when they actively participate in the selection of symptomatic approaches.

#### CHRONIC LOW BACK PAIN WITHOUT RADICULOPATHY

Back pain is considered chronic when the symptoms last >12 weeks; it accounts for 50% of total back pain costs. Risk factors include obesity, female gender, older age, prior history of back pain, restricted spinal mobility, pain radiating into a leg, high levels of psychological distress, poor self-rated health, minimal physical activity, smoking, job dissatisfaction, and widespread pain. In general, the same treatments that are recommended for ALBP can be useful for patients with CLBP. In this setting, however, the benefit of opioid therapy or muscle relaxants is less clear. In general, improved activity tolerance is the primary goal, while pain relief is secondary.

Some observers have raised concerns that CLBP may often be overtreated. For CLBP without radiculopathy, multiple guidelines explicitly recommend against use of SSRIs, any type of injection, TENS, lumbar supports, traction, radiofrequency facet joint denervation, intradiskal electrothermal therapy, or intradiskal radiofrequency thermocoagulation. On the other hand, exercise therapy and treatment of depression appear to be useful and underused.

**Exercise Programs** Evidence supports the use of exercise therapy to alleviate pain symptoms and improve function. Exercise can be one of the mainstays of treatment for CLBP. Effective regimens have generally included a combination of core-strengthening exercises, stretching, and gradually increasing aerobic exercise. A program of supervised exercise can improve compliance. Supervised intensive

physical exercise or “work hardening” regimens have been effective in returning some patients to work, improving walking distance, and reducing pain. In addition, some forms of yoga have been evaluated in randomized trials and may be helpful for patients who are interested.

Intensive multidisciplinary rehabilitation programs can include daily or frequent physical therapy, exercise, CBT, a workplace evaluation, and other interventions. For patients who have not responded to other approaches, such programs appear to offer some benefit. Systematic reviews, however, suggest that the evidence and benefits are limited.

**Nonopioid Medications** Medications for CLBP may include short courses of NSAIDs or acetaminophen. Duloxetine is approved for the treatment of CLBP (60 mg daily) and may also treat coincident depression. Tricyclic antidepressants can provide modest pain relief for some patients without evidence of depression. Depression is common among patients with chronic pain and should be appropriately treated.

**Cognitive Behavioral Therapy** CBT is based on evidence that psychological and social factors, as well as somatic pathology, are important in the genesis of chronic pain and disability; CBT focuses on efforts to identify and modify patients’ thinking about their condition. In one randomized trial, CBT reduced disability and pain in patients with CLBP. Such behavioral treatments appear to provide benefits similar in magnitude to exercise therapy.

**Complementary Medicine** Back pain is the most frequent reason for seeking complementary and alternative treatments. Spinal manipulation or massage therapy may provide short-term relief, but long-term benefit is unproven. Biofeedback has not been studied rigorously. There is no convincing evidence that either TENS, laser therapy, or ultrasound are effective in treating CLBP. Rigorous trials of acupuncture suggest that true acupuncture is not superior to sham acupuncture, but that both may offer an advantage over routine care. Whether this is due entirely to placebo effects provided even by sham acupuncture is uncertain.

**Injections and Other Interventions** Various injections, including epidural glucocorticoid injections, facet joint injections, and trigger point injections, have been used for treating CLBP. However, in the absence of radiculopathy, there is no clear evidence that these approaches are sustainably effective.

Injection studies are sometimes used diagnostically to help determine the anatomic source of back pain. Pain relief following a glucocorticoid and anesthetic injection into a facet or medial branch block are used as evidence that the facet joint is the pain source; however, the possibility that the response was a placebo effect or due to systemic absorption of the glucocorticoids is difficult to exclude.

Another category of intervention for CLBP is electrothermal and radiofrequency therapy. Intradiskal therapy has been proposed using energy to thermocoagulate and destroy nerves in the intervertebral disk, using specially designed catheters or electrodes. Current evidence does not support the use of discography to identify a specific disk as the pain source, or the use of intradiskal electrothermal or radiofrequency therapy for CLBP.

Radiofrequency denervation is sometimes used to destroy nerves that are thought to mediate pain, and this technique has been used for facet joint pain (with the target nerve being the medial branch of the primary dorsal ramus), for back pain thought to arise from the intervertebral disk (ramus communicans), and radicular back pain (dorsal root ganglia). These interventional therapies have not been studied in sufficient detail to draw firm conclusions regarding their value for CLBP.

**Surgery** Surgical intervention for CLBP without radiculopathy has been evaluated in a number of randomized trials. The case for fusion surgery for CLBP without radiculopathy is weak. While some studies have shown modest benefit, there has been no benefit when compared to an active medical treatment arm, often including highly structured, rigorous rehabilitation combined with CBT. The

use of bone matrix protein (BMP) instead of iliac crest graft for the fusion was shown to increase hospital costs and length of stay but not improve clinical outcomes.

Guidelines suggest that referral for an opinion on spinal fusion can be considered for patients who have completed an optimal nonsurgical treatment program (including combined physical and psychological treatment) and who have persistent severe back pain for which they would consider surgery. The high cost, wide geographic variations, and rapidly increasing rates of spinal fusion surgery have prompted scrutiny regarding the lack of standardization of appropriate indications. Some insurance carriers have begun to limit coverage for the most controversial indications, such as LBP without radiculopathy.

Lumbar disk replacement with prosthetic disks is US Food and Drug Administration-approved for uncomplicated patients needing single-level surgery at the L3-S1 levels. The disks are generally designed as metal plates with a polyethylene cushion sandwiched in between. The trials that led to approval of these devices were not blinded. When compared to spinal fusion, the artificial disks were “not inferior.” Long-term follow-up is needed to determine device failure rates over time. Serious complications are somewhat more likely with the artificial disk. This treatment remains controversial for CLBP.

## LOW BACK PAIN WITH RADICULOPATHY

A common cause of back pain with radiculopathy is a herniated disk affecting the nerve root and producing back pain with radiation down the leg. The term *sciatica* is used when the leg pain radiates posteriorly in a sciatic or L5/S1 distribution. The prognosis for acute low back and leg pain with radiculopathy due to disk herniation is generally favorable, with most patients showing substantial improvement over months. Serial imaging studies suggest spontaneous regression of the herniated portion of the disk in two-thirds of patients over 6 months. Nonetheless, several important treatment options provide symptomatic relief while the healing process unfolds.

Resumption of normal activity is recommended. Randomized trial evidence suggests that bed rest is ineffective for treating sciatica as well as back pain alone. Acetaminophen and NSAIDs are useful for pain relief, although severe pain may require short courses (3–7 days) of opioid analgesics. Opioids are superior for acute pain relief in the emergency department.

Epidural glucocorticoid injections have a role in providing symptom relief for acute lumbar radiculopathy due to a herniated disk, but do not reduce the use of subsequent surgical intervention. A brief course of high-dose oral glucocorticoids (methylprednisolone dose pack) for 3 days followed by a rapid taper over 4 more days can be helpful for some patients with acute disk-related radiculopathy, although this specific regimen has not been studied rigorously.

Diagnostic nerve root blocks have been advocated to determine if pain originates from a specific nerve root. However, improvement may result even when the nerve root is not responsible for the pain; this may occur as a placebo effect, from a pain-generating lesion located distally along the peripheral nerve, or from effects of systemic absorption.

Urgent surgery is recommended for patients who have evidence of CES or spinal cord compression, generally manifesting as combinations of bowel or bladder dysfunction, diminished sensation in a saddle distribution, a sensory level on the trunk, and bilateral leg weakness or spasticity. Surgical intervention is also indicated for patients with progressive motor weakness due to nerve root injury demonstrated on clinical examination or EMG.

Surgery is also an important option for patients who have disabling radicular pain despite optimal conservative treatment. Because patients with a herniated disk and sciatica generally experience rapid improvement over weeks, most experts do not recommend considering surgery unless the patient has failed to respond to a minimum of 6–8 weeks of nonsurgical management. For patients who have not improved, randomized trials show that surgery results in more rapid pain relief than nonsurgical treatment. However, after

2 years of follow-up, patients appear to have similar pain relief and functional improvement with or without surgery. Thus, both treatment approaches are reasonable, and patient preferences and needs (e.g., rapid return to employment) strongly influence decision-making. Some patients will want the fastest possible relief and find surgical risks acceptable. Others will be more risk-averse and more tolerant of symptoms and will choose watchful waiting, especially if they understand that improvement is likely in the end.

The usual surgical procedure is a partial hemilaminectomy with excision of the prolapsed disk (discectomy). Minimally invasive techniques have gained in popularity in recent years, but some evidence suggests they may be less effective than standard surgical techniques, with more residual back pain, leg pain, and higher rates of rehospitalization. Fusion of the involved lumbar segments should be considered only if significant spinal instability is present (i.e., degenerative spondylolisthesis). The costs associated with lumbar interbody fusion have increased dramatically in recent years. There are no large prospective, randomized trials comparing fusion to other types of surgical intervention. In one study, patients with persistent LBP despite an initial discectomy fared no better with spine fusion than with a conservative regimen of cognitive intervention and exercise. Artificial disks, as discussed above, are used in Europe; their utility remains controversial in the United States.

## PAIN IN THE NECK AND SHOULDER

Neck pain, which usually arises from diseases of the cervical spine and soft tissues of the neck, is common, typically precipitated by movement, and may be accompanied by focal tenderness and limitation of motion. Many of the earlier comments made regarding causes of LBP also apply to disorders of the cervical spine. The text below will emphasize differences. Pain arising from the brachial plexus, shoulder, or peripheral nerves can be confused with cervical spine disease (Table 17-4), but the history and examination usually identify a more distal origin for the pain. When the site of nerve tissue injury is unclear, EMG studies can localize the lesion. Cervical spine trauma, disk disease, or spondylosis with intervertebral foraminal narrowing may be asymptomatic or painful and can produce a myelopathy, radiculopathy, or both. The same risk factors for serious causes of LBP also apply to neck pain with the additional feature that neurologic signs of myelopathy (incontinence, sensory level, spastic legs) may also occur. Lhermitte's sign, an electrical shock down the spine with neck flexion, suggests involvement of the cervical spinal cord.

## ■ TRAUMA TO THE CERVICAL SPINE

Trauma (fractures, subluxation) places the spinal cord at risk for compression. Motor vehicle accidents, violent crimes, or falls account for 87% of cervical spinal cord injuries (Chap. 442). Immediate immobilization of the neck is essential to minimize further spinal cord injury from movement of unstable cervical spine segments. A CT scan is the diagnostic procedure of choice for detection of acute fractures following severe trauma; plain x-rays are used for lesser degrees of trauma or in settings where CT is unavailable. When traumatic injury to the vertebral arteries or cervical spinal cord is suspected, visualization by MRI with magnetic resonance angiography is preferred.

The decision to obtain imaging should be based on the clinical context of the injury. The National Emergency X-Radiography Utilization Study (NEXUS) low-risk criteria established that normally alert patients without palpation tenderness in the midline; intoxication; neurologic deficits; or painful distracting injuries were very unlikely to have sustained a clinically significant traumatic injury to the cervical spine. The Canadian C-spine rule recommends that imaging should be obtained following neck region trauma if the patient is >65 years old or has limb paresthesias or if there was a dangerous mechanism for the injury (e.g., bicycle collision with tree or parked car, fall from height >3 ft or five stairs, diving accident). These guidelines are helpful but must be tailored to individual circumstances; for example, patients with advanced osteoporosis, glucocorticoid use, or cancer may warrant imaging after even mild trauma.

*Whiplash injury* is due to rapid flexion and extension of the neck, usually from automobile accidents. The likely mechanism involves injury to the facet joints. This diagnosis should not be applied to patients with fractures, disk herniation, head injury, focal neurologic findings, or altered consciousness. Up to 50% of persons reporting whiplash injury acutely have persistent neck pain 1 year later. When personal compensation for pain and suffering was removed from the Australian health care system, the prognosis for recovery at 1 year improved. Imaging of the cervical spine is not cost-effective acutely but is useful to detect disk herniations when symptoms persist for >6 weeks following the injury. Severe initial symptoms have been associated with a poor long-term outcome.

## ■ CERVICAL DISK DISEASE

Degenerative cervical disk disease is very common and usually asymptomatic. Herniation of a lower cervical disk is a common cause of pain or tingling in the neck, shoulder, arm, or hand. Neck pain, stiffness, and a range of motion limited by pain are the usual manifestations.

TABLE 17-4 Cervical Radiculopathy: Neurologic Features

CERVICAL NERVE ROOT	EXAMINATION FINDINGS			PAIN DISTRIBUTION
	REFLEX	SENSORY	MOTOR	
C5	Biceps	Lateral deltoid	Rhombooids <sup>a</sup> (elbow extends backward with hand on hip) Infraspinatus <sup>a</sup> (arm rotates externally with elbow flexed at the side) Deltoid <sup>a</sup> (arm raised laterally 30°–45° from the side)	Lateral arm, medial scapula
C6	Biceps	Palmar thumb/index finger Dorsal hand/lateral forearm	Biceps <sup>a</sup> (arm flexed at the elbow in supination) Pronator teres (forearm pronated)	Lateral forearm, thumb/index fingers
C7	Triceps	Middle finger Dorsal forearm	Triceps <sup>a</sup> (forearm extension, flexed at elbow) Wrist/finger extensors <sup>a</sup>	Posterior arm, dorsal forearm, dorsal hand
C8	Finger flexors	Palmar surface of little finger Medial hand and forearm	Abductor pollicis brevis (abduction of thumb) First dorsal interosseous (abduction of index finger) Abductor digiti minimi (abduction of little finger)	Fourth and fifth fingers, medial hand and forearm
T1	Finger flexors	Axilla, medial arm, anteromedial forearm	Abductor pollicis brevis (abduction of thumb) First dorsal interosseous (abduction of index finger) Abductor digiti minimi (abduction of little finger)	Medial arm, axilla

<sup>a</sup>These muscles receive the majority of innervation from this root.

Herniated cervical disks are responsible for ~25% of cervical radiculopathies. Extension and lateral rotation of the neck narrow the ipsilateral intervertebral foramen and may reproduce radicular symptoms (Spurling's sign). In young adults, acute nerve root compression from a ruptured cervical disk is often due to trauma. Cervical disk herniations are usually posterolateral near the lateral recess. Typical patterns of reflex, sensory, and motor changes that accompany cervical nerve root lesions are summarized in Table 17-4. Although the classic patterns are clinically helpful, there are numerous exceptions because (1) there is overlap in sensory function between adjacent nerve roots, (2) symptoms and signs may be evident in only part of the injured nerve root territory, and (3) the location of pain is the most variable of the clinical features.

### CERVICAL SPONDYLOYSIS

Osteoarthritis of the cervical spine may produce neck pain that radiates into the back of the head, shoulders, or arms, or may be the source of headaches in the posterior occipital region (supplied by the C2-C4 nerve roots). Osteophytes, disk protrusions, or hypertrophic facet or uncovertebral joints may alone or in combination compress one or several nerve roots at the intervertebral foramina; these causes together account for 75% of cervical radiculopathies. The roots most commonly affected are C7 and C6. Narrowing of the spinal canal by osteophytes, ossification of the posterior longitudinal ligament (OPLL), or a large central disk may compress the cervical spinal cord and produce signs of myelopathy alone or radiculopathy with myelopathy (myeloradiculopathy). When little or no neck pain accompanies cervical cord involvement, other diagnoses to be considered include amyotrophic lateral sclerosis (Chap. 437), multiple sclerosis (Chap. 444), spinal cord tumors, or syringomyelia (Chap. 442). Cervical spondylotic myelopathy should be considered even when the patient presents with symptoms or spinal cord signs in the legs only. MRI is the study of choice to define soft tissues in the cervical region including the spinal cord, whereas plain CT is optimal to identify bone pathology including foraminal, lateral recess, OPLL, or spinal canal stenosis. In spondylotic myelopathy, focal enhancement by MRI, sometimes in a characteristic "pancake pattern," may be present at the site of maximal cord compression.

There is no evidence to support prophylactic surgery for asymptomatic cervical spinal stenosis unaccompanied by myelopathic signs or abnormal spinal cord findings on MRI, except in the setting of *dynamic instability* (see spondylolisthesis above). If the patient has postural neck pain, a prior history of whiplash or other spine/head injury, a Lhermitte sign, or preexisting listhesis at the stenotic segment on cervical MRI or CT, then cervical spine flexion-extension x-rays or MRI are indicated to look for dynamic instability. Surgical intervention is not recommended for patients with listhesis alone, unaccompanied by dynamic instability.

### OTHER CAUSES OF NECK PAIN

Rheumatoid arthritis (RA) (Chap. 358) of the cervical facet joints produces neck pain, stiffness, and limitation of motion. Synovitis of the atlantoaxial joint (C1-C2; Fig. 17-2) may damage the transverse ligament of the atlas, producing forward displacement of the atlas on the axis (atlantoaxial subluxation). Radiologic evidence of atlantoaxial subluxation occurs in up to 30% of patients with RA and plain x-ray films of the neck should be routinely performed preoperatively to assess the risk of neck hyperextension in patients requiring intubation. The degree of subluxation correlates with the severity of erosive disease. When subluxation is present, careful assessment is important to identify early signs of myelopathy that could be a harbinger of life-threatening spinal cord compression. Surgery should be considered when myelopathy or spinal instability is present. Ankylosing spondylitis is another cause of neck pain and less commonly atlantoaxial subluxation.

Acute *herpes zoster* can present as acute posterior occipital or neck pain prior to the outbreak of vesicles. *Neoplasms* metastatic to the cervical spine, *infections* (osteomyelitis and epidural abscess), and *metabolic bone diseases* may be the cause of neck pain, as discussed

above. Neck pain may also be referred from the heart with coronary artery ischemia (cervical angina syndrome). Rheumatologic disease should be considered if the neck pain is accompanied by shoulder or hip girdle pain.

### THORACIC OUTLET SYNDROMES

The thoracic outlet contains the first rib, the subclavian artery and vein, the brachial plexus, the clavicle, and the lung apex. Injury to these structures may result in postural or movement-induced pain around the shoulder and supraclavicular region, classified as follows.

*True neurogenic thoracic outlet syndrome (TOS)* is an uncommon disorder resulting from compression of the lower trunk of the brachial plexus or ventral rami of the C8 or T1 nerve roots, caused most often by an anomalous band of cartilaginous tissue connecting an elongate transverse process at C7 with the first rib. Pain is mild or may be absent. Signs include weakness and wasting of intrinsic muscles of the hand and diminished sensation on the palmar aspect of the fifth digit. An anteroposterior cervical spine x-ray will show an elongate C7 transverse process (an anatomic marker for the anomalous cartilaginous band), and EMG and NCSs confirm the diagnosis. Treatment consists of surgical resection of the anomalous band. The weakness and wasting of intrinsic hand muscles typically do not improve, but surgery halts the insidious progression of weakness.

*Arterial TOS* results from compression of the subclavian artery by a cervical rib, resulting in poststenotic dilatation of the artery and in some cases secondary thrombus formation. Blood pressure is reduced in the affected limb, and signs of emboli may be present in the hand. Neurologic signs are absent. Ultrasound can confirm the diagnosis noninvasively. Treatment is with thrombolysis or anticoagulation (with or without embolectomy) and surgical excision of the cervical rib compressing the subclavian artery.

*Venous TOS* is due to subclavian vein thrombosis resulting in swelling of the arm and pain. The vein may be compressed by a cervical rib or anomalous scalene muscle. Venography is the diagnostic test of choice.

*Disputed TOS* accounts for 95% of patients diagnosed with TOS; chronic arm and shoulder pain are prominent and of unclear cause. The lack of sensitive and specific findings on physical examination or specific markers for this condition results in diagnostic uncertainty. The role of surgery in disputed TOS is controversial. Major depression, chronic symptoms, work-related injury, and diffuse arm symptoms predict poor surgical outcomes. Multidisciplinary pain management is a conservative approach, although treatment is often unsuccessful.

### BRACHIAL PLEXUS AND NERVES

Pain from injury to the brachial plexus or peripheral nerves of the arm can occasionally mimic referred pain of cervical spine origin, including cervical radiculopathy, but the pain typically begins distal to the posterior neck region in the shoulder girdle or upper arm. Neoplastic infiltration of the lower trunk of the brachial plexus may produce shoulder or supraclavicular pain radiating down the arm, numbness of the fourth and fifth fingers or medial forearm, and weakness of intrinsic hand muscles innervated by the lower trunk and medial cord of the brachial plexus. Delayed radiation injury may produce weakness in the upper arm or numbness of the lateral forearm or arm due to involvement of the upper trunk and lateral cord of the plexus. Pain is less common and less severe than with neoplastic infiltration. A Pancoast tumor of the lung (Chap. 78) is another cause and should be considered, especially when a concurrent Horner's syndrome is present. *Acute brachial neuritis* is often confused with radiculopathy; the acute onset of severe shoulder or scapular pain is followed typically over days by weakness of the proximal arm and shoulder girdle muscles innervated by the upper brachial plexus. The onset may be preceded by an infection, vaccination, or minor surgical procedure. The long thoracic nerve may be affected, resulting in a winged scapula. Brachial neuritis may also present as an isolated paralysis of the diaphragm with or without involvement of other nerves of the upper limb. Recovery may take up to 3 years, and full functional recovery can be expected in the majority of patients.

Occasional cases of carpal tunnel syndrome produce pain and paresthesias extending into the forearm, arm, and shoulder resembling a C5 or C6 root lesion. Lesions of the radial or ulnar nerve can also mimic radiculopathy, at C7 or C8, respectively. EMG and NCSs can accurately localize lesions to the nerve roots, brachial plexus, or peripheral nerves.

For further discussion of peripheral nerve disorders, see Chap. 446.

## ■ SHOULDER

Pain arising from the shoulder can on occasion mimic pain from the spine. If symptoms and signs of radiculopathy are absent, then the differential diagnosis includes mechanical shoulder pain (bicipital tendonitis, frozen shoulder, bursitis, rotator cuff tear, dislocation, adhesive capsulitis, or rotator cuff impingement under the acromion) and referred pain (subdiaphragmatic irritation, angina, Pancoast tumor). Mechanical pain is often worse at night, associated with local shoulder tenderness and aggravated by passive abduction, internal rotation, or extension of the arm. Demonstrating normal passive full range of motion of the arm at the shoulder without worsening the usual pain can help exclude mechanical shoulder pathology as a cause of neck region pain. Pain from shoulder disease may radiate into the arm or hand, but focal neurologic signs (sensory, motor, or reflex changes) are absent.

## ■ GLOBAL CONSIDERATIONS

Many of the considerations described above for LBP also apply to neck pain. The Global Burden of Diseases Study 2019 reported that neck pain ranked second only to back pain as a cause of total years lived with disability (YLD). In general, neck pain rankings were also higher in developed regions of the world.

## TREATMENT

### Neck Pain Without Radiculopathy

The evidence regarding treatment for neck pain is less comprehensive than that for LBP, but the approach is remarkably similar in many respects. As with LBP, spontaneous improvement is the norm for acute neck pain. The usual goals of therapy are to promote a rapid return to normal function and provide pain relief while healing proceeds.

Acute neck pain is often treated with NSAIDs, acetaminophen, cold packs, or heat, alone or in combination while awaiting recovery. Patients should be specifically educated regarding the favorable natural history of acute neck pain to avoid unrealistic fear and inappropriate requests for imaging and other tests. For patients kept awake by symptoms, cyclobenzaprine (5–10 mg) at night can help relieve muscle spasm and promote drowsiness. For patients with neck pain unassociated with trauma, supervised exercise with or without mobilization appears to be effective. Exercises often include shoulder rolls and neck stretches. The evidence in support of non-surgical treatments for whiplash-associated disorders is generally of limited quality and neither supports nor refutes the common treatments used for symptom relief. Gentle mobilization of the cervical spine combined with exercise programs may be beneficial. Evidence is insufficient to recommend the use of cervical traction, TENS, ultrasound, trigger point injections, botulinum toxin injections, tricyclic antidepressants, and SSRIs for acute or chronic neck pain. Some patients obtain modest pain relief using a soft neck collar; there is little risk or cost. Massage can produce temporary pain relief.

For patients with chronic neck pain, supervised exercise programs can provide symptom relief and improve function. Acupuncture provided short-term benefit for some patients when compared to a sham procedure and is an option. Spinal manipulation alone has not been shown to be effective and carries a risk for injury. Surgical treatment for chronic neck pain without radiculopathy or spine instability is not recommended.

## Neck Pain With Radiculopathy

The natural history of acute neck pain with radiculopathy due to disk disease is favorable, and many patients will improve without specific therapy. Although there are no randomized trials of NSAIDs for neck pain, a course of NSAIDs, acetaminophen, or both, with or without muscle relaxants, and avoidance of activities that trigger symptoms are reasonable as initial therapy. Gentle supervised exercise and avoidance of inactivity are reasonable as well. A short course of high-dose oral glucocorticoids with a rapid taper, or epidural steroids administered under imaging guidance can be effective for acute or subacute disk-related cervical radicular pain, but have not been subjected to rigorous trials. The risk of injection-related complications is higher in the neck than the low back; vertebral artery dissection, dural puncture, spinal cord injury, and embolism in the vertebral arteries have all been reported. Opioid analgesics can be used in the emergency department and for short courses as an outpatient. Soft cervical collars can be modestly helpful by limiting spontaneous and reflex neck movements that exacerbate pain; hard collars are in general poorly tolerated.

If cervical radiculopathy is due to bony compression from cervical spondylosis with foraminal narrowing, periodic follow-up to assess for progression is indicated and consideration of surgical decompression is reasonable. Surgical treatment can produce rapid pain relief, although it is unclear if long-term functional outcomes are improved over nonsurgical therapy. Indications for cervical disk surgery include a progressive motor deficit due to nerve root compression, functionally limiting pain that fails to respond to conservative management, or spinal cord compression. In other circumstances, clinical improvement over time regardless of therapeutic intervention is common.

Surgical treatments include anterior cervical discectomy alone, laminectomy with discectomy, or discectomy with fusion. The risk of subsequent radiculopathy or myelopathy at cervical segments adjacent to a fusion is ~3% per year and 26% per decade. Although this risk is sometimes portrayed as a late complication of surgery, it may also reflect the natural history of degenerative cervical disk disease.

## ■ FURTHER READING

- A H R Q (AHRQ): Non-invasive treatments for low back pain. AHRQ Publication No. 16-EHC004-EF. February 2016, <https://effectivehealthcare.ahrq.gov/ehc/products/553/2178/back-pain-treatment-report-160229.pdf>
- A IM et al: Decompression with or without fusion in degenerative lumbar spondylolisthesis. *N Engl J Med* 385:526, 2021.
- B CS et al: Surgery versus conservative care for persistent sciatica lasting 4 to 12 months. *N Engl J Med* 19;382:1093, 2020.
- C A et al: Global estimates of the need for rehabilitation based on the Global Burden of Disease study 2019: A systematic analysis for the Global Burden of Disease Study 2019. *Lancet* 396:2006, 2021.
- E JW: Physical and Neurologic Examination. In Steinmetz et al (eds). *Benzel's Spine Surgery*, 5th ed. Philadelphia, Elsevier, 2021.
- G H et al: Oral steroids for acute radiculopathy due to a herniated lumbar disk. *JAMA* 313:1915, 2015.
- H K et al: Past-year prescription drug monitoring program opioid prescriptions and self-reported opioid use in an emergency department population with opioid use disorder. *Acad Emerg Med* 25:508, 2018.
- J JG et al: Association of early imaging for back pain with clinical outcomes in older adults. *JAMA* 313:1143, 2015.
- K JN, H MB: Clinical practice. Lumbar spinal stenosis. *N Engl J Med* 358:818, 2008.
- T N: Degenerative cervical spondylosis. *N Engl J Med* 383:159, 2020.
- Z CC et al: Geographic and hospital variation in cost of lumbar laminectomy and lumbar fusion for degenerative conditions. *Neurosurgery* 81:331, 2017.

## Section 2 Alterations in Body Temperature

### 18

### Fever

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Body temperature is controlled by the hypothalamus. Neurons in both the preoptic anterior hypothalamus and the posterior hypothalamus receive two kinds of signals: one from peripheral nerves that transmit information from warmth/cold receptors in the skin and the other from the temperature of the blood bathing the region. These two types of signals are integrated by the thermoregulatory center of the hypothalamus to maintain normal temperature. In a neutral temperature environment, the human metabolic rate produces more heat than is necessary to maintain the core body temperature in the range of 36.5–37.5°C (97.7–99.5°F).

A normal body temperature is ordinarily maintained despite environmental variations because the hypothalamic thermoregulatory center balances the excess heat production derived from metabolic activity in muscle and the liver with heat dissipation from the skin and lungs. According to a study of >35,000 individuals  $\geq 18$  years of age seen in routine medical visits, the mean oral temperature is 36.6°C (95% confidence interval, 35.7–37.3°C). In light of this study, *a temperature of >37.7°C (>99.9°F), which represents the 99th percentile for healthy individuals, defines a fever.* Importantly, higher ambient temperatures are linked to higher baseline body temperatures. Additionally, body temperatures have diurnal and seasonal variation, with low levels at 8 . . . and during summer and higher levels at 4 . . . and during winter. Baseline temperatures are also affected by age (lower by 0.02°C for every 10-year increase in age), demographics (African-American women have temperatures 0.052°C higher than white men), and comorbid conditions (cancer is associated with 0.02°C higher temperatures; hypothyroidism is linked to temperatures lower by 0.01°C). After controlling for age, sex, race, vital signs, and comorbidities, an increase in baseline temperature of 0.15°C (or 1 standard deviation) intriguingly translates into a 0.52% absolute increase in 1-year mortality.

Rectal temperatures are generally 0.4°C (0.7°F) higher than oral readings. The lower oral readings are probably attributable to mouth breathing, which is a factor in patients with respiratory infections and rapid breathing. Lower-esophageal temperatures closely reflect core temperature. Tympanic membrane thermometers measure radiant heat from the tympanic membrane and nearby ear canal and display that absolute value (*unadjusted mode*) or a value automatically calculated from the absolute reading on the basis of nomograms relating the radiant temperature measured to actual core temperatures obtained in clinical studies (*adjusted mode*). These measurements, although convenient, may be more variable than directly determined oral or rectal values. Studies in adults show that readings are lower with unadjusted-mode than with adjusted-mode tympanic membrane thermometers and that unadjusted-mode tympanic membrane values are 0.8°C (1.6°F) lower than rectal temperatures.

In women who menstruate, the . . . temperature is generally lower during the 2 weeks before ovulation; it then rises by ~0.6°C (1°F) with ovulation and stays at that level until menses occur. During the luteal phase, the amplitude of the circadian rhythm remains the same.

#### FEVER VERSUS HYPERTHERMIA

*Fever* is an elevation of body temperature that exceeds the normal daily variation and occurs *in conjunction with an increase in the hypothalamic set point* (e.g., from 37°C to 39°C). This shift of the set point from “normothermic” to febrile levels very much resembles the resetting of

the home thermostat to a higher level in order to raise the ambient temperature in a room. Once the hypothalamic set point is raised, neurons in the vasoconstrictor center are activated and vasoconstriction commences. The individual first notices vasoconstriction in the hands and feet. Shunting of blood away from the periphery to the internal organs essentially decreases heat loss from the skin, and the person feels cold. For most fevers, body temperature increases by 1–2°C. Shivering, which increases heat production from the muscles, may begin at this time; however, shivering is not required if mechanisms of heat conservation raise blood temperature sufficiently. Nonshivering heat production from the liver also contributes to increasing core temperature. Behavioral adjustments (e.g., putting on more clothing or bedding) help raise body temperature by decreasing heat loss.

The processes of heat conservation (vasoconstriction) and heat production (shivering and increased nonshivering thermogenesis) continue until the temperature of the blood bathing the hypothalamic neurons matches the new “thermostat setting.” Once that point is reached, the hypothalamus maintains the temperature at the febrile level by the same mechanisms of heat balance that function in the afebrile state. When the hypothalamic set point is again reset downward (in response to either a reduction in the concentration of pyrogens or the use of antipyretics), the processes of heat loss through vasodilation and sweating are initiated. Loss of heat by sweating and vasodilation continues until the blood temperature at the hypothalamic level matches the lower setting. Behavioral changes (e.g., removal of clothing) facilitate heat loss.

A fever of >41.5°C (>106.7°F) is called *hyperpyrexia*. This extraordinarily high fever can develop in patients with severe infections but most commonly occurs in patients with central nervous system (CNS) hemorrhages. In the preantibiotic era, fever due to a variety of infectious diseases rarely exceeded 106°F, and there has been speculation that this natural “thermal ceiling” is mediated by neuropeptides functioning as central antipyretics.

In rare cases, the hypothalamic set point is elevated as a result of local trauma, hemorrhage, tumor, or intrinsic hypothalamic malfunction. The term *hypothalamic fever* is sometimes used to describe elevated temperature caused by abnormal hypothalamic function. However, most patients with hypothalamic damage have *subnormal*, not *supranormal*, body temperatures.

Although most patients with elevated body temperature have fever, there are circumstances in which elevated temperature represents not fever but *hyperthermia* (*heat stroke*). Hyperthermia is characterized by an uncontrolled increase in body temperature that exceeds the body's ability to lose heat. The setting of the hypothalamic thermoregulatory center is unchanged. In contrast to fever in infections, hyperthermia does not involve pyrogenic molecules. Exogenous heat exposure and endogenous heat production are two mechanisms by which hyperthermia can result in dangerously high internal temperatures. Excessive heat production can easily cause hyperthermia despite physiologic and behavioral control of body temperature. For example, work or exercise in hot environments can produce heat faster than peripheral mechanisms can lose it. *For a detailed discussion of hyperthermia, see Chap. 465.*

It is important to distinguish between fever and hyperthermia since hyperthermia can be rapidly fatal and characteristically does not respond to antipyretics. In an emergency situation, however, making this distinction can be difficult. For example, in systemic sepsis, fever (hyperpyrexia) can be rapid in onset, and temperatures can exceed 40.5°C (104.9°F). Hyperthermia is often diagnosed on the basis of the events immediately preceding the elevation of core temperature—e.g., heat exposure or treatment with drugs that interfere with thermoregulation. In patients with heat stroke syndromes and in those taking drugs that block sweating, the skin is hot but dry, whereas in fever, the skin can be cold as a consequence of vasoconstriction. Antipyretics do not reduce the elevated temperature in hyperthermia, whereas in fever—and even in hyperpyrexia—adequate doses of either aspirin or acetaminophen usually result in some decrease in body temperature.

## PATHOGENESIS OF FEVER

### ■ PYROGENS

The term *pyrogen* (Greek *pyro*, “fire”) is used to describe any substance that causes fever. *Exogenous* pyrogens are derived from outside the patient; most are microbial products, microbial toxins, or whole microorganisms (including viruses). The classic example of an exogenous pyrogen is the lipopolysaccharide (endotoxin) produced by all gram-negative bacteria. Pyrogenic products of gram-positive organisms include the enterotoxins of *Staphylococcus aureus* and the groups A and B streptococcal toxins, also called *superantigens*. One staphylococcal toxin of clinical importance is that associated with isolates of *S. aureus* from patients with toxic shock syndrome. These products of staphylococci and streptococci cause fever in experimental animals when injected intravenously at concentrations of 1–10 µg/kg. Endotoxin is a highly pyrogenic molecule in humans: when injected intravenously into volunteers, a dose of 2–3 ng/kg produces fever, leukocytosis, acute-phase proteins, and generalized symptoms of malaise.

### ■ PYROGENIC CYTOKINES

Cytokines are small proteins (molecular mass, 10,000–20,000 Da) that regulate immune, inflammatory, and hematopoietic processes. For example, the elevated leukocytosis seen in several infections with an absolute neutrophilia is attributable to the cytokines interleukin (IL) 1 and IL-6. Some cytokines also cause fever; formerly referred to as *endogenous pyrogens*, they are now called *pyrogenic cytokines*. The pyrogenic cytokines include IL-1, IL-6, tumor necrosis factor (TNF), and ciliary neurotropic factor, a member of the IL-6 family. Fever is a prominent side effect of interferon  $\alpha$  therapy. Each pyrogenic cytokine is encoded by a separate gene, and each has been shown to cause fever in laboratory animals and in humans. When injected into humans at low doses (10–100 ng/kg), IL-1 and TNF produce fever; in contrast, for IL-6, a dose of 1–10 µg/kg is required for fever production.

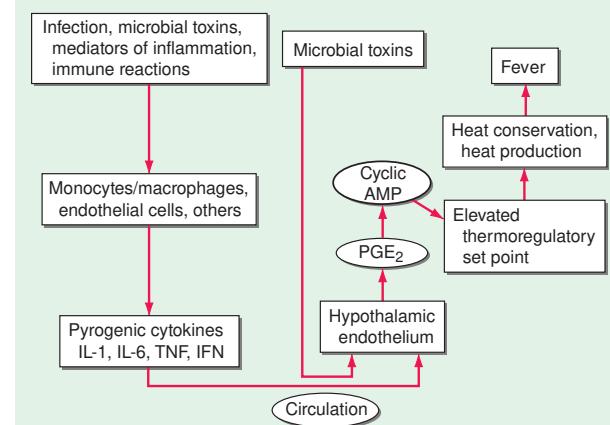
A wide spectrum of bacterial and fungal products induce the synthesis and release of pyrogenic cytokines. However, fever can be a manifestation of disease in the absence of microbial infection. For example, inflammatory processes such as pericarditis, trauma, stroke, and routine immunizations induce the production of IL-1, TNF, and/or IL-6; individually or in combination, these cytokines trigger the hypothalamus to raise the set point to febrile levels.

### ■ ELEVATION OF THE HYPOTHALAMIC SET POINT BY CYTOKINES

During fever, levels of prostaglandin E<sub>2</sub> (PGE<sub>2</sub>) are elevated in hypothalamic tissue and the third cerebral ventricle. The concentrations of PGE<sub>2</sub> are highest near the circumventricular vascular organs (organum vasculosum of lamina terminalis)—networks of enlarged capillaries surrounding the hypothalamic regulatory centers. Destruction of these organs reduces the ability of pyrogens to produce fever. Most studies in animals have failed to show, however, that pyrogenic cytokines pass from the circulation into the brain itself. Thus, it appears that both exogenous pyrogens and pyrogenic cytokines interact with the endothelium of these capillaries and that this interaction is the first step in initiating fever—i.e., in raising the set point to febrile levels.

The key events in the production of fever are illustrated in Fig. 18-1. Myeloid and endothelial cells are the primary cell types that produce pyrogenic cytokines. Pyrogenic cytokines such as IL-1, IL-6, and TNF are released from these cells and enter the systemic circulation. Although these circulating cytokines lead to fever by inducing the synthesis of PGE<sub>2</sub>, they also induce PGE<sub>2</sub> in peripheral tissues. The increase in PGE<sub>2</sub> in the periphery accounts for the nonspecific myalgias and arthralgias that often accompany fever. It is thought that some systemic PGE<sub>2</sub> escapes destruction by the lung and gains access to the hypothalamus via the internal carotid. However, it is the elevation of PGE<sub>2</sub> in the brain that starts the process of raising the hypothalamic set point for core temperature.

There are four receptors for PGE<sub>2</sub>, and each signals the cell in different ways. Of the four receptors, the third (EP-3) is essential for fever: when the gene for this receptor is deleted in mice, no fever follows the



**FIGURE 18-1** Chronology of events required for the induction of fever. AMP, adenosine 5'-monophosphate; IFN, interferon; IL, interleukin; PGE<sub>2</sub>, prostaglandin E<sub>2</sub>; TNF, tumor necrosis factor.

injection of IL-1 or endotoxin. Deletion of the other PGE<sub>2</sub> receptor genes leaves the fever mechanism intact. Although PGE<sub>2</sub> is essential for fever, it is not a neurotransmitter. Rather, the release of PGE<sub>2</sub> from the brain side of the hypothalamic endothelium triggers the PGE<sub>2</sub> receptor on glial cells, and this stimulation results in the rapid release of cyclic adenosine 5'-monophosphate (cAMP), which is a neurotransmitter. As shown in Fig. 18-1, the release of cAMP from glial cells activates neuronal endings from the thermoregulatory center that extend into the area. The elevation of cAMP is thought to account for changes in the hypothalamic set point either directly or indirectly (by inducing the release of neurotransmitters). Distinct receptors for microbial products are located on the hypothalamic endothelium. These receptors are called *Toll-like receptors* and are similar in many ways to IL-1 receptors. IL-1 receptors and Toll-like receptors share the same signal-transducing mechanism. Thus, the direct activation of Toll-like receptors or IL-1 receptors results in PGE<sub>2</sub> production and fever.

### ■ PRODUCTION OF CYTOKINES IN THE CNS

Cytokines produced in the brain may account for the hyperpyrexia of CNS hemorrhage, trauma, or infection. Viral infections of the CNS induce microglial and possibly neuronal production of IL-1, TNF, and IL-6. In experimental animals, the concentration of a cytokine required to cause fever is several orders of magnitude lower with direct injection into the brain substance or brain ventricles than with systemic injection. Therefore, cytokines produced in the CNS can raise the hypothalamic set point, bypassing the circumventricular organs. CNS cytokines likely account for the hyperpyrexia of CNS hemorrhage, trauma, or infection.

## APPROACH TO THE PATIENT

### Fever

#### HISTORY AND PHYSICAL EXAMINATION

There are a range of disease processes that present with fever as a cardinal manifestation, and a thorough history can help distinguish between these broad categories (Table 18-1). The chronology of events preceding fever, including exposure to other symptomatic individuals or to vectors of disease, should be ascertained. Electronic devices for measuring oral, tympanic membrane, or rectal temperatures are reliable, but the same site should be used consistently to monitor a febrile disease. Moreover, physicians should be aware that newborns, elderly patients, patients with chronic hepatic or renal failure, and patients taking glucocorticoids or being treated with an anticytokine may have active disease in the absence of fever because of a blunted febrile response.

**TABLE 18-1 Disease Categories That Present with Fever as a Cardinal Sign**

Infectious diseases
Autoimmune and noninfectious inflammatory disorders
Cancer
Medication related (e.g., vaccines, drug fever)
Endocrine disorders (e.g., hyperthyroidism)
Intrinsic hypothalamic malfunction

### LABORATORY TESTS

The workup should include a complete blood count; a differential count should be performed manually or with an instrument sensitive to the identification of juvenile or band forms, toxic granulations, and Döhle bodies, which are suggestive of bacterial infection. Neutropenia may be present with some viral infections.

Measurement of circulating cytokines in patients with fever is not helpful since levels of cytokines such as IL-1 and TNF in the circulation often are below the detection limit of the assay or do not coincide with fever. However, in patients with low-grade fevers or with suspected occult disease, the most valuable measurements are the C-reactive protein (CRP) level and the erythrocyte sedimentation rate. These markers of inflammatory processes are particularly helpful in detecting occult disease. Measurement of circulating IL-6, which induces CRP, can be useful. However, whereas IL-6 levels may vary during a febrile disease, CRP levels remain elevated. Acute-phase reactants are discussed in *Chap. 304*.

### FEVER IN PATIENTS RECEIVING ANTICYTOKINE THERAPY

Patients receiving long-term treatment with anticytokine-based regimens are at increased risk of infection because of lowered host defenses. For example, latent *Mycobacterium tuberculosis* infection can disseminate in patients receiving anti-TNF therapy. With the increasing use of anticytokines to reduce the activity of IL-1, IL-6, IL-12, IL-17, or TNF in patients with Crohn's disease, rheumatoid arthritis, or psoriasis, the possibility that these therapies blunt the febrile response should be kept in mind.

The blocking of cytokine activity has the distinct clinical drawback of lowering the level of host defenses against both routine bacterial and opportunistic infections such as *M. tuberculosis* and fungal infections. The use of monoclonal antibodies to reduce IL-17 in psoriasis increases the risk of systemic candidiasis.

In nearly all reported cases of infection associated with anticytokine therapy, fever is among the presenting signs. However, the extent to which the febrile response is blunted in these patients remains unknown. Therefore, low-grade fever in patients receiving anticytakine therapies is of considerable concern. The physician should conduct an early and rigorous diagnostic evaluation in these cases. The febrile response is also blunted in patients receiving chronic glucocorticoid therapy or anti-inflammatory agents such as nonsteroidal anti-inflammatory drugs (NSAIDs).

## TREATMENT

### Fever

#### THE DECISION TO TREAT FEVER

In deciding whether to treat fever, it is important to remember that fever itself is not an illness: it is an ordinary response to a perturbation of normal host physiology. Most fevers are associated with self-limited infections, such as common viral diseases. The use of antipyretics is not contraindicated in these infections: no significant clinical evidence indicates either that antipyretics delay the resolution of viral or bacterial infections or that fever facilitates recovery from infection or acts as an adjuvant to the immune system. In short, treatment of fever and its symptoms with routine antipyretics

does no harm and does not slow the resolution of common viral and bacterial infections.

However, in bacterial infections, the withholding of antipyretic therapy can be helpful in evaluating the effectiveness of a particular antibiotic, especially in the absence of positive cultures of the infecting organism, and the routine use of antipyretics can mask an inadequately treated bacterial infection. Withholding antipyretics in some cases may facilitate the diagnosis of an unusual febrile disease. Temperature–pulse dissociation (*relative bradycardia*) occurs in typhoid fever, brucellosis, leptospirosis, some drug-induced fevers, and factitious fever. As stated earlier, in newborns, elderly patients, patients with chronic liver or kidney failure, and patients taking glucocorticoids, fever may not be present despite infection. Hypothermia can develop in patients with septic shock.

Some infections have characteristic patterns in which febrile episodes are separated by intervals of normal temperature. For example, *Plasmodium vivax* causes fever every third day, whereas fever occurs every fourth day with *Plasmodium malariae*. Another relapsing fever is related to *Borrelia* infection, with days of fever followed by a several-day afebrile period and then a relapse into additional days of fever. In the Pel-Ebstein pattern, fever lasting 3–10 days is followed by afebrile periods of 3–10 days; this pattern can be classic for Hodgkin's disease and other lymphomas. In cyclic neutropenia, fevers occur every 21 days and accompany the neutropenia. There are also a number of periodic fever syndromes (e.g., familial Mediterranean fever, TNF receptor-associated periodic syndrome [TRAPS]) that differ in their periodicity, duration of attack, constellation of clinical features, genetic causes, and therapies (*Chap. 369*). Understanding these clinical differences can help tailor diagnostic testing to confirm the diagnosis and guide therapy.

#### ANTICYTOKINE THERAPY TO REDUCE FEVER IN AUTOIMMUNE AND AUTOINFLAMMATORY DISEASES

Recurrent fever is documented at some point in most autoimmune diseases and many autoinflammatory diseases, which include the periodic fever syndromes as well as disorders of inflammasomes (e.g., NLRP3, pyrin) and other components of the innate immune system (*Chap. 349*). Although fever can be a manifestation of autoimmune diseases, recurrent fevers are characteristic of autoinflammatory diseases, including uncommon diseases such as adult and juvenile Still's disease, familial Mediterranean fever, and hyper-IgD syndrome but also common diseases such as idiopathic pericarditis and gout. In addition to recurrent fevers, neutrophilia and serosal inflammation characterize autoinflammatory diseases. The fevers associated with many of these illnesses are dramatically reduced by blocking of IL-1 activity with anakinra or canakinumab. Anticytokines therefore reduce fever in autoimmune and autoinflammatory diseases. Although fevers in autoinflammatory diseases are mediated by IL-1 $\beta$ , patients also respond to antipyretics.

#### MECHANISMS OF ANTI PYRETIC AGENTS

The reduction of fever by lowering of the elevated hypothalamic set point is a direct function of reduction of the PGE<sub>2</sub> level in the thermoregulatory center. The synthesis of PGE<sub>2</sub> depends on the constitutively expressed enzyme cyclooxygenase. The substrate for cyclooxygenase is arachidonic acid released from the cell membrane, and this release is the rate-limiting step in the synthesis of PGE<sub>2</sub>. Therefore, inhibitors of cyclooxygenase are potent antipyretics. The antipyretic potency of various drugs is directly correlated with the inhibition of brain cyclooxygenase. Acetaminophen is a poor cyclooxygenase inhibitor in peripheral tissue and lacks noteworthy anti-inflammatory activity; in the brain, however, acetaminophen is oxidized by the P450 cytochrome system, and the oxidized form inhibits cyclooxygenase activity. Moreover, in the brain, the inhibition of another enzyme, COX-3, by acetaminophen may account for the antipyretic effect of this agent. However, COX-3 is not found outside the CNS.

Oral aspirin and acetaminophen are equally effective in reducing fever in humans. NSAIDs such as ibuprofen and specific inhibitors of COX-2 also are excellent antipyretics. Chronic, high-dose

therapy with antipyretics such as aspirin or any NSAID does not reduce normal core body temperature. Thus, PGE<sub>2</sub> appears to play no role in normal thermoregulation.

As effective antipyretics, glucocorticoids act at two levels. First, similar to the cyclooxygenase inhibitors, glucocorticoids reduce PGE<sub>2</sub> synthesis by inhibiting the activity of phospholipase A<sub>2</sub>, which is needed to release arachidonic acid from the cell membrane. Second, glucocorticoids block the transcription of the mRNA for the pyrogenic cytokines. Limited experimental evidence indicates that ibuprofen and COX-2 inhibitors reduce IL-1-induced IL-6 production and may contribute to the antipyretic activity of NSAIDs.

### REGIMENS FOR THE TREATMENT OF FEVER

The objectives in treating fever are first to reduce the elevated hypothalamic set point and second to facilitate heat loss. Reducing fever with antipyretics also reduces systemic symptoms of headache, myalgias, and arthralgias.

Oral aspirin and NSAIDs effectively reduce fever but can adversely affect platelets and the gastrointestinal tract. Therefore, acetaminophen is preferred as an antipyretic. In children, acetaminophen or oral ibuprofen must be used because aspirin increases the risk of Reye's syndrome. If the patient cannot take oral antipyretics, parenteral preparations of NSAIDs and rectal suppositories of various antipyretics can be used.

Treatment of fever in some patients is highly recommended. Fever increases the demand for oxygen (i.e., for every increase of 1°C over 37°C, there is a 13% increase in oxygen consumption) and can aggravate the condition of patients with preexisting impairment of cardiac, pulmonary, or CNS function. Children with a history of febrile or nonfebrile seizure should be aggressively treated to reduce fever. However, it is unclear what triggers the febrile seizure, and there is no correlation between absolute temperature elevation and onset of a febrile seizure in susceptible children.

In hyperpyrexia, the use of cooling blankets facilitates the reduction of temperature; however, cooling blankets should not be used without oral antipyretics. In hyperpyretic patients with CNS disease or trauma (CNS bleeding), reducing core temperature mitigates the detrimental effects of high temperature on the brain.

For a discussion of treatment for hyperthermia, see Chap. 465.

### FURTHER READING

- D CA et al: Treating inflammation by blocking interleukin-1 in a broad spectrum of diseases. *Nature Rev* 11:633, 2012.
- G M et al: Classification criteria for autoinflammatory recurrent fevers. *Ann Rheum Dis* 78:1025, 2019.
- K T et al: Long-term safety profile of anakinra in patients with severe cryopyrin-associated periodic syndromes. *Rheumatology* 55:1499, 2016.
- S A et al: Temperature control in critically ill patients with fever: A meta-analysis of randomized controlled trials. *J Crit Care* 61:89, 2021.

## 19

### Fever and Rash

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The acutely ill patient with fever and rash often presents a diagnostic challenge for physicians, yet the distinctive appearance of an eruption in concert with a clinical syndrome can facilitate a prompt diagnosis and the institution of life-saving therapy or critical infection-control interventions. Representative images of many of the rashes discussed in this chapter are included in Chap. A1.

## APPROACH TO THE PATIENT

### Fever and Rash

A thorough history of patients with fever and rash includes the following relevant information: immune status, medications taken within the previous month, specific travel history, immunization status, exposure to domestic pets and other animals, history of animal (including arthropod) bites, recent dietary exposures, existence of cardiac abnormalities, presence of prosthetic material, recent exposure to ill individuals, and sexual exposures. The history should also include the site of onset of the rash and its direction and rate of spread.

### PHYSICAL EXAMINATION

A thorough physical examination entails close attention to the rash, with an assessment and precise definition of its salient features. First, it is critical to determine what *type* of lesions make up the eruption. *Macules* are flat lesions defined by an area of changed color (i.e., a blanchable erythema). *Papules* are raised, solid lesions <5 mm in diameter; *plaques* are lesions >5 mm in diameter with a flat, plateau-like surface; and *nodules* are lesions >5 mm in diameter with a more rounded configuration. *Wheals* (urticaria, hives) are papules or plaques that are pale pink and may appear annular (ringlike) as they enlarge; classic (nonvasculitic) wheals are transient, lasting only 24 h in any defined area. *Vesicles* (<5 mm) and *bullae* (>5 mm) are circumscribed, elevated lesions containing fluid. *Pustules* are raised lesions containing purulent exudate; vesicular processes such as varicella or herpes simplex may evolve to pustules. *Nonpalpable purpura* is a flat lesion that is due to bleeding into the skin. If <3 mm in diameter, the purpuric lesions are termed *petechiae*; if >3 mm, they are termed *eccymoses*. *Palpable purpura* is a raised lesion that is due to inflammation of the vessel wall (vasculitis) with subsequent hemorrhage. An *ulcer* is a defect in the skin extending at least into the upper layer of the dermis, and an *eschar* (tâche noire) is a necrotic lesion covered with a black crust.

Other pertinent features of rashes include their *configuration* (i.e., annular or target), the *arrangement* of their lesions, and their *distribution* (i.e., central or peripheral).

For further discussion, see Chaps. 56, 58, 122, and 129.

### CLASSIFICATION OF RASH

This chapter reviews rashes that reflect systemic disease, but it does not include localized skin eruptions (i.e., cellulitis, impetigo) that may also be associated with fever (Chap. 129). The chapter is not intended to be all-inclusive, but it covers the most important and most common diseases associated with fever and rash. Rashes are classified herein on the basis of lesion morphology and distribution. For practical purposes, this classification system is based on the most typical disease presentations. However, morphology may vary as rashes evolve, and the presentation of diseases with rashes is subject to many variations (Chap. 58). For instance, the classic petechial rash of Rocky Mountain spotted fever (Chap. 187) may initially consist of blanchable erythematous macules distributed peripherally; at times, however, the rash associated with this disease may not be predominantly acral, or no rash may develop at all.

Diseases with fever and rash may be classified by type of eruption: centrally distributed maculopapular, peripheral, confluent desquamative erythematous, vesiculobullous, urticaria-like, nodular, purpuric, ulcerated, or with eschars. Diseases are listed by these categories in Table 19-1, and many are highlighted in the text. However, for a more detailed discussion of each disease associated with a rash, the reader is referred to the chapter dealing with that specific disease. (Reference chapters are cited in the text and listed in Table 19-1.)

### CENTRALLY DISTRIBUTED MACULOPAPULAR ERUPTIONS

Centrally distributed rashes, in which lesions are primarily truncal, are the most common type of eruption. The rash of *rubeola* (measles) starts

TABLE 19-1 Diseases Associated with Fever and Rash

DISEASE	ETIOLOGY	DESCRIPTION	GROUP AFFECTED/ EPIDEMIOLOGIC FACTORS	CLINICAL SYNDROME	CHAPTER
<b>Centrally Distributed Maculopapular Eruptions</b>					
Acute meningococcemia <sup>a</sup>	—	—	—	—	155
Drug reaction with eosinophilia and systemic symptoms (DRESS); also termed drug-induced hypersensitivity syndrome (DIHS) <sup>b</sup> ; Chikungunya <sup>c</sup> ; COVID-19 <sup>d</sup>	—	—	—	—	60
Rubeola (measles, first disease) (Fig. 19-1, Fig. A1-2, Fig. A1-3)	Paramyovirus	Discrete lesions that become confluent as rash spreads from hairline downward, usually sparing palms and soles; lasts ≥3 days; Koplik's spots	Nonimmune individuals	Cough, conjunctivitis, coryza, severe prostration	205
Rubella (German measles, third disease) (Fig. A1-4)	Togavirus	Spreads from hairline downward, clearing as it spreads; Forchheimer spots	Nonimmune individuals	Adenopathy, arthritis	206
Erythema infectiosum (fifth disease) (Fig. A1-1)	Human parvovirus B19	Bright-red "slapped-cheeks" appearance followed by lacy reticular rash that waxes and wanes over 3 weeks; rarely, papular-purpuric "gloves-and-socks" syndrome on hands and feet	Most common among children 3–12 years old; occurs in winter and spring	Mild fever; arthritis in adults; rash following resolution of fever	197
Exanthem subitum (roseola, sixth disease) (Fig. A1-5)	Human herpesvirus 6 or, less commonly, the closely related human herpesvirus 7	Diffuse maculopapular eruption over trunk and neck; resolves within 2 days	Usually affects children <3 years old	Rash following resolution of fever; similar to Boston exanthem (echovirus 16); febrile seizures may occur	195
Primary HIV infection (Fig. A1-6)	HIV	Nonspecific diffuse macules and papules most commonly on upper thorax, face, collar region; less commonly, urticarial or vesicular lesions; oral or genital ulcers	Individuals recently infected with HIV	Pharyngitis, adenopathy, arthralgias	202
Infectious mononucleosis	Epstein-Barr virus	Diffuse maculopapular eruption (5% of cases; 30–90% if ampicillin is given); urticaria, petechiae in some cases; periorbital edema (50%); palatal petechiae (25%)	Adolescents, young adults	Hepatosplenomegaly, pharyngitis, cervical lymphadenopathy, atypical lymphocytosis, heterophile antibody	194
Other viral exanthems	Echoviruses 2, 4, 9, 11, 16, 19, 25; coxsackieviruses A9, B1, B5; etc.	Wide range of skin findings that may mimic rubella or measles	Affect children more commonly than adults	Nonspecific viral syndromes	204
Exanthematous drug-induced eruption (Fig. A1-7)	Drugs (antibiotics, anticonvulsants, diuretics, etc.)	Intensely pruritic, bright-red macules and papules, symmetric on trunk and extremities; may become confluent	Occurs 2–3 days after exposure in previously sensitized individuals; otherwise, after 2–3 weeks (but can occur anytime, even shortly after drug is discontinued)	Variable findings: fever and eosinophilia	60
Epidemic typhus	<i>Rickettsia prowazekii</i>	Maculopapular eruption appearing in axillae, spreading to trunk and later to extremities; usually spares face, palms, soles; evolves from blanchable macules to confluent eruption with petechiae; rash evanescent in recrudescent typhus (Brill-Zinsser disease)	Exposure to body lice; occurrence of recrudescent typhus as relapse after 30–50 years	Headache, myalgias; mortality rates 10–40% if untreated; milder clinical presentation in recrudescent form	187
Endemic (murine) typhus	<i>Rickettsia typhi</i>	Maculopapular eruption, usually sparing palms, soles	Exposure to rat or cat fleas	Headache, myalgias	187
Scrub typhus	<i>Orientia tsutsugamushi</i>	Diffuse macular rash starting on trunk; eschar at site of mite bite	Endemic in South Pacific, Australia, Asia; transmitted by mites	Headache, myalgias, regional adenopathy; mortality rates up to 30% if untreated	187
Rickettsial spotted fevers (Fig. 19-8)	<i>Rickettsia conorii</i> (boutonneuse fever), <i>Rickettsia australis</i> (North Queensland tick typhus), <i>Rickettsia sibirica</i> (Siberian tick typhus), <i>Rickettsia africae</i> (African tick-bite fever), and others	Eschar common at bite site; maculopapular (rarely, vesicular and petechial) eruption on proximal extremities, spreading to trunk and face	Exposure to ticks; <i>R. conorii</i> in Mediterranean region, India, Africa; <i>R. australis</i> in Australia; <i>R. sibirica</i> in Siberia, Mongolia; <i>R. africae</i> in Africa, Caribbean	Headache, myalgias, regional adenopathy	187

(Continued)

TABLE 19-1 Diseases Associated with Fever and Rash (Continued)

DISEASE	ETIOLOGY	DESCRIPTION	GROUP AFFECTED/ EPIDEMIOLOGIC FACTORS	CLINICAL SYNDROME	CHAPTER
Human monocytotropic ehrlichiosis <sup>a</sup>	<i>Ehrlichia chaffeensis</i>	Maculopapular eruption (40% of cases), involves trunk and extremities; may be petechial	Tick-borne; most common in U.S. Southeast, southern Midwest, and mid-Atlantic regions	Headache, myalgias, leukopenia	187
Leptospirosis	<i>Leptospira interrogans</i> and other <i>Leptospira</i> species	Maculopapular eruption; conjunctivitis; scleral hemorrhage in some cases	Exposure to water contaminated with animal urine	Myalgias; aseptic meningitis; <i>fulminant form</i> : icterohemorrhagic fever (Weil's disease)	184
Lyme disease (Fig. A1-8)	<i>Borrelia burgdorferi</i> (sole cause in U.S.), <i>Borrelia afzelii</i> , <i>Borrelia garinii</i>	Papule expanding to erythematous annular lesion with central clearing (erythema migrans; average diameter, 15 cm), sometimes with concentric rings, sometimes with indurated or vesicular center; multiple secondary erythema migrans lesions in some cases	Bite of <i>Ixodes</i> tick vector	Headache, myalgias, chills, photophobia occurring acutely; CNS disease, myocardial disease, arthritis weeks to months later in some cases	186
Southern tick-associated rash illness (STARI, Master's disease)	Unknown (possibly <i>Borrelia lonestari</i> or other <i>Borrelia</i> spirochetes)	Similar to erythema migrans of Lyme disease with several differences, including: multiple secondary lesions less likely; lesions tending to be smaller (average diameter, ~8 cm); central clearing more likely	Bite of tick vector <i>Amblyomma americanum</i> (Lone Star tick); often found in regions where Lyme disease is uncommon, including southern United States	Compared with Lyme disease: fewer constitutional symptoms, tick bite more likely to be recalled; other Lyme disease sequelae lacking	186
Typhoid fever (Fig. A1-9)	<i>Salmonella typhi</i>	Transient, blanchable erythematous macules and papules, 2–4 mm, usually on trunk (rose spots)	Ingestion of contaminated food or water (rare in U.S.)	Variable abdominal pain and diarrhea; headache, myalgias, hepatosplenomegaly	165
Dengue fever <sup>a</sup> (Fig. A1-53)	Dengue virus (4 serotypes; flaviviruses)	Rash in 50% of cases; initially diffuse flushing; midway through illness, onset of maculopapular rash, which begins on trunk and spreads centrifugally to extremities and face; pruritus, hyperesthesia in some cases; after defervescence, petechiae on extremities may occur	Occurs in tropics and subtropics; transmitted by mosquito	Headache; musculoskeletal pain ("breakbone fever"); leukopenia; occasionally biphasic ("saddleback") fever	209
Rat-bite fever (sodoku)	<i>Spirillum minus</i>	Eschar at bite site; then blotchy violaceous or red-brown rash involving trunk and extremities	Rat bite; primarily found in Asia; rare in U.S.	Regional adenopathy; recurrent fevers if untreated	141
Relapsing fever	<i>Borrelia</i> species	Central rash at end of febrile episode; petechiae in some cases	Exposure to ticks or body lice	Recurrent fever, headache, myalgias, hepatosplenomegaly	185
Erythema marginatum (rheumatic fever)	Group A <i>Streptococcus</i>	Erythematous annular papules and plaques occurring as polycyclic lesions in waves over trunk, proximal extremities; evolving and resolving within hours	Patients with rheumatic fever	Pharyngitis preceding polyarthritides, carditis, subcutaneous nodules, chorea	388
Systemic lupus erythematosus (SLE) (Fig. A1-10, Fig. A1-11, Fig. A1-12)	Autoimmune disease	Macular and papular erythema, often in sun-exposed areas; discoid lupus lesions (local atrophy, scale, pigmentary changes); periungual telangiectasis; malar rash; vasculitis sometimes causing urticaria, palpable purpura; oral erosions in some cases	Most common in young to middle-aged women; flares precipitated by sun exposure	Arthritis; cardiac, pulmonary, renal, hematologic, and vasculitic disease	359
Still's disease (Fig. A1-13)	Autoimmune disease	Transient 2- to 5-mm erythematous papules appearing at height of fever on trunk, proximal extremities; lesions evanescent	Children and young adults	High spiking fever, polyarthritides, splenomegaly; erythrocyte sedimentation rate >100 mm/h	—
African trypanosomiasis (Fig. A1-47)	<i>Trypanosoma brucei rhodesiense/gambiense</i>	Blotchy or annular erythematous macular and papular rash (trypanid), primarily on trunk; pruritus; chancre at site of tsetse fly bite may precede rash by several weeks	Tsetse fly bite in eastern ( <i>T. brucei rhodesiense</i> ) or western ( <i>T. brucei gambiense</i> ) Africa	Hemolympathic disease followed by meningoencephalitis; Winterbottom's sign (posterior cervical lymphadenopathy) ( <i>T. brucei gambiense</i> )	227
Arcanobacterial pharyngitis	<i>Arcanobacterium (Corynebacterium) haemolyticum</i>	Diffuse, erythematous, maculopapular eruption involving trunk and proximal extremities; may desquamate	Children and young adults	Exudative pharyngitis, lymphadenopathy	150

(Continued)

TABLE 19-1 Diseases Associated with Fever and Rash (Continued)

DISEASE	ETIOLOGY	DESCRIPTION	GROUP AFFECTED/ EPIDEMIOLOGIC FACTORS	CLINICAL SYNDROME	CHAPTER
West Nile virus infection	West Nile virus	Maculopapular eruption involving the trunk, extremities, and head or neck; rash in 20–50% of cases	Mosquito bite; rarely, blood transfusion or transplanted organ	Headache, weakness, malaise, myalgia, neuroinvasive disease (encephalitis, meningitis, flaccid paralysis)	209
Zika virus infection (Fig. A1-5f)	Zika virus	Pruritic macular and papular erythema; rash may begin on trunk and descend to lower body; conjunctival injection; palatal petechiae may occur	Mosquito bite; sexual transmission or blood transfusion less common	Arthralgia (especially of small joints), myalgia, lymphadenopathy, headache, low-grade fever; illness in pregnancy may cause severe birth defects, including microcephaly; neurologic complications, including Guillain-Barré, may occur	209
<b>Peripheral Eruptions</b>					
Chronic meningococcemia, disseminated gonococcal infection, <sup>a</sup> human parvovirus B19 infection, <sup>f</sup> MIRM <sup>g</sup>	—	—	—	—	155, 156, 197
Rocky Mountain spotted fever (Fig. 19-2, Fig. A1-16)	<i>Rickettsia rickettsii</i>	Rash beginning on wrists and ankles and spreading centripetally; appears on palms and soles later in disease; lesion evolution from blanchable macules to petechiae	Tick vector; widespread but more common in southeastern and southwest-central U.S.	Headache, myalgias, abdominal pain; mortality rates up to 40% if untreated	187
Secondary syphilis (Figs. A1-18, Fig. A1-19, Fig. A1-20, Fig. A1-21)	<i>Treponema pallidum</i>	Coincident primary chancre in 10% of cases; copper-colored, scaly papular eruption, diffuse but prominent on palms and soles; rash never vesicular in adults; condyloma latum, mucous patches, and alopecia in some cases	Sexually transmitted	Fever, constitutional symptoms	182
Chikungunya fever (Fig. A1-54)	Chikungunya virus	Maculopapular eruption; typically occurs on trunk, but also occurs on extremities and face	<i>Aedes aegypti</i> and <i>A. albopictus</i> mosquito bites; tropical and subtropical regions	Severe polyarticular, migratory arthralgias, especially involving small joints (e.g., hands, wrists, ankles)	209
Hand-foot-and-mouth disease (Fig. A1-22)	Coxsackievirus A16 and enterovirus 71 most common causes; coxsackievirus A6 associated with atypical syndrome	Tender vesicles, erosions in mouth; 0.25-cm papules on hands and feet with rim of erythema evolving into tender vesicles; shedding of nails (onychomadesis) can occur 1–2 months after acute illness; coxsackievirus A6 lesions may also be maculopapular, petechial, purpuric, or erosive; atypical form often extends to perioral area, extremities, trunk, buttocks, genitals, and areas affected by eczema (eczema coxsackium)	Summer and fall; primarily children <10 years old; multiple family members; coxsackievirus A6 infection also occurs in young adults	Transient fever; enterovirus 71 can be associated with brain stem encephalitis, flaccid paralysis resembling polio, or aseptic meningitis	204
Erythema multiforme (EM) (Fig. A1-24)	Infection, drugs, idiopathic causes	Target lesions (central erythema surrounded by area of clearing and another rim of erythema) up to 2 cm; symmetric on knees, elbows, palms, soles; spreads centripetally; papular, sometimes vesicular; when extensive and involving mucous membranes, termed EM major	Herpes simplex virus or <i>Mycoplasma pneumoniae</i> infection; drug intake (i.e., sulfa, phenytoin, penicillin)	50% of patients <20 years old; fever more common in most severe form, EM major, which can be confused with Stevens-Johnson syndrome (but EM major lacks prominent skin sloughing)	— <sup>h</sup>
Rat-bite fever (Haverhill fever)	<i>Streptobacillus moniliformis</i>	Maculopapular eruption over palms, soles, and extremities; tends to be more severe at joints; eruption sometimes becoming generalized; may be purpuric; may desquamate	Rat bite, ingestion of contaminated food	Myalgias; arthritis (50%); fever recurrence in some cases	141

(Continued)

TABLE 19-1 Diseases Associated with Fever and Rash (Continued)

DISEASE	ETOLOGY	DESCRIPTION	GROUP AFFECTED/ EPIDEMIOLOGIC FACTORS	CLINICAL SYNDROME	CHAPTER
Bacterial endocarditis (Fig. A1-23)	Streptococcus, Staphylococcus, etc.	Subacute course (e.g., viridans streptococci): Osler's nodes (tender pink nodules on finger or toe pads); petechiae on skin and mucosa; splinter hemorrhages. Acute course (e.g., <i>Staphylococcus aureus</i> ): Janeway lesions (painless erythematous or hemorrhagic macules, usually on palms and soles)	Abnormal heart valve (e.g., viridans streptococci), intravenous drug use	New or changing heart murmur	128
COVID-19 (Fig. A1-57)	SARS-CoV-2	Mild or asymptomatic COVID-19: Pernio (macules, papules, or plaques that are tender, erythematous/violaceous; acral, feet more common than hands); Moderate/severe COVID-19: vesicles, urticaria, maculopapular erythema; often pruritic; occur on trunk, extremities; Severe COVID-19: Retiform purpura (net-like, purple patches/plaques often with necrosis); lesions often asymptomatic; occur on extremities, buttocks; Multisystem inflammatory syndrome in children (MIS-C): findings similar to Kawasaki disease	Infection with SARS-CoV-2; MIS-C in older children/adolescents	Ranging from asymptomatic to mild/moderate with loss of taste/smell, pharyngitis, cough, fever, to severe with dyspnea, ARDS; complications include thrombosis, especially with retiform purpura; lesions may be delayed compared to other COVID-19 symptoms; MIS-C occurs ~2-6 weeks following acute (often asymptomatic) infection	
<b>Confluent Desquamative Erythemas</b>					
Scarlet fever (second disease) (Fig. A1-25)	Group A <i>Streptococcus</i> (pyrogenic exotoxins A, B, C)	Diffuse blanchable erythema beginning on face and spreading to trunk and extremities; circumoral pallor; "sandpaper" texture to skin; accentuation of linear erythema in skin folds (Pastia's lines); exanthem of white evolving into red "strawberry" tongue; desquamation in second week	Most common among children 2–10 years old; usually follows group A streptococcal pharyngitis	Fever, pharyngitis, headache	148
Kawasaki disease (Fig. A1-29)	Idiopathic	Rash similar to scarlet fever (scarlatiniform) or EM; fissuring of lips, strawberry tongue; conjunctivitis; edema of hands, feet; desquamation later in disease	Children <8 years old	Cervical adenopathy, pharyngitis, coronary artery vasculitis	58, 363
Streptococcal toxic shock syndrome	Group A <i>Streptococcus</i> (associated with pyrogenic exotoxin A and/or B or certain M types)	When present, rash often scarlatiniform	May occur in setting of severe group A streptococcal infections (e.g., necrotizing fasciitis, bacteremia, pneumonia)	Multiorgan failure, hypotension; mortality rate 30%	148
Staphylococcal toxic shock syndrome	<i>S. aureus</i> (toxic shock syndrome toxin 1, enterotoxins B and others)	Diffuse erythema involving palms; pronounced erythema of mucosal surfaces; conjunctivitis; desquamation 7–10 days into illness	Colonization with toxin-producing <i>S. aureus</i>	Fever >39°C (>102°F), hypotension, multiorgan dysfunction	147
Staphylococcal scalded-skin syndrome (Fig. 19-3, Fig. A1-28)	<i>S. aureus</i> , phage group II	Diffuse tender erythema, often with bullae and desquamation; Nikolsky's sign	Colonization with toxin-producing <i>S. aureus</i> ; occurs in children <10 years old (termed Ritter's disease in neonates) or adults with renal dysfunction	Irritability; nasal or conjunctival secretions	147
Exfoliative erythroderma syndrome (Fig. A1-27)	Underlying psoriasis, eczema, drug eruption, mycosis fungoides	Diffuse erythema (often scaling) interspersed with lesions of underlying condition	Usually occurs in adults over age 50; more common among men	Fever, chills (i.e., difficulty with thermoregulation); lymphadenopathy	58, 60
DRESS (drug-induced hypersensitivity syndrome [DIHS]) (Fig. A1-48)	Aromatic anticonvulsants; other drugs, including sulfonamides, minocycline	Maculopapular eruption (mimicking exanthematous drug rash), sometimes progressing to exfoliative erythroderma; profound edema, especially facial; pustules may occur	Individuals genetically unable to detoxify arene oxides (anticonvulsant metabolites), patients with slow N-acetylation capacity (sulfonamides)	Lymphadenopathy, multiorgan failure (especially hepatic), eosinophilia, atypical lymphocytes; mimics sepsis	60
Stevens-Johnson syndrome (SJS), toxic epidermal necrolysis (TEN) (Fig. A1-26)	Drugs (80% of cases; often allopurinol, anticonvulsants, antibiotics), infection, idiopathic factors	Erythematous and purpuric macules, sometimes targetoid, or diffuse erythema progressing to bullae, with sloughing and necrosis of entire epidermis; Nikolsky's sign; involves mucosal surfaces; TEN (>30% epidermal necrosis) is maximal form; SJS involves <10% of epidermis; SJS/TEN overlap involves 10–30% of epidermis	Uncommon among children; more common among patients with HIV infection, systemic lupus erythematosus, certain HLA types, or slow acetylators	Dehydration, sepsis sometimes resulting from lack of normal skin integrity; mortality rates up to 30%	60

(Continued)

TABLE 19-1 Diseases Associated with Fever and Rash (Continued)

DISEASE	ETIOLOGY	DESCRIPTION	GROUP AFFECTED/ EPIDEMIOLOGIC FACTORS	CLINICAL SYNDROME	CHAPTER
<b>Vesiculobullous or Pustular Eruptions</b>					
Hand-foot-and-mouth syndrome <sup>c</sup> ; staphylococcal scalded-skin syndrome <sup>d</sup> ; TEN <sup>e</sup> ; DRESS <sup>f</sup> ; COVID-19 <sup>g</sup>	—	—	—	—	— <sup>h</sup>
Varicella (chickenpox) (Fig. 19-4, Fig. A1-30)	Varicella-zoster virus (VZV)	Macules (2–3 mm) evolving into papules, then vesicles (sometimes umbilicated), on an erythematous base ("dewdrops on a rose petal"); pustules then forming and crusting; lesions appearing in crops; may involve scalp, mouth; intensely pruritic	Usually affects children; 10% of adults susceptible; most common in late winter and spring; incidence down by 90% in U.S. as a result of varicella vaccination	Malaise; generally mild disease in healthy children; more severe disease with complications in adults and immunocompromised children	193
<i>Pseudomonas</i> "hot-tub" folliculitis (Fig. A1-55)	<i>Pseudomonas aeruginosa</i>	Pruritic erythematous follicular, papular, vesicular, or pustular lesions that may involve axillae, buttocks, abdomen, and especially areas occluded by bathing suits; can manifest as tender isolated nodules on palmar or plantar surfaces (the latter designated " <i>Pseudomonas</i> hot-foot syndrome")	Bathers in hot tubs or swimming pools; occurs in outbreaks	Earache, sore eyes and/or throat; fever may be absent; generally self-limited	164
Variola (smallpox) (Fig. A1-50)	Variola major virus	Red macules on tongue and palate evolving to papules and vesicles; skin macules evolving to papules, then vesicles, then pustules over 1 week, with subsequent lesion crusting; lesions initially appearing on face and spreading centrifugally from trunk to extremities; differs from varicella in that (1) skin lesions in any given area are at same stage of development and (2) there is a prominent distribution of lesions on face and extremities (including palms, soles)	Nonimmune individuals exposed to smallpox	Prodrome of fever, headache, backache, myalgias; vomiting in 50% of cases	S3
Primary herpes simplex virus (HSV) infection	HSV	Erythema rapidly followed by hallmark painful grouped vesicles that may evolve into pustules that ulcerate, especially on mucosal surfaces; lesions at site of inoculation: commonly gingivostomatitis for HSV-1 and genital lesions for HSV-2; recurrent disease milder (e.g., herpes labialis does not involve oral mucosa)	Primary infection most common among children and young adults for HSV-1 and among sexually active young adults for HSV-2; no fever in recurrent infection	Regional lymphadenopathy	192
Disseminated herpesvirus infection (Fig. A1-31)	VZV or HSV	Generalized vesicles that can evolve to pustules and ulcerations; individual lesions similar for VZV and HSV. <i>Zoster cutaneus dissemination</i> : >25 lesions extending outside involved dermatome. HSV: extensive, progressive mucocutaneous lesions that may occur in absence of dissemination, sometimes disseminate in eczematous skin (eczema herpeticum); HSV visceral dissemination may occur with only localized mucocutaneous disease; in disseminated neonatal disease, skin lesions diagnostically helpful when present, but rash absent in a substantial minority of cases	Patients with immunosuppression, eczema; neonates	Visceral organ involvement (e.g., liver, lungs) in some cases; neonatal disease particularly severe	138, 192, 193
Rickettsialpox (Fig. A1-33)	<i>Rickettsia akari</i>	Eschar found at site of mite bite; generalized rash involving face, trunk, extremities; may involve palms and soles; <100 papules and plaques (2–10 mm); centers of papules develop vesicles or pustules	Seen in urban settings; transmitted by mouse mites	Headache, myalgias, regional adenopathy; mild disease	187
Acute generalized exanthematic pustulosis (Fig. A1-49)	Drugs (mostly anticonvulsants or antimicrobials); also viral	Tiny, sterile, nonfollicular pustules on erythematous, edematous skin; begins on face and in body folds, then becomes generalized	Appears 2–21 days after start of drug therapy, depending on whether patient has been sensitized	Acute fever, pruritus, leukocytosis	60

(Continued)

TABLE 19-1 Diseases Associated with Fever and Rash (Continued)

DISEASE	ETOLOGY	DESCRIPTION	GROUP AFFECTED/ EPIDEMIOLOGIC FACTORS	CLINICAL SYNDROME	CHAPTER
Disseminated <i>Vibrio vulnificus</i> infection	<i>V. vulnificus</i>	Erythematous lesions evolving into hemorrhagic bullae and then into necrotic ulcers	Patients with cirrhosis, diabetes, renal failure; exposure by ingestion of contaminated saltwater, seafood	Hypotension; mortality rate 50%	168
Ecthyma gangrenosum (Fig. A1-34)	<i>P. aeruginosa</i> , other gram-negative rods, fungi	Indurated plaque evolving into hemorrhagic bulla or pustule that sloughs, resulting in eschar formation; erythematous halo; most common in axillary, groin, perianal regions	Usually affects neutropenic patients; occurs in up to 28% of individuals with <i>Pseudomonas</i> bacteremia	Clinical signs of sepsis	164
Mycoplasma-induced rash and mucositis (MIRM)	<i>Mycoplasma pneumoniae</i>	Severe mucositis of at least two sites (e.g., oropharynx, ocular, genital) with nearly universal hemorrhagic crusting of lips; sparse, vesiculobullous, or atypical targetoid rash over <10% of body; lesions typically on extremities but can be truncal; rash sometimes absent (MIRM sine rash)	More common in males; usually children (mean age 11–12 years old)	Evidence of <i>M. pneumoniae</i> infection (typically pneumonia); good prognosis; distinct from SJS/TEN; rarely <i>Chlamydophila pneumoniae</i> can cause similar syndrome	
<b>Urticaria-Like Eruptions</b>					
COVID-19 <sup>a</sup>					
Urticular vasculitis (Fig. 19-5, Fig. A1-35)	Serum sickness, often due to infection (including acute hepatitis B, enteroviral, parasitic), drugs; connective tissue disease	Erythematous, edematous “urticaria-like” plaques, pruritic or burning; unlike urticaria: typical lesion duration >24 h (up to 5 days) and lack of complete lesion blanching with compression due to hemorrhage	Patients with serum sickness (including acute hepatitis B), connective tissue disease	Fever variable; arthralgias/arthritis	363 <sup>b</sup>
<b>Nodular Eruptions</b>					
Disseminated infection (Fig. 19-6, Fig. A1-36, Fig. A1-37, Fig. A1-38)	Fungal infections (e.g., candidiasis, histoplasmosis, cryptococcosis, sporotrichosis, coccidioidomycosis); mycobacteria	Subcutaneous nodules (up to 3 cm); fluctuance, draining common with mycobacteria; necrotic nodules (extremities, periorbital or nasal regions) common with <i>Aspergillus</i> , <i>Mucor</i>	Immuno compromised hosts (e.g., bone marrow transplant recipients, patients undergoing chemotherapy, HIV-infected patients)	Features vary with organism	— <sup>b</sup>
Erythema nodosum (septal panniculitis) (Fig. A1-39)	Infections (e.g., streptococcal, fungal, mycobacterial, yersinial); drugs (e.g., sulfas, penicillins, oral contraceptives); sarcoidosis; idiopathic causes	Large, violaceous, nonulcerative, subcutaneous nodules; exquisitely tender; usually on lower legs but also on upper extremities	More common among females 15–30 years old	Arthralgias (50%); features vary with associated condition	— <sup>b</sup>
Sweet syndrome (acute febrile neutrophilic dermatosis) (Fig. A1-40)	<i>Yersinia</i> infection; upper respiratory infection; inflammatory bowel disease; pregnancy; malignancy (usually hematologic); drugs (G-CSF)	Tender red or blue edematous nodules giving impression of vesiculation; usually on face, neck, upper extremities; when on lower extremities, may mimic erythema nodosum	More common among women and among persons 30–60 years old; 20% of cases associated with malignancy (men and women equally affected in this group)	Headache, arthralgias, leukocytosis	58
Bacillary angiomatosis	<i>Bartonella henselae</i> , <i>B. quintana</i>	Many forms, including erythematous, smooth vascular nodules; friable, exophytic lesions; erythematous plaques (may be dry, scaly); subcutaneous nodules (may be erythematous)	Immunosuppressed individuals, especially those with advanced HIV infection	Peliosis of liver and spleen in some cases; lesions sometimes involving multiple organs; bacteremia	172
<b>Purpuric Eruptions</b>					
Rocky Mountain spotted fever, rat-bite fever, endocarditis <sup>c</sup> ; epidemic typhus <sup>d</sup> ; dengue fever <sup>e,f</sup> ; human parvovirus B19 infection <sup>f</sup> ; COVID-19 <sup>g</sup>	—	—	—	—	— <sup>b</sup>
Acute meningococcemia	<i>Neisseria meningitidis</i>	Initially pink maculopapular lesions evolving into petechiae; petechiae rapidly becoming numerous, sometimes enlarging and becoming vesicular; trunk, extremities most commonly involved; may appear on face, hands, feet; may include purpura fulminans (see below) reflecting DIC	Most common among children, individuals with asplenia or terminal complement component deficiency (C5–C8)	Hypotension, meningitis (sometimes preceded by upper respiratory infection)	155

(Continued)

TABLE 19-1 Diseases Associated with Fever and Rash (Continued)

DISEASE	ETIOLOGY	DESCRIPTION	GROUP AFFECTED/EPIDEMIOLOGIC FACTORS	CLINICAL SYNDROME	CHAPTER
Purpura fulminans (Fig. 19-7, Fig. A1-41)	Severe DIC	Large ecchymoses with sharply irregular shapes evolving into hemorrhagic bullae and then into black necrotic lesions	Individuals with sepsis (e.g., involving <i>N. meningitidis</i> ), malignancy, or massive trauma; asplenic patients at high risk for sepsis	Hypotension	155, 304
Chronic meningococcemia (Fig. A1-42)	<i>N. meningitidis</i>	Variety of recurrent eruptions, including pink maculopapular; nodular (usually on lower extremities); petechial (sometimes developing vesicular centers); purpuric areas with pale blue-gray centers	Individuals with complement deficiencies	Fever, sometimes intermittent; arthritis, myalgias, headache	155
Disseminated gonococcal infection (Fig. A1-43)	<i>Neisseria gonorrhoeae</i>	Papules (1–5 mm) evolving over 1–2 days into hemorrhagic pustules with gray necrotic centers; hemorrhagic bullae occurring rarely; lesions (usually <40) distributed peripherally near joints (more commonly on upper extremities)	Sexually active individuals (more often females), some with complement deficiency	Low-grade fever, tenosynovitis, arthritis	156
Enteroviral petechial rash	Usually echovirus 9 or coxsackievirus A9	Disseminated petechial lesions (may also be maculopapular, vesicular, or urticarial)	Often occurs in outbreaks	Pharyngitis, headache; aseptic meningitis with echovirus 9	204
Viral hemorrhagic fever	Arenaviruses, bunyaviruses, filoviruses (including Ebola), flaviviruses (including dengue)	Petechial rash	Residence in or travel to endemic areas, other virus exposure	Triad of fever, shock, hemorrhage from mucosa or gastrointestinal tract	209, 210
Thrombotic thrombocytopenic purpura/hemolytic-uremic syndrome	Idiopathic, bloody diarrhea caused by Shiga toxin–generating bacteria (e.g., <i>Escherichia coli</i> O157:H7), deficiency in ADAMTS13 (cleaves von Willebrand factor), drugs (e.g., quinine, chemotherapy, immunosuppression)	Petechiae	Individuals with <i>E. coli</i> O157:H7 gastroenteritis (especially children), cancer chemotherapy, HIV infection, autoimmune diseases, pregnant/postpartum women, those with ADAMTS13 deficiency	Fever (not always present), microangiopathic hemolytic anemia, thrombocytopenia, renal dysfunction, neurologic dysfunction; coagulation studies normal	58, 100, 115, 161, 166
Cutaneous small-vessel vasculitis (leukocytoclastic vasculitis) (Fig. A1-44)	Infections (including group A streptococcal infection, hepatitis B or C), drugs, idiopathic factors	Palpable purpuric lesions appearing in crops on legs or other dependent areas; may become vesicular or ulcerative	Occurs in a wide spectrum of diseases, including connective tissue disease, cryoglobulinemia, malignancy, Henoch-Schönlein purpura (HSP); more common among children	Fever (not always present), malaise, arthralgias, myalgias; systemic vasculitis in some cases; renal, joint, and gastrointestinal involvement common in HSP	58
<b>Eruptions with Ulcers and/or Eschars</b>					
Scrub typhus, rickettsial spotted fevers, rat-bite fever, African trypanosomiasis <sup>a</sup> ; rickettsialpox, ecthyma gangrenosum <sup>b</sup>	—	—	—	—	— <sup>c</sup>
Tularemia (Fig. A1-45, Fig. A1-46)	<i>Francisella tularensis</i>	Ulceroglandular form: erythematous, tender papule evolves into necrotic, tender ulcer with raised borders; in 35% of cases, eruptions (maculopapular, vesiculopapular, acneiform, or urticarial; erythema nodosum; or EM) may occur	Exposure to ticks, biting flies, infected animals	Fever, headache, lymphadenopathy	170
Anthrax (Fig. A1-52)	<i>Bacillus anthracis</i>	Pruritic papule enlarging and evolving into a 1- by 3-cm painless ulcer surrounded by vesicles and then developing a central eschar with edema; residual scar	Exposure to infected animals or animal products, other exposure to anthrax spores	Lymphadenopathy, headache	S3

<sup>a</sup>See “Purpuric Eruptions.” <sup>b</sup>See “Confluent Desquamative Erythemas.” <sup>c</sup>See “Peripheral Eruptions.” <sup>d</sup>Pash is rare in human granulocytotropic ehrlichiosis or anaplasmosis (caused by *Anaplasma phagocytophilum*; most common in the upper midwestern and northeastern United States). <sup>e</sup>See “Viral hemorrhagic fever” under “Purpuric Eruptions” for dengue hemorrhagic fever/dengue shock syndrome. <sup>f</sup>See “Centrally Distributed Maculopapular Eruptions.” <sup>g</sup>See “Vesiculobullous or Pustular Eruptions.” <sup>h</sup>See etiology-specific chapters.

Abbreviations: CNS, central nervous system; DIC, disseminated intravascular coagulation; G-CSF, granulocyte colony-stimulating factor; HLA, human leukocyte antigen.



**FIGURE 19-1** Centrally distributed, maculopapular eruption on the trunk in a patient with measles. (From EJ Mayeaux Jr et al: Measles, in Usatine RP et al [eds]: *Color Atlas and Synopsis of Family Medicine*, 3rd ed. New York, McGraw-Hill, 2019, p. 797, Figure 132-2. Reproduced with permission from Richard P. Usatine, MD.)

at the hairline 2–3 days into the illness and moves down the body, typically sparing the palms and soles (Fig. 19-1; see also Fig. A1-3) (Chap. 205). It begins as discrete erythematous lesions, which become confluent as the rash spreads. Koplik's spots (1- to 2-mm white or bluish lesions with an erythematous halo on the buccal mucosa) (Fig. A1-2) are pathognomonic for measles and are generally seen during the first 2 days of symptoms. They should not be confused with Fordyce's spots (ectopic sebaceous glands), which have no erythematous halos and are found in the mouth of healthy individuals. Koplik's spots may briefly overlap with the measles exanthem.

*Rubella* (German measles) (Fig. A1-4) also spreads from the hairline downward; unlike that of measles, however, the rash of rubella tends to clear from originally affected areas as it migrates, and it may be pruritic (Chap. 206). Forchheimer spots (palatal petechiae) may develop but are nonspecific because they also develop in *infectious mononucleosis* (Chap. 194), *scarlet fever* (Chap. 148), and *Zika virus infection* (Chap. 209) (Fig. A1-51D). Postauricular and suboccipital adenopathy and arthritis are common among adults with rubella. Exposure of pregnant women to ill individuals should be avoided, as rubella causes severe congenital abnormalities. Numerous strains of *enteroviruses* (Chap. 204), primarily echoviruses and coxsackieviruses, cause non-specific syndromes of fever and eruptions that may mimic rubella or measles. Patients with *infectious mononucleosis* caused by Epstein-Barr virus (Chap. 194) or with *primary HIV infection* (Fig. A1-6; see also Chapter 202) may exhibit pharyngitis, lymphadenopathy, and a non-specific maculopapular exanthem.

The rash of *erythema infectiosum* (fifth disease), which is caused by human parvovirus B19, primarily affects children 3–12 years old; it develops after fever has resolved as a bright blanchable erythema on the cheeks ("slapped cheeks") (Fig. A1-1A) with perioral pallor (Chap. 197). A more diffuse rash (often pruritic) appears the next day on the trunk and extremities and then rapidly develops into a lacy reticular eruption (Fig. A1-1B) that may wax and wane (especially with temperature change) over 3 weeks. Adults with fifth disease often have arthritis, and fetal hydrops can develop in association with this condition in pregnant women.

*Exanthem subitum* (roseola) is caused by human herpesvirus 6, or less commonly by the closely related human herpesvirus 7, and is most

common among children <3 years of age (Chap. 195). As in erythema infectiosum, the rash usually appears after fever has subsided. It consists of 2- to 3-mm rose-pink macules and papules that coalesce only rarely, occur initially on the trunk (Fig. A1-5) and sometimes on the extremities (sparing the face), and fade within 2 days.

Although drug reactions have many manifestations, including urticaria, exanthematos drug-induced eruptions (Chap. 60) (Fig. A1-7) are most common and are often difficult to distinguish from viral exanthems. Eruptions elicited by drugs are usually more intensely erythematous and pruritic than viral exanthems, but this distinction is not reliable. A history of new medications and an absence of prostration may help to distinguish a drug-related rash from an eruption of another etiology. Rashes may persist for up to 2 weeks after administration of the offending agent is discontinued. Certain populations are more prone than others to drug rashes. Of HIV-infected patients, 50–60% develop a rash in response to sulfa drugs; 30–90% of patients with mononucleosis due to Epstein-Barr virus develop a rash when given ampicillin.

*Rickettsial illnesses* (Chap. 187) should be considered in the evaluation of individuals with centrally distributed maculopapular eruptions. The usual setting for *epidemic typhus* is a site of war or natural disaster in which people are exposed to body lice. Endemic typhus or *leptospirosis* (the latter caused by a spirochete) (Chap. 184) may be seen in urban environments where rodents proliferate. Outside the United States, other rickettsial diseases cause a spotted-fever syndrome and should be considered in residents of or travelers to endemic areas. Similarly, *typhoid fever*, a nonrickettsial disease caused by *Salmonella typhi* (Chap. 165) (Fig. A1-9), is usually acquired during travel outside the United States. *Dengue fever* (Fig. A1-53), caused by a mosquito-transmitted flavivirus, occurs in tropical and subtropical regions of the world (Chap. 209).

Some centrally distributed maculopapular eruptions have distinctive features. Erythema migrans (Fig. A1-8), the rash of *Lyme disease* (Chap. 186), typically manifests as single or multiple annular lesions. Untreated erythema migrans lesions usually fade within a month but may persist for more than a year. *Southern tick-associated rash illness* (STARI) (Chap. 186) has an erythema migrans-like rash, but is less severe than Lyme disease and often occurs in regions where Lyme is not endemic. Erythema marginatum, the rash of *acute rheumatic fever* (Chap. 359), has a distinctive pattern of enlarging and shifting transient annular lesions.

Collagen vascular diseases may cause fever and rash. Patients with *systemic lupus erythematosus* (Chap. 356) typically develop a sharply defined, erythematous eruption in a butterfly distribution on the cheeks (malar rash) (Fig. A1-10) as well as many other skin manifestations (Figs. A1-11, A1-12). *Still's disease* presents as an evanescent, salmon-colored rash on the trunk and proximal extremities that coincides with fever spikes (Fig. A1-13).

Hemophagocytic lymphohistiocytosis may be familial or triggered by infection, autoimmunity, or neoplasia. Cutaneous manifestations are protean and can present as an erythematous maculopapular eruption, pyoderma gangrenosum, purpura, panniculitis, or Stevens Johnson syndrome.

*Zika virus* is a mosquito-transmitted flavivirus that is associated with severe birth defects (Chap. 209). Zika is widespread among tropical and subtropical regions of the world. The eruption of Zika virus infection (Fig. A1-51A, A1-51B) is typically pruritic and often accompanied by conjunctival injection (Fig. A1-51C).

## ■ PERIPHERAL ERUPTIONS

These rashes are alike in that they are most prominent peripherally or begin in peripheral (acral) areas before spreading centripetally. Early diagnosis and therapy are critical in *Rocky Mountain spotted fever* (Chap. 187) because of its grave prognosis if untreated. Lesions (Fig. 19-2; see also Fig. A1-16) evolve from macular to petechial, start on the wrists and ankles, spread centripetally, and appear on the palms and soles only later in the disease. The rash of *secondary syphilis* (Chap. 182), which may be generalized (Fig. A1-18) but is prominent on the palms and soles (Fig. A1-19), should be considered in the differential diagnosis of pityriasis rosea, especially in sexually active patients. *Chikungunya fever* (Chap. 209), which is transmitted by mosquito bite



**FIGURE 19-2** Peripheral eruption on the wrist and palm exhibiting erythematous macules in the process of evolving into petechial lesions in a patient with Rocky Mountain spotted fever. (From K Wolff et al [eds]: *Fitzpatrick's Color Atlas and Synopsis of Clinical Dermatology*, 8th ed. New York, McGraw-Hill, 2017, p. 562, Figure 25-50; with permission.)

in tropical and subtropical regions, is associated with a maculopapular eruption (Fig. A1-54) and severe polyarticular small-joint arthralgias. *Hand-foot-and-mouth disease* (Chap. 204), most commonly caused by coxsackievirus A16 or enterovirus 71, is distinguished by tender vesicles distributed on the hands and feet and in the mouth (Fig. A1-22); coxsackievirus A6 causes an atypical syndrome with more extensive lesions. The classic target lesions of *erythema multiforme* (Fig. A1-24) appear symmetrically on the elbows, knees, palms, soles, and face. In severe cases, these lesions spread diffusely and involve mucosal surfaces. Lesions may develop on the hands and feet in *endocarditis* (Fig. A1-23) (Chap. 128). Pernio, tender violaceous lesions that are acral (Fig. A1-57), occur most commonly on the feet, in asymptomatic or mild COVID-19. Vesicles, urticaria, or maculopapular eruptions, often pruritic, may occur on the trunk and extremities in moderate or severe disease, while retiform purpura occurs on the extremities and buttocks in severe COVID-19.

### ■ CONFLUENT DESQUAMATIVE ERYTHEMAS

These eruptions consist of diffuse erythema frequently followed by desquamation. The eruptions caused by group A *Streptococcus* or *Staphylococcus aureus* is toxin-mediated. *Scarlet fever* (Chap. 148) (Fig. A1-25) usually follows pharyngitis; patients have a facial flush, a "strawberry" tongue, and accentuated petechiae in body folds (Pastia's lines). *Kawasaki disease* (Fig. A1-29) (Chaps. 58 and 363) presents in the pediatric population as fissuring of the lips, a strawberry tongue, conjunctivitis, adenopathy, and sometimes cardiac abnormalities. *Streptococcal toxic shock syndrome* (Chap. 148) manifests with hypotension, multiorgan failure, and, often, a severe group A streptococcal infection (e.g., necrotizing fasciitis). *Staphylococcal toxic shock syndrome* (Chap. 147) also presents with hypotension and multiorgan failure, but usually only *S. aureus* colonization—not a severe *S. aureus* infection—is documented. *Staphylococcal scalded-skin syndrome* (Fig. A1-28) (Chap. 147) is seen primarily in children and in immunocompromised adults. Generalized erythema is often evident during

the prodrome of fever and malaise; profound tenderness of the skin is distinctive. In the exfoliative stage, the skin can be induced to form bullae with light lateral pressure (Nikolsky's sign) (Fig. 19-3). In a mild form, a scarlatiniform eruption mimics scarlet fever, but the patient does not exhibit a strawberry tongue or circumoral pallor. In contrast to the staphylococcal scalded-skin syndrome, in which the cleavage plane is superficial in the epidermis, *toxic epidermal necrolysis* (Chap. 60), a maximal variant of *Stevens-Johnson syndrome*, involves sloughing of the entire epidermis (Fig. A1-26), resulting in severe disease. *Exfoliative erythroderma syndrome* (Chaps. 58 and 60) is a serious reaction associated with systemic toxicity that is often due to eczema, psoriasis (Fig. A1-27), a drug reaction, or mycosis fungoides. *Drug rash with eosinophilia and systemic symptoms* (DRESS), often due to antiepileptic and antibiotic agents (Chap. 60), initially appears similar to an exanthematous drug reaction (Fig. A1-48) but may progress to exfoliative erythroderma; it is accompanied by multiorgan failure and has an associated mortality rate of ~10%.

### ■ VESICULOBULLOUS OR PUSTULAR ERUPTIONS

*Varicella* (Chap. 193) is highly contagious, often occurring in winter or spring, and is characterized by pruritic lesions that, within a given region of the body, are in different stages of development at any point in time (Fig. 19-4; see also Fig. A1-30). In immunocompromised hosts, varicella vesicles may lack the characteristic erythematous base or may appear hemorrhagic. Lesions of *Pseudomonas "hot-tub" folliculitis* (Chap. 164) are also pruritic and may appear similar to those of varicella (Fig. A1-55). However, hot-tub folliculitis generally occurs in outbreaks after bathing in hot tubs or swimming pools, and lesions occur in regions occluded by bathing suits. Lesions of *variola (smallpox)* (Chap. S3) also appear similar to those of varicella but are



**FIGURE 19-3** Confluent desquamative erythema in a patient with Staphylococcal scalded-skin syndrome. Nikolsky sign evident as shearing of epidermis due to gentle, lateral pressure. (From K Wolff et al [eds]: *Fitzpatrick's Color Atlas and Synopsis of Clinical Dermatology*, 8th ed. New York, McGraw-Hill, 2017, p. 554, Figure 25-42; with permission.)



**FIGURE 19-4** Vesicular and pustular lesions on the chest in a patient with varicella. (From K Wolff et al [eds]: *Fitzpatrick's Color Atlas and Synopsis of Clinical Dermatology*, 8th ed. New York, McGraw-Hill, 2017, p. 695, Figure 27-48; with permission.)

all at the same stage of development in a given region of the body (Figs. A1-50B, A1-50C). Variola lesions are most prominent on the face (Fig. A1-50A) and extremities, while varicella lesions are most prominent on the trunk. *Herpes simplex virus infection* (Chap. 192) is characterized by hallmark grouped vesicles on an erythematous base. Primary herpes infection is accompanied by fever and toxicity, while recurrent disease is milder. *Rickettsialpox* (Chap. 187) is often documented in urban settings and is characterized by vesicles followed by pustules (Figs. A1-33B, A1-33C). It can be distinguished from varicella by an eschar at the site of the mouse-mite bite (Fig. A1-33A) and the papule/plaque base of each vesicle. *Acute generalized exanthematous pustulosis* (Fig. A1-49) should be considered in individuals who are acutely febrile and are taking new medications, especially anticonvulsant or antimicrobial agents (Chap. 60). Disseminated *Vibrio vulnificus* infection (Chap. 168) or *ecthyma gangrenosum* due to *Pseudomonas aeruginosa* (Fig. A1-34) (Chap. 164) should be considered in immunosuppressed individuals with sepsis and hemorrhagic bullae. In children, *Mycoplasma pneumoniae*-induced rash and mucositis (MIRM) (Fig. A1-56) is characterized by a sparse, often vesiculobullous eruption with prominent oral, ocular, or urogenital mucositis.

#### ■ URTICARIA LIKE ERUPTIONS

Individuals with classic urticaria ("hives") (Fig. 19-5; see also Fig. A1-35) usually have a hypersensitivity reaction without associated fever. In the presence of fever, urticaria-like eruptions are most often due to *urticarial vasculitis* (Chap. 363). Unlike individual lesions of classic urticaria, which last up to 24 h, these lesions may last 3–5 days. Etiologies include serum sickness (often induced by drugs such as penicillins, sulfas, salicylates, or barbiturates), connective-tissue disease (e.g., systemic lupus erythematosus or Sjögren's syndrome), and infection (e.g., with hepatitis B virus, enteroviruses, or parasites). Malignancy, especially lymphoma, may be associated with fever and chronic urticaria (Chap. 58).



**FIGURE 19-5** Urticarial eruption. (From K Wolff et al [eds]: *Fitzpatrick's Color Atlas and Synopsis of Clinical Dermatology*, 8th ed. New York, McGraw-Hill, 2017, p. 299, Figure 14-2; with permission.)

#### ■ NODULAR ERUPTIONS

In immunocompromised hosts, nodular lesions often represent disseminated infection. Patients with disseminated *candidiasis* (Fig. A1-37) (often due to *Candida tropicalis*) may have a triad of fever, myalgias, and eruptive nodules (Chap. 216). Disseminated *cryptococcosis* lesions (Fig. 19-6; see also Fig. A1-36) (Chap. 215) may resemble molluscum contagiosum (Chap. 196). Necrosis of nodules should raise the suspicion of *aspergillosis* (Fig. A1-38) (Chap. 217) or *mucormycosis*



**FIGURE 19-6** Nodular eruption on the face due to disseminated *Cryptococcus* in a patient with HIV infection. (From K Wolff et al [eds]: *Fitzpatrick's Color Atlas and Synopsis of Clinical Dermatology*, 8th ed. New York, McGraw-Hill, 2017, p. 641, Figure 26-57. Used with permission from Loïc Vallant, MD.)



**FIGURE 19-7** Purpura fulminans in a patient with acute meningococcemia. (From K Wolff et al [eds]: *Fitzpatrick's Color Atlas and Synopsis of Clinical Dermatology*, 8th ed. New York, McGraw-Hill, 2017, p. 568, Figure 25-59; with permission.)

([Chap. 218](#)). *Erythema nodosum* presents with exquisitely tender nodules on the lower extremities ([Fig. A1-39](#)). *Sweet syndrome* ([Chap. 58](#)) should be considered in individuals with multiple nodules and plaques, often so edematous ([Fig. A1-40](#)) that they give the appearance of vesicles or bullae. *Sweet syndrome* may occur in individuals with infection, inflammatory bowel disease, or malignancy and can also be induced by drugs.

### PURPURIC ERUPTIONS

*Acute meningococcemia* ([Chap. 155](#)) classically presents in children as a petechial eruption, but initial lesions may appear as blanchable macules or urticaria. Rocky Mountain spotted fever should be considered in the differential diagnosis of acute meningococcemia. *Echovirus 9 infection* ([Chap. 204](#)) may mimic acute meningococcemia; patients should be treated as if they have bacterial sepsis because prompt differentiation of these conditions may be impossible. Large ecchymotic areas of *purpura*

*fulminans* ([Fig. 19-7](#); see also [Fig. A1-41](#)) ([Chaps. 155 and 304](#)) reflect severe underlying disseminated intravascular coagulation, which may be due to infectious or noninfectious causes. The lesions of *chronic meningococcemia* ([Fig. A1-42](#)) ([Chap. 155](#)) may have a variety of morphologies, including petechial. Purpuric nodules may develop on the legs and resemble *erythema nodosum* but lack its exquisite tenderness. Lesions of *disseminated gonococcemia* ([Chap. 156](#)) are distinctive, sparse, countable hemorrhagic pustules ([Fig. A1-43](#)), usually located near joints. The lesions of chronic meningococcemia and those of gonococcemia may be indistinguishable in terms of appearance and distribution. *Viral hemorrhagic fever* ([Chaps. 209 and 210](#)) should be considered in patients with an appropriate travel history and a petechial rash. *Thrombotic thrombocytopenic purpura* ([Chaps. 58, 100, and 115](#)) and *hemolytic-uremic syndrome* ([Chaps. 115, 161, and 166](#)) are closely related and are non-infectious causes of fever and petechiae. *Cutaneous small-vessel vasculitis* (*leukocytoclastic vasculitis*) typically manifests as palpable purpura ([Fig. A1-44](#)) and has a wide variety of causes ([Chap. 58](#)).

### ERUPTIONS WITH ULCERS OR ESCHARS

The presence of an ulcer or eschar ([Fig. 19-8](#)) in the setting of a more widespread eruption can provide an important diagnostic clue. For example, an eschar may suggest the diagnosis of *scrub typhus* or *rickettsialpox* ([Fig. A1-33A](#)) ([Chap. 187](#)) in the appropriate setting. In other illnesses (e.g., anthrax) ([Fig. A1-52](#)) ([Chap. S3](#)), an ulcer or eschar may be the only skin manifestation.

### FURTHER READING

- C JD: Cutaneous manifestations of systemic infections, in *Feigin and Cherry's Textbook of Pediatric Infectious Diseases*, 8th ed. JD Cherry et al (eds). Philadelphia, Elsevier, 2019, pp 539–559.
- J JJ et al: The acutely ill patient with fever and rash, in *Mandell, Douglas, and Bennett's Principles and Practice of Infectious Diseases*, vol 1, 9th ed. JI Bennett et al (eds). Philadelphia, Elsevier, 2020, pp 801–818.
- K S et al (eds): *Fitzpatrick's Dermatology*, 9th ed. New York, McGraw-Hill, 2019.
- W K et al: *Fitzpatrick's Color Atlas and Synopsis of Clinical Dermatology*, 8th ed. New York, McGraw-Hill, 2017.



**FIGURE 19-8** Eschar with surrounding erythema at the site of a tick bite in a patient with African tick-bite fever. (From K Wolff et al [eds]: *Fitzpatrick's Color Atlas and Synopsis of Clinical Dermatology*, 8th ed. New York, McGraw-Hill, 2017, p. 561, Figure 25-49; with permission.)

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## DEFINITION

Clinicians commonly refer to any febrile illness without an initially obvious etiology as *fever of unknown origin* (FUO). Most febrile illnesses either resolve before a diagnosis can be made or develop distinguishing characteristics that lead to a diagnosis. The term *FUO* should be reserved for prolonged febrile illnesses without an established etiology despite intensive evaluation and diagnostic testing. This chapter focuses on FUO in the adult patient.

FUO was originally defined by Petersdorf and Beeson in 1961 as an illness of >3 weeks' duration with fever of  $\geq 38.3^{\circ}\text{C}$  ( $\geq 101^{\circ}\text{F}$ ) on two occasions and an uncertain diagnosis despite 1 week of inpatient evaluation. Nowadays, most patients with FUO are hospitalized only if their clinical condition requires it, and not for diagnostic purposes alone; thus the in-hospital evaluation requirement has been eliminated from the definition. The definition of FUO has been further modified by the exclusion of immunocompromised patients, whose workup requires an entirely different diagnostic and therapeutic approach. For optimal comparison of patients with FUO in different geographic areas, it has been proposed that the quantitative criterion (diagnosis uncertain after 1 week of evaluation) be changed to a qualitative criterion that requires the performance of a specific list of investigations. Accordingly, FUO is now defined as follows:

1. Fever  $\geq 38.3^{\circ}\text{C}$  ( $\geq 101^{\circ}\text{F}$ ) on at least two occasions
2. Illness duration of  $\geq 3$  weeks
3. No known immunocompromised state
4. Diagnosis that remains uncertain after a thorough history-taking, physical examination, and the following obligatory investigations: determination of erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) level; platelet count; leukocyte count and differential; measurement of levels of hemoglobin, electrolytes, creatinine, total protein, alkaline phosphatase, alanine aminotransferase, aspartate aminotransferase, lactate dehydrogenase, creatine kinase, ferritin, antinuclear antibodies, and rheumatoid factor; protein electrophoresis; urinalysis; blood cultures ( $n = 3$ ); urine culture; chest x-ray; abdominal ultrasonography; and tuberculin skin test (TST) or interferon  $\gamma$  release assay (IGRA).

Closely related to FUO is *inflammation of unknown origin* (IUO), which has the same definition as FUO, except for the body temperature

criterion: IUO is defined as the presence of elevated inflammatory parameters (CRP or ESR) on multiple occasions for a period of at least 3 weeks in an immunocompetent patient with normal body temperature, for which a final explanation is lacking despite history-taking, physical examination, and the obligatory tests listed above. It has been shown that the causes and workup for IUO are the same as for FUO. Therefore, for convenience, the term FUO will refer to both FUO and IUO within the remainder of this chapter.

## Etiology and Epidemiology

**Table 20-1** summarizes the findings of large studies on FUO conducted over the past 20 years.

The range of FUO etiologies has evolved since its first definition as a result of changes in the spectrum of diseases causing FUO, the widespread use of antibiotics, and especially the availability of new diagnostic techniques. The proportion of cases caused by intraabdominal abscesses and tumors, for example, has decreased because of earlier detection by CT and ultrasound. In addition, infective endocarditis is a less frequent cause because blood culture and echocardiographic techniques have improved. Conversely, some diagnoses such as acute HIV infection were unknown six decades ago.

Roughly comparable to 60 years ago, in non-Western cohorts infections remain the most common cause of FUO. Up to half of all infections in patients with FUO outside Western nations are caused by *Mycobacterium tuberculosis*, which is a less common cause in Western Europe and probably also in the United States. Recent data from the latter, however, have not been reported. In Western cohorts, noninfectious inflammatory diseases (NIIDs), including autoimmune, autoinflammatory, and granulomatous diseases, as well as vasculitides, form the most common cause of FUO. More than one-third of Western patients with FUO have a diagnosis that falls within the category of NIIDs. The number of FUO patients diagnosed with NIIDs probably will not decrease in the near future, as fever may precede more typical manifestations or laboratory evidence of these diseases by months. Moreover, many NIIDs can be diagnosed only after prolonged observation and exclusion of other diseases.

In Western cohorts, FUO remains unexplained in more than one-third of patients. This is much higher than 60 years ago. This difference can be explained by the fact that in patients with fever a diagnosis is often established before 3 weeks have elapsed because these patients tend to seek medical advice earlier, and because better diagnostic techniques, such as CT, MRI, and positron emission tomography (PET)/CT, are now available. Therefore, only the cases that are most difficult to diagnose continue to meet the criteria for FUO. Furthermore, most patients who have FUO without a diagnosis currently do well. A less aggressive diagnostic approach may be used in clinically stable patients once diseases with immediate therapeutic or prognostic consequences have been ruled out. In patients with recurrent fever (defined as repeated episodes of fever

TABLE 20-1 Etiology of FUO: Pooled Results of Large Studies Published in the Past 20 Years (1999–2019)

GEOGRAPHIC AREA	NO. OF COHORTS (INCLUSION PERIOD)	NO. OF PATIENTS	INFECTIONS, MEDIAN % (RANGE)	NONINFECTIOUS INFLAMMATORY DISEASES, MEDIAN % (RANGE)	MALIGNANCY, MEDIAN % (RANGE)	MISCELLANEOUS, MEDIAN % (RANGE)	NO. DIAGNOSIS, MEDIAN % (RANGE)
Western Europe	10 (1990–2014)	1820	17 (11–32)	25 (12–32)	10 (3–20)	10 (0–15)	37 (26–51)
Other European and Turkey	13 (1984–2015)	1316	38 (26–59)	25 (15–38)	14 (5–19)	6 (2–18)	16 (4–35)
Middle East	3 2009–2010 and ? <sup>a</sup>	1235	66 (42–79)	15 (7–17)	7 (1–30)	1 (0–12)	8 (2–12)
Asia	20 (1994–2017)	3802	42 (11–58)	20 (7–57)	13 (6–22)	9 (0–15)	18 (0–36)

<sup>a</sup>One study (published in 2015) did not report the inclusion period.

Abbreviation: NIID, non-infectious inflammatory disease.

For references, see supplementary material at [www.accessmedicine.com/harrison](http://www.accessmedicine.com/harrison).

interspersed with fever-free intervals of at least 2 weeks and apparent remission of the underlying disease), the chance of attaining an etiologic diagnosis is <50%.

## ■ DIFFERENTIAL DIAGNOSIS

The differential diagnosis for FUO is extensive. It is important to remember that FUO is far more often caused by an atypical presentation of a rather common disease than by a very rare disease. Table 20-2 presents an overview of possible causes of FUO. Atypical presentations of endocarditis, diverticulitis, vertebral osteomyelitis, and extrapulmonary tuberculosis are the more common infectious disease diagnoses.

Q fever and Whipple's disease (*Tropheryma whipplei* infection) are quite rare but should always be kept in mind as a cause of FUO since the presenting symptoms can be nonspecific. Serologic testing for Q fever, which results from exposure to animals or animal products, should be performed by immunofluorescence assay (IFA) when the patient lives in a rural area or has a history of heart valve disease, an aortic aneurysm, or a vascular prosthesis. In patients with unexplained symptoms localized to the central nervous system, gastrointestinal tract, or joints, polymerase chain reaction testing for *Tropheryma whipplei* should be performed. Travel to or (former) residence in tropical countries or the American Southwest should lead to consideration

TABLE 20-2 All Reported Causes of Fever of Unknown Origin (FUO)<sup>a</sup>

Infections	
Bacterial, nonspecific	Abdominal abscess, adnexitis, apical granuloma, appendicitis, cholangitis, cholecystitis, diverticulitis, endocarditis, endometritis, epidural abscess, infected joint prosthesis, infected vascular catheter, infected vascular prosthesis, infectious arthritis, infective myonecrosis, intracranial abscess, liver abscess, lung abscess, malakoplakia, mastoiditis, mediastinitis, mycotic aneurysm, osteomyelitis, pelvic inflammatory disease, prostatitis, pyelonephritis, pylephlebitis, renal abscess, septic phlebitis, sinusitis, spondylodiscitis, xanthogranulomatous urinary tract infection
Bacterial, specific	Actinomycosis, atypical mycobacterial infection, bartonellosis, brucellosis, <i>Campylobacter</i> infection, <i>Chlamydia pneumoniae</i> infection, chronic meningococcemia, ehrlichiosis, gonococcemia, legionellosis, leptospirosis, listeriosis, louse-borne relapsing fever ( <i>Borrelia recurrentis</i> ), Lyme disease, melioidosis ( <i>Pseudomonas pseudomallei</i> ), <i>Mycoplasma</i> infection, nocardiosis, psittacosis, Q fever ( <i>Coxiella burnetii</i> ), rickettsiosis, <i>Spirillum minor</i> infection, <i>Streptobacillus moniliformis</i> infection, syphilis, tick-borne relapsing fever ( <i>Borrelia duttoni</i> ), tuberculosis, tularemia, typhoid fever and other salmonelloses, Whipple's disease ( <i>Tropheryma whipplei</i> ), yersiniosis
Fungal	Aspergillosis, blastomycosis, candidiasis, coccidioidomycosis, cryptococcosis, histoplasmosis, <i>Malassezia furfur</i> infection, paracoccidioidomycosis, <i>Pneumocystis jirovecii</i> pneumonia, sporotrichosis, zygomycosis
Parasitic	Amebiasis, babesiosis, echinococcosis, fascioliasis, malaria, schistosomiasis, strongyloidiasis, toxocariasis, toxoplasmosis, trichinellosis, trypanosomiasis, visceral leishmaniasis
Viral	Colorado tick fever, coxsackievirus infection, cytomegalovirus infection, dengue, Epstein-Barr virus infection, hantavirus infection, hepatitis (A, B, C, D, E), herpes simplex, HIV infection, human herpesvirus 6 infection, parvovirus infection, West Nile virus infection
Noninfectious Inflammatory Diseases	
Systemic rheumatic and autoimmune diseases	Ankylosing spondylitis, antiphospholipid syndrome, autoimmune hemolytic anemia, autoimmune hepatitis, Behcet's disease, cryoglobulinemia, dermatomyositis, Felty syndrome, gout, mixed connective-tissue disease, polymyositis, pseudogout, reactive arthritis, relapsing polychondritis, rheumatic fever, rheumatoid arthritis, Sjögren's syndrome, systemic lupus erythematosus, Vogt-Koyanagi-Harada syndrome
Vasculitis	Allergic vasculitis, eosinophilic granulomatosis with polyangiitis, giant cell vasculitis/polymyalgia rheumatica, granulomatosis with polyangiitis, hypersensitivity vasculitis, Kawasaki disease, polyarteritis nodosa, Takayasu arteritis, urticarial vasculitis
Granulomatous diseases	Idiopathic granulomatous hepatitis, sarcoidosis
Autoinflammatory syndromes	Adult-onset Still's disease, Blau syndrome, CAPS <sup>b</sup> (cryopyrin-associated periodic syndromes), Crohn's disease, DIRA (deficiency of the interleukin 1 receptor antagonist), familial Mediterranean fever, hemophagocytic syndrome, hyper-IgD syndrome (HIDS, also known as mevalonate kinase deficiency), juvenile idiopathic arthritis, PAPA syndrome (pyogenic sterile arthritis, pyoderma gangrenosum, and acne), PFAPA syndrome (periodic fever, aphthous stomatitis, pharyngitis, adenitis), recurrent idiopathic pericarditis, SAPHO (synovitis, acne, pustulosis, hyperostosis, osteomyelitis), Schnitzler syndrome, TRAPS (tumor necrosis factor receptor-associated periodic syndrome)
Neoplasms	
Hematologic malignancies	Amyloidosis, angioimmunoblastic lymphoma, Castleman's disease, Hodgkin's disease, hypereosinophilic syndrome, leukemia, lymphomatoid granulomatosis, malignant histiocytosis, multiple myeloma, myelodysplastic syndrome, myelofibrosis, non-Hodgkin's lymphoma, plasmacytoma, systemic mastocytosis, vaso-occlusive crisis in sickle cell disease
Solid tumors	Most solid tumors and metastases can cause fever. Those most commonly causing FUO are breast, colon, hepatocellular, lung, pancreatic, and renal cell carcinomas.
Benign tumors	Angiomyolipoma, cavernous hemangioma of the liver, craniopharyngioma, necrosis of dermoid tumor in Gardner's syndrome
Miscellaneous Causes	
	ADEM (acute disseminated encephalomyelitis), adrenal insufficiency, aneurysms, anomalous thoracic duct, aortic dissection, aortic-enteral fistula, aseptic meningitis (Mollaret's syndrome), atrial myxoma, brewer's yeast ingestion, Caroli disease, cholesterol emboli, cirrhosis, complex partial status epilepticus, cyclic neutropenia, drug fever, Erdheim-Chester disease, extrinsic allergic alveolitis, Fabry's disease, factitious disease, fire-eater's lung, fraudulent fever, Gaucher disease, Hamman-Rich syndrome (acute interstitial pneumonia), Hashimoto's encephalopathy, hematoma, hypersensitivity pneumonitis, hypertriglyceridemia, hypothalamic hypopituitarism, idiopathic normal-pressure hydrocephalus, inflammatory pseudotumor, Kikuchi's disease, linear IgA dermatosis, mesenteric fibromatosis, metal fume fever, milk protein allergy, myotonic dystrophy, nonbacterial osteitis, organic dust toxic syndrome, panniculitis, POEMS (polyneuropathy, organomegaly, endocrinopathy, monoclonal protein, skin changes), polymer fume fever, post-cardiac injury syndrome, primary biliary cirrhosis, primary hyperparathyroidism, pulmonary embolism, pyoderma gangrenosum, retroperitoneal fibrosis, Rosai-Dorfman disease, sclerosing mesenteritis, silicone embolization, subacute thyroiditis (de Quervain's), Sweet syndrome (acute febrile neutrophilic dermatosis), thrombosis, tubulointerstitial nephritis and uveitis syndrome (TINU), ulcerative colitis
Thermoregulatory Disorders	
Central	Brain tumor, cerebrovascular accident, encephalitis, hypothalamic dysfunction
Peripheral	Anhidrotic ectodermal dysplasia, exercise-induced hyperthermia, hyperthyroidism, pheochromocytoma

<sup>a</sup>This table includes all causes of FUO that have been described in the literature. <sup>b</sup>CAPS includes chronic infantile neurologic cutaneous and articular syndrome (CINCA, also known as neonatal-onset multisystem inflammatory disease, or NOMID), familial cold autoinflammatory syndrome (FCAS), and Muckle-Wells syndrome.

of infectious diseases such as malaria, leishmaniasis, histoplasmosis, or coccidioidomycosis. Fever with signs of endocarditis and negative blood culture results poses a special problem. Culture-negative endocarditis (Chap. 128) may be due to difficult-to-culture bacteria such as nutritionally variant bacteria, HACEK organisms (including *Haemophilus parainfluenzae*, *H. paraphrophilus*, *Aggregatibacter actinomycetemcomitans*, *A. aphrophilus*, *A. paraphrophilus*, *Cardiobacterium hominis*, *C. valvarum*, *Eikenella corrodens*, and *Kingella kingae*; discussed below), *Coxiella burnetii*, *T. whipplei*, and *Bartonella* species. Marantic endocarditis is a sterile thrombotic disease that occurs as a paraneoplastic phenomenon, especially with adenocarcinomas. Sterile endocarditis is also seen in the context of systemic lupus erythematosus and antiphospholipid syndrome.

Of the NIDs, adult-onset Still's disease, large-vessel vasculitis, polymyalgia rheumatica, systemic lupus erythematosus (SLE), and sarcoidosis are rather common diagnoses in patients with FUO. The hereditary autoinflammatory syndromes are very rare (with the exception of familial Mediterranean fever in specific geographic regions) and usually present in young patients. Schnitzler syndrome, which can present at any age, is uncommon but can often be diagnosed easily in a patient with FUO who presents with urticaria, bone pain, and monoclonal gammopathy.

Although most tumors can present with fever, malignant lymphoma is by far the most common diagnosis of FUO among the neoplasms. Sometimes the fever even precedes lymphadenopathy detectable by physical examination.

Apart from drug-induced fever and exercise-induced hyperthermia, none of the miscellaneous causes of fever is found very frequently in patients with FUO. Virtually all drugs can cause fever, even after long-term use. *Drug-induced fever*, including DRESS (drug reaction with eosinophilia and systemic symptoms; Fig. A1-48), is often accompanied by eosinophilia and also by lymphadenopathy, which can be extensive. More common causes of drug-induced fever are allopurinol, carbamazepine, lamotrigine, phenytoin, sulfasalazine, furosemide, antimicrobial drugs (especially sulfonamides, minocycline, vancomycin,  $\beta$ -lactam antibiotics, and isoniazid), some cardiovascular drugs (e.g., quinidine), and some antiretroviral drugs (e.g., nevirapine). *Exercise-induced hyperthermia* (Chaps. 18 and 465) is characterized by an elevated body temperature that is associated with moderate to strenuous exercise lasting from half an hour up to several hours without an increase in CRP level or ESR. Unlike patients with fever, these patients typically sweat during the temperature elevation. *Factitious fever* (fever artificially induced by the patient—for example, by IV injection of contaminated water) should be considered in all patients but is more common among young women in health-care professions. In *fraudulent fever*, the patient is normothermic but manipulates the thermometer. Simultaneous measurements at different body sites (rectum, ear, mouth) should rapidly identify this diagnosis. Another clue to fraudulent fever is dissociation between pulse rate and temperature.

Previous studies of FUO have shown that a cause is more likely to be found in elderly patients than in younger age groups. In many cases, FUO in the elderly results from an atypical manifestation of a common disease, among which giant cell arteritis and polymyalgia rheumatica are most frequently involved. Tuberculosis is the most common infectious disease associated with FUO in elderly patients, occurring much more often than in younger patients. As many of these diseases are treatable, it is well worth pursuing the cause of fever in elderly patients.

## APPROACH TO THE PATIENT

### Fever of Unknown Origin

#### FIRST-STAGE DIAGNOSTIC TESTS

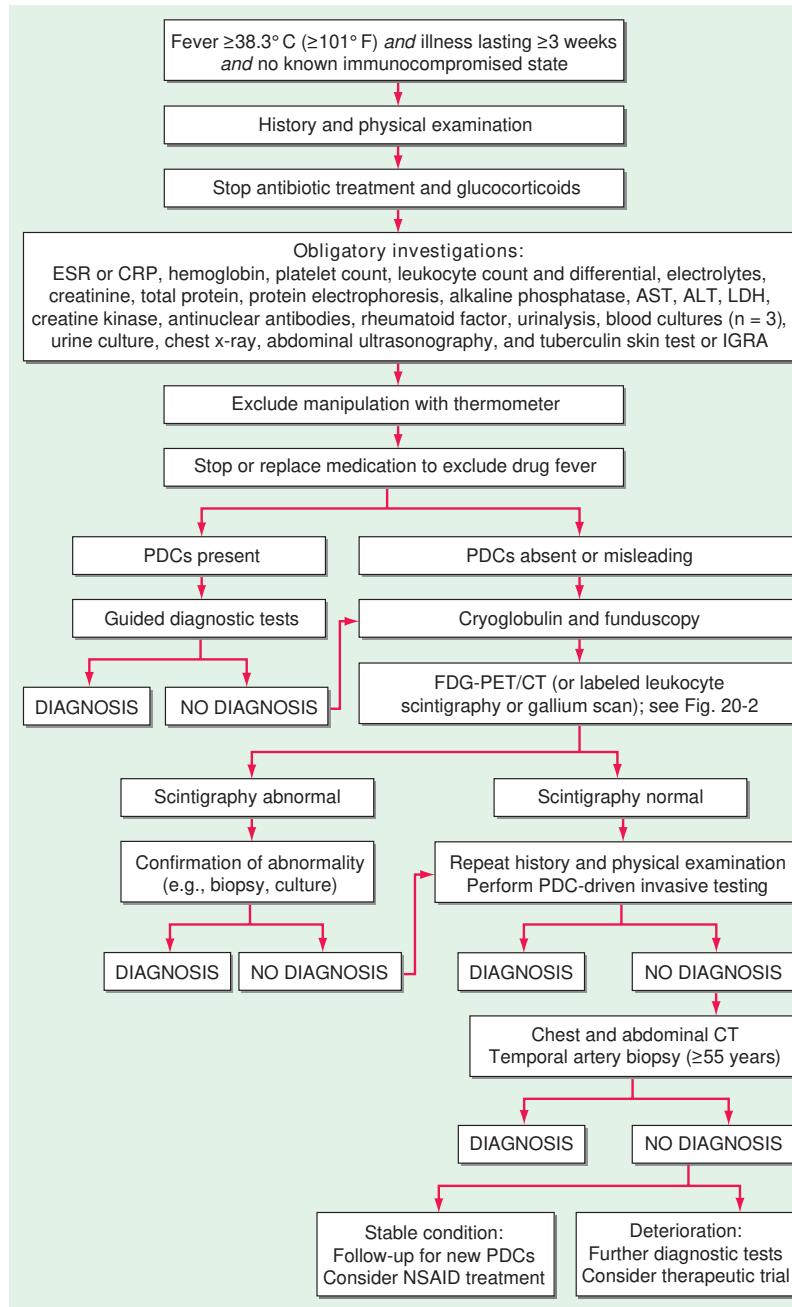
**Figure 20-1** shows a structured approach to patients presenting with FUO. The most important step in the diagnostic workup is the search for potentially diagnostic clues (PDCs) through complete and repeated history-taking and physical examination and the obligatory investigations listed above and in the figure. *PDCs* are defined as all localizing signs, symptoms, and abnormalities

potentially pointing toward a diagnosis. Although PDCs are often misleading, only with their help can a concise list of probable diagnoses be made. The history should include information about the fever pattern (continuous or recurrent) and duration, previous medical history, present and recent drug use, family history, sexual history, country of origin, recent and remote travel, unusual environmental exposures associated with travel or hobbies, and animal contacts. A complete physical examination should be performed, with special attention to the eyes, lymph nodes, temporal arteries, liver, spleen, sites of previous surgery, entire skin surface, and mucous membranes. Before further diagnostic tests are initiated, antibiotic and glucocorticoid treatment, which can mask many diseases, should be stopped. For example, blood and other cultures are not reliable when samples are obtained during antibiotic treatment, and the size of enlarged lymph nodes usually decreases during glucocorticoid treatment, regardless of the cause of lymphadenopathy. Despite the high percentage of false-positive ultrasounds and the relatively low sensitivity of chest x-rays, the performance of these simple, low-cost diagnostic tests remains obligatory in all patients with FUO in order to separate cases that are caused by easily diagnosed diseases from those that are not. Abdominal ultrasound is preferred to abdominal CT as an obligatory test because of relatively low cost, lack of radiation burden, and absence of side effects.

Only rarely do biochemical tests (beyond the obligatory tests needed to classify a patient's fever as FUO) lead directly to a definitive diagnosis in the absence of PDCs. The diagnostic yield of immunologic serology other than that included in the obligatory tests is relatively low. These tests more often yield false-positive rather than true-positive results and are of little use without PDCs pointing to specific immunologic disorders. Given the absence of specific symptoms in many patients and the relatively low cost of the test, investigation of cryoglobulins appears to be a valuable screening test in patients with FUO.

Multiple blood samples should be cultured in the laboratory long enough to ensure ample growth time for any fastidious organisms, such as HACEK organisms. It is critical to inform the laboratory of the intent to test for unusual organisms. Specialized media should be used when the history suggests uncommon microorganisms, such as *Histoplasma* or *Legionella*. Performing more than three blood cultures or more than one urine culture is useless in patients with FUO in the absence of PDCs (e.g., a high level of clinical suspicion of endocarditis). Repeating blood or urine cultures is useful only when previously cultured samples were collected during antibiotic treatment or within 1 week after its discontinuation. FUO with headache should prompt microbiologic examination of cerebrospinal fluid (CSF) for organisms including herpes simplex virus (especially type 2), *Cryptococcus neoformans*, and *Mycobacterium tuberculosis*. In central nervous system tuberculosis, the CSF typically has elevated protein and lowered glucose concentrations, with a mononuclear pleocytosis. CSF protein levels range from 100 to 500 mg/dL in most patients, the CSF glucose concentration is <45 mg/dL in 80% of cases, and the usual CSF cell count is between 100 and 500 cells/ $\mu$ L.

Microbiologic serology should not be included in the diagnostic workup of patients without PDCs for specific infections. A tuberculin skin test (TST) or interferon  $\gamma$  release assay (IGRA, QuantiFERON test) is included in the obligatory investigations, but it may yield false-negative results in patients with miliary tuberculosis, malnutrition, or immunosuppression. Although the IGRA is less influenced by prior vaccination with bacille Calmette-Guérin (BCG) or by infection with nontuberculous mycobacteria, its sensitivity is similar to that of the TST; a negative TST or IGRA therefore does not exclude a diagnosis of tuberculosis. Miliary tuberculosis is especially difficult to diagnose. Granulomatous disease in liver or bone marrow biopsy samples, for example, should always lead to a (re)consideration of this diagnosis. If miliary tuberculosis is suspected, liver biopsy for acid-fast smear, culture, and polymerase chain reaction probably still has the highest diagnostic yield;



**FIGURE 20-1** Structured approach to patients with FUO. ALT, alanine aminotransferase; AST, aspartate aminotransferase; CRP, C-reactive protein; ESR, erythrocyte sedimentation rate; FDG-PET/CT, <sup>18</sup>F-fluorodeoxyglucose positron emission tomography combined with low-dose CT; IGRA, interferon  $\gamma$  release assay; LDH, lactate dehydrogenase; NSAID, nonsteroidal anti-inflammatory drug; PDCs, potentially diagnostic clues (all localizing signs, symptoms, and abnormalities potentially pointing toward a diagnosis).

however, biopsies of bone marrow, lymph nodes, or other involved organs also can be considered.

The diagnostic yield of echocardiography, sinus radiography, radiologic or endoscopic evaluation of the gastrointestinal tract, and bronchoscopy is very low in the absence of PDCs. Therefore, these tests should not be used as screening procedures.

After identification of all PDCs retrieved from the history, physical examination, and obligatory tests, a limited list of the most probable diagnoses should be made. Since most investigations are

helpful only for patients who have PDCs for the diagnoses sought, further diagnostic procedures should be limited to specific investigations aimed at confirming or excluding diseases on this list. In FUO, the diagnostic pointers are numerous and diverse but may be missed on initial examination, often being detected only by a very careful examination performed subsequently. In the absence of PDCs, the history and physical examination should therefore be repeated regularly. One of the first steps should be to rule out factitious or fraudulent fever, particularly in patients without signs

of inflammation in laboratory tests. All medications, including nonprescription drugs and nutritional supplements, should be discontinued early in the evaluation to exclude drug fever. If fever persists beyond 72 h after discontinuation of the suspected drug, it is unlikely that this drug is the cause. In patients without PDCs or with only misleading PDCs, fundoscopy by an ophthalmologist may be useful in the early stage of the diagnostic workup to exclude retinal vasculitis. When the first-stage diagnostic tests do not lead to a diagnosis, <sup>18</sup>F-fluorodeoxyglucose (<sup>18</sup>F-FDG) positron emission tomography combined with computed tomography (PET/CT) or, if the former is not available, radiolabeled leukocyte scintigraphy should be performed, especially when the ESR or the CRP level is elevated.

**Recurrent Fever** In patients with recurrent fever, the diagnostic workup should consist of thorough history-taking, physical examination, and obligatory tests. The search for PDCs should be directed toward clues matching known recurrent syndromes (Table 20-3). Patients should be asked to return during a febrile episode so that the history, physical examination, and laboratory tests can be repeated during a symptomatic phase. Further diagnostic tests, such as PET/CT or scintigraphic imaging (see below), should be performed only during a febrile episode or when inflammatory parameters are abnormal because abnormalities may be absent between episodes. In patients with recurrent fever lasting >2 years, it is very unlikely that the fever is caused by infection or malignancy. Further diagnostic tests in that

direction should be considered only when PDCs for infections, vasculitis syndromes, or malignancy are present or when the patient's clinical condition is deteriorating.

**Fluorodeoxyglucose Positron Emission Tomography** <sup>18</sup>F-FDG PET/CT has become an established imaging procedure in FUO. FDG accumulates in tissues with a high rate of glycolysis, which occurs not only in malignant cells but also in activated leukocytes and thus permits the imaging of acute and chronic inflammatory processes. Compared with conventional scintigraphy (see below), FDG-PET/CT offers the advantages of higher resolution, greater sensitivity in chronic low-grade infections, and a high degree of accuracy in the central skeleton. Furthermore, vascular uptake of FDG is increased in patients with vasculitis (Fig. 20-2). The mechanisms responsible for FDG uptake do not allow differentiation among infection, sterile inflammation, and malignancy. However, since all of these disorders are causes of FUO, FDG-PET/CT can be used to guide additional diagnostic tests (e.g., targeted biopsies) that may yield the final diagnosis. It is important to realize that physiologic uptake of FDG may obscure pathologic foci in the brain, heart, bowel, kidneys, and bladder. FDG uptake in the heart, which obscures endocarditis, may be prevented by consumption of a low-carbohydrate diet before the PET investigation. In patients with fever, bone marrow uptake is frequently increased in a non-specific way due to cytokine activation, which upregulates glucose transporters in bone marrow cells.

TABLE 20-3 All Reported Causes of Recurrent Fever<sup>a</sup>

#### Infections

Bacterial, nonspecific	Apical granuloma, diverticulitis, prostatitis, recurrent bacteremia caused by colonic neoplasia or persistent focal infection, recurrent cellulitis, recurrent cholangitis or cholecystitis, recurrent pneumonia, recurrent sinusitis, recurrent urinary tract infection
Bacterial, specific	Bartonellosis, brucellosis, chronic gonococcemia, chronic meningococcemia, louse-borne relapsing fever ( <i>Borrelia recurrentis</i> ), melioidosis ( <i>Pseudomonas pseudomallei</i> ), Q fever ( <i>Coxiella burnetii</i> ), salmonellosis, <i>Spirillum minor</i> infection, <i>Streptobacillus moniliformis</i> infection, syphilis, tick-borne relapsing fever ( <i>Borrelia duttonii</i> ), tularemia, Whipple's disease ( <i>Tropheryma whipplei</i> ), yersiniosis
Fungal	Coccidioidomycosis, histoplasmosis, paracoccidioidomycosis
Parasitic	Babesiosis, malaria, toxoplasmosis, trypanosomiasis, visceral leishmaniasis
Viral	Cytomegalovirus infection, Epstein-Barr virus infection, herpes simplex

#### Noninfectious Inflammatory Diseases

Systemic rheumatic and autoimmune diseases	Ankylosing spondylitis, antiphospholipid syndrome, autoimmune hemolytic anemia, autoimmune hepatitis, Behcet's disease, cryoglobulinemia, gout, polymyositis, pseudogout, reactive arthritis, relapsing polychondritis, systemic lupus erythematosus
Vasculitis	Churg-Strauss syndrome, giant cell vasculitis/polymyalgia rheumatica, hypersensitivity vasculitis, polyarteritis nodosa, urticarial vasculitis
Granulomatous diseases	Idiopathic granulomatous hepatitis, sarcoidosis
Autoinflammatory syndromes	Adult-onset Still's disease, Blau syndrome, CANDLE (chronic atypical neutrophilic dermatitis with lipodystrophy and elevated temperature syndrome), CAPS <sup>b</sup> (cryopyrin-associated periodic syndrome), CRMO (chronic recurrent multifocal osteomyelitis), Crohn's disease, DIRA (deficiency of the interleukin 1 receptor antagonist), familial Mediterranean fever, hemophagocytic syndrome, hyper-IgD syndrome (HIDS, also known as mevalonate kinase deficiency), juvenile idiopathic arthritis, NLRC4-activating mutations, PAPA syndrome (pyogenic sterile arthritis, pyoderma gangrenosum, and acne), PFAPA syndrome (periodic fever, aphthous stomatitis, pharyngitis, adenitis), recurrent idiopathic pericarditis, SAPHO (synovitis, acne, pustulosis, hyperostosis, osteomyelitis), SAVI (stimulator of interferon genes [STING]-associated vasculopathy with onset in infancy), Schnitzler syndrome, TRAPS (tumor necrosis factor receptor-associated periodic syndrome)

#### Neoplasms

Angioimmunoblastic lymphoma, Castleman's disease, colon carcinoma, craniopharyngioma, Hodgkin's disease, malignant histiocytosis, mesothelioma, non-Hodgkin's lymphoma
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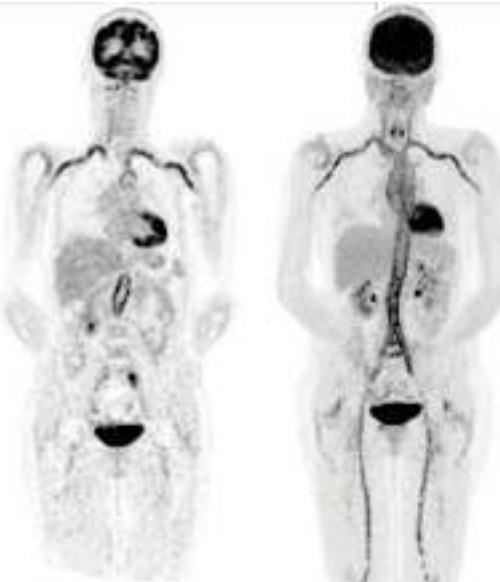
#### Miscellaneous Causes

Adrenal insufficiency, aortic-enteral fistula, aseptic meningitis (Mollaret's syndrome), atrial myxoma, brewer's yeast ingestion, cholesterol emboli, cyclic neutropenia, drug fever, extrinsic allergic alveolitis, Fabry's disease, factitious disease, fraudulent fever, Gaucher disease, hypersensitivity pneumonitis, hypertriglyceridemia, hypothalamic hypopituitarism, inflammatory pseudotumor, metal fume fever, milk protein allergy, polymer fume fever, pulmonary embolism, sclerosing mesenteritis
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#### Thermoregulatory Disorders

Central	Hypothalamic dysfunction
Peripheral	Anhidrotic ectodermal dysplasia, exercise-induced hyperthermia, pheochromocytoma

<sup>a</sup>This table includes all causes of recurrent fever that have been described in the literature. <sup>b</sup>CAPS includes chronic infantile neurologic cutaneous and articular syndrome (CINCA, also known as neonatal-onset multisystem inflammatory disease, or NOMID), familial cold autoinflammatory syndrome (FCAS), and Muckle-Wells syndrome.



**FIGURE 20-2** FDG-PET/CT in a patient with FUO. This 72-year-old woman presented with a low-grade fever and severe fatigue of almost 3 months' duration. An extensive history was taken, but the patient had no specific complaints and had not traveled recently. Her previous history was unremarkable, and she did not use any drugs. Physical examination, including palpation of the temporal arteries, yielded completely normal results. Laboratory examination showed normocytic anemia, a C-reactive protein level of 43 mg/L, an erythrocyte sedimentation rate of 87 mm/h, and mild hypoalbuminemia. Results of the other obligatory tests were all normal. Since there were no potentially diagnostic clues, FDG-PET/CT was performed. This test showed increased FDG uptake in all major arteries (carotid, jugular, and subclavian arteries; thoracic and abdominal aorta; iliac, femoral, and popliteal arteries) and in the soft tissue around the shoulders, hips, and knees—findings compatible with large-vessel vasculitis and polymyalgia rheumatica. Within 1 week after the initiation of treatment with prednisone (60 mg once daily), the patient completely recovered. After 1 month, the prednisone dose was slowly tapered.

In recent years, many cohort studies and several meta-analyses have focused on the diagnostic yield of PET and PET/CT in FUO. These studies are highly variable in terms of the selection of patients, the follow-up, and the selection of a gold-standard reference. Indirect comparisons of test performance suggested that FDG-PET/CT outperformed stand-alone FDG-PET, gallium scintigraphy, and leukocyte scintigraphy. Similarly, indirect comparisons of diagnostic yield suggested that FDG-PET/CT was more likely than alternative tests to correctly identify the cause of FUO. Meta-analyses report a high diagnostic yield for PET and PET/CT in the workup of FUO patients, with pooled sensitivity and specificity figures of ~85% and ~50%, respectively, and a total diagnostic yield of ~50% for PET/CT and ~40% for PET.

As many patients with FUO present with periodic fever, correct timing of PET/CT increases its diagnostic value. Few studies on the use of biomarkers such as elevated CRP or ESR for a contributory outcome of PET/CT have been performed. When both CRP and ESR are normal at the time of FDG-PET/CT, outcome may only be contributory when a patient does have fever at the time of the scan.

Although PET/CT and other scintigraphic techniques do not directly provide a definitive diagnosis (with the exception of some patients with, for instance, large vessel vasculitis), they often identify the anatomic location of a particular ongoing metabolic process. With the help of other techniques such as biopsy and culture, a timely diagnosis and treatment can be facilitated. Pathologic FDG uptake is quickly eradicated by treatment with glucocorticoids in many diseases, including vasculitis and lymphoma; therefore, glucocorticoid use should be stopped or postponed until after FDG-PET/CT is performed.

FDG-PET/CT is a relatively expensive procedure whose availability is still limited compared with that of CT and conventional scintigraphy. Nevertheless, FDG-PET/CT can be cost-effective in the FUO diagnostic workup if used at an early stage, helping to

establish an early diagnosis, reducing days of hospitalization for diagnostic purposes, and obviating unnecessary and unhelpful tests. When FDG-PET/CT has been made under the right conditions (i.e., when elevated CRP or ESR or fever were present during the scan) but has not contributed to the final diagnosis, repeating PET/CT is probably of little value, unless new signs or symptoms appear.

#### *Conventional scintigraphic imaging other than PET/CT*

Conventional scintigraphic methods used in clinical practice are <sup>67</sup>Ga-citrate scintigraphy and <sup>111</sup>In- or <sup>99m</sup>Tc-labeled leukocyte scintigraphy. Sensitivity and specificity of conventional scintigraphic studies are lower than for PET/CT: the diagnostic yield of gallium scintigraphy ranges from 21% to 54%, and on average the location of a source of fever can correctly be localized in approximately one-third of patients. The diagnostic value of leukocyte scintigraphy ranges from 8% to 31%, and overall the cause of FUO can correctly be identified in one-fifth of patients. When PET/CT is not available, these techniques are the only alternative.

#### **LATER-STAGE DIAGNOSTIC TESTS**

In some cases, more invasive tests are appropriate. Abnormalities found with imaging often need to be confirmed by pathology and/or culture of biopsy specimens. If lymphadenopathy is found, lymph node biopsy is necessary, even when the affected lymph nodes are hard to reach or when previous biopsies were inconclusive. In the case of skin lesions, skin biopsy should be undertaken.

If no diagnosis is reached despite PET/CT and PDC-driven histologic investigations or culture, second-stage screening diagnostic tests should be considered (Fig. 20-1). In three studies, the diagnostic yield of screening chest and abdominal CT in patients with FUO was ~20%. The specificity of chest CT was ~80%, but that of abdominal CT varied between 63% and 80%. Despite the

relatively limited specificity of abdominal CT and the probably limited additional value of chest CT after normal FDG-PET/CT, chest and abdominal CT may be used as screening procedures at a later stage of the diagnostic protocol because of their noninvasive nature and high sensitivity. Bone marrow aspiration is seldom useful in the absence of PDCs for bone marrow disorders. With addition of FDG-PET/CT, which is highly sensitive in detecting lymphoma, carcinoma, and osteomyelitis, the value of bone marrow biopsy as a screening procedure is probably further reduced. Several studies have shown a high prevalence of giant cell arteritis among patients with FUO, with rates up to 17% among elderly patients. Giant cell arteritis often involves large arteries and in most cases can be diagnosed by FDG-PET/CT. However, temporal artery biopsy is still recommended for patients ≥55 years of age in a later stage of the diagnostic protocol: FDG-PET/CT will not be useful in vasculitis limited to the temporal arteries because of the small diameter of these vessels and the high levels of FDG uptake in the brain. In the past, liver biopsies were often performed as a screening procedure in patients with FUO. In each of two studies, liver biopsy as part of the later stage of a screening diagnostic protocol was helpful in only one patient. Moreover, abnormal liver tests are not predictive of a diagnostic liver biopsy in FUO. Liver biopsy is an invasive procedure that carries the possibility of complications and even death. Therefore, it should not be used for screening purposes in patients with FUO except in those with PDCs for liver disease or miliary tuberculosis.

In patients with unexplained fever after all of the above procedures, the last steps in the diagnostic workup—with only a marginal diagnostic yield—come at an extraordinarily high cost in terms of both expense and discomfort for the patient. Repetition of a thorough history-taking and physical examination and review of laboratory results and imaging studies (including those from other hospitals) are recommended. Diagnostic delay often results from a failure to recognize PDCs in the available information. In these patients with persisting FUO, waiting for new PDCs to appear probably is better than ordering more screening investigations. Only when a patient's condition deteriorates without providing new PDCs should a further diagnostic workup be performed.

#### SECOND OPINION IN AN EXPERT CENTER

When despite the workup described above no explanation for FUO is found, second opinion in an expert center on FUO should be considered. The single study on the value of second opinion in FUO reported that in 57.3% of patients with unexplained FUO, a diagnosis could be found in an expert center. Additionally, of all patients who remained without a diagnosis even after second opinion, 10.9% became fever-free upon empirical treatment, adding up to a beneficial outcome in 68.2% of patients.

## TREATMENT

### Fever of Unknown Origin

Empirical therapeutic trials with antibiotics, glucocorticoids, or antituberculous agents should be avoided in FUO except when a patient's condition is rapidly deteriorating after the aforementioned diagnostic tests have failed to provide a definite diagnosis.

#### ANTIBIOTICS AND ANTITUBERCULOUS THERAPY

Antibiotic or antituberculous therapy may irrevocably diminish the ability to culture fastidious bacteria or mycobacteria. However, hemodynamic instability or neutropenia is a good indication for empirical antibiotic therapy. If the TST or IGRA is positive or if granulomatous disease is present with anergy and sarcoidosis seems unlikely, a trial of therapy for tuberculosis should be started. Especially in miliary tuberculosis, it may be very difficult to obtain

a rapid diagnosis. If the fever does not respond after 6 weeks of empirical antituberculous treatment, another diagnosis should be considered.

#### COLCHICINE, NONSTEROIDAL ANTI-INFLAMMATORY DRUGS, AND GLUCOCORTICOIDS

Colchicine is highly effective in preventing attacks of familial Mediterranean fever (FMF) but is not always effective once an attack is well under way. When FMF is suspected, the response to colchicine is not a completely reliable diagnostic tool in the acute phase, but with colchicine treatment most patients show remarkable improvements in the frequency and severity of subsequent febrile episodes within weeks to months. Therefore, colchicine may be tried in patients with features compatible with FMF, especially when these patients originate from a high-prevalence region.

If the fever persists and the source remains elusive after completion of the later-stage investigations, supportive treatment with nonsteroidal anti-inflammatory drugs (NSAIDs) can be helpful. The response of adult-onset Still's disease to NSAIDs is dramatic in some cases.

The effects of glucocorticoids on giant cell arteritis and polymyalgia rheumatica are equally impressive. Early empirical trials with glucocorticoids, however, decrease the chances of reaching a diagnosis for which more specific and sometimes life-saving treatment might be more appropriate, such as malignant lymphoma. The ability of NSAIDs and glucocorticoids to mask fever while permitting the spread of infection or lymphoma dictates that their use should be avoided unless infectious diseases and malignant lymphoma have been largely ruled out and inflammatory disease is probable and is likely to be debilitating or threatening.

#### INTERLEUKIN 1 INHIBITION

Interleukin (IL) 1 is a key cytokine in local and systemic inflammation and the febrile response. The availability of specific IL-1-targeting agents has revealed a pathologic role of IL-1-mediated inflammation in a growing list of diseases. Anakinra, a recombinant form of the naturally occurring IL-1 receptor antagonist (IL-1Ra), blocks the activity of both IL-1 $\alpha$  and IL-1 $\beta$ . Anakinra is extremely effective in the treatment of many autoinflammatory syndromes, such as FMF, cryopyrin-associated periodic syndrome, tumor necrosis factor receptor-associated periodic syndrome, mevalonate kinase deficiency (hyper IgD syndrome), Schnitzler syndrome, and adult onset Still's disease. There are many other chronic inflammatory disorders in which anti-IL-1 therapy is highly effective. A therapeutic trial with anakinra can be considered in patients whose FUO has not been diagnosed after later-stage diagnostic tests. Although most chronic inflammatory conditions without a known basis can be controlled with glucocorticoids, monotherapy with IL-1 blockade can provide improved control without the metabolic, immunologic, and gastrointestinal side effects of glucocorticoid administration.

#### PROGNOSIS

In patients in whom FUO remains unexplained, prognosis is favorable. Two large studies on mortality in these patients have been performed. The first study included 436 patients of whom 168 remained without a diagnosis. Of these, 4 (2.4%) died during follow-up. All 4 patients died during the index admission, and in 2 of them a diagnosis was made upon autopsy (1 had intravascular lymphoma and 1 had bilateral pneumonia). The second study included 131 patients with unexplained FUO. Of these patients, 9 (6.9%) died during a median follow-up of 5 years. In 6 of these patients the cause of death was known, and in 5 of them death was considered unrelated to the febrile disease. Overall, FUO-related mortality rates have continuously declined over recent decades. The majority of fevers are caused by treatable diseases, and the risk of death related to FUO is, of course, dependent on the underlying disease.

## 21 Syncope

Roy Freeman



Syncope is a transient, self-limited loss of consciousness due to acute global impairment of cerebral blood flow. The onset is rapid, duration brief, and recovery spontaneous and complete. Other causes of transient loss of consciousness need to be distinguished from syncope; these include seizures, vertebrobasilar ischemia, hypoxemia, and hypoglycemia. A syncopal prodrome (*presyncope*) is common, although loss of consciousness may occur without any warning symptoms. Typical presyncopal symptoms include lightheadedness or faintness, dizziness, weakness, fatigue, and visual and auditory disturbances. The causes of syncope can be divided into three general categories: (1) neurally mediated syncope (also called *reflex or vasovagal syncope*), (2) orthostatic hypotension, and (3) cardiac syncope.

Neurally mediated syncope comprises a heterogeneous group of functional disorders that are characterized by a transient change in the reflexes responsible for maintaining cardiovascular homeostasis. Episodic vasodilation (or loss of vasoconstrictor tone), decreased cardiac output, and bradycardia occur in varying combinations, resulting in temporary failure of blood pressure control. In contrast, in patients with orthostatic hypotension due to autonomic failure, these cardiovascular homeostatic reflexes are chronically impaired. Cardiac syncope may be due to arrhythmias or structural cardiac diseases that cause a decrease in cardiac output. The clinical features, underlying pathophysiological mechanisms, therapeutic interventions, and prognoses differ markedly among these three causes.

### EPIDEMIOLOGY AND NATURAL HISTORY

Syncope is a common presenting problem, accounting for ~3% of all emergency department (ED) visits and 1% of all hospital admissions. The annual cost for syncope-related hospitalization in the United States is ~\$2.4 billion. Syncope has a lifetime cumulative incidence of up to 35% in the general population. The peak incidence in the young occurs between ages 10 and 30 years, with a median peak around 15 years. Neurally mediated syncope is the etiology in the vast majority of these cases. In older adults, there is a sharp rise in the incidence of syncope after 70 years of age.

In population-based studies, neurally mediated syncope is the most common cause of syncope. The incidence is higher in women than men. In young subjects, there is often a family history in first-degree relatives. Cardiovascular disease due to structural disease or arrhythmias is the next most common cause in most series, particularly in ED

**TABLE 21-1** High-Risk Features Indicating Hospitalization or Intensive Evaluation of Syncope

Chest pain suggesting coronary ischemia
Features of congestive heart failure
Moderate or severe valvular disease
Moderate or severe structural cardiac disease
Electrocardiographic features of ischemia
History of ventricular arrhythmias
Prolonged QT interval (>500 ms)
Repetitive sinoatrial block or sinus pauses
Persistent sinus bradycardia
Bi- or trifascicular block or intraventricular conduction delay with QRS duration ≥120 ms
Atrial fibrillation
Nonsustained ventricular tachycardia
Family history of sudden death
Preexcitation syndromes
Brugada pattern on ECG
Palpitations at time of syncope
Syncope at rest or during exercise

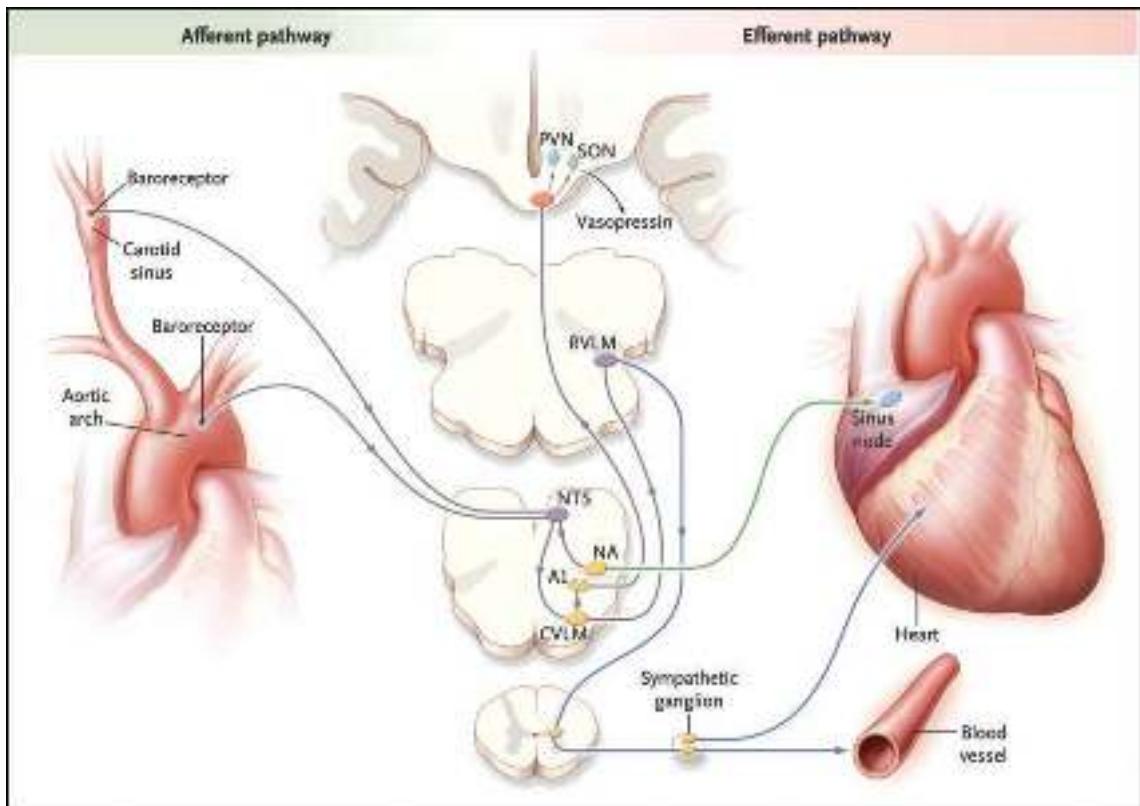
settings and in older patients. Orthostatic hypotension also increases in prevalence with age because of the reduced baroreflex responsiveness, decreased cardiac compliance, and attenuation of the vestibulosympathetic reflex associated with aging. Other contributors are reduced fluid intake and vasoactive medications, also more likely in this age group. In the elderly, orthostatic hypotension is more common in institutionalized than community-dwelling individuals, most likely explained by a greater prevalence of predisposing neurologic disorders, physiologic impairment, and vasoactive medication use among institutionalized patients.

Syncope of noncardiac and unexplained origin in younger individuals has an excellent prognosis; life expectancy is unaffected. By contrast, syncope due to a cardiac cause, either structural heart disease or a primary arrhythmic disorder, is associated with an increased risk of sudden cardiac death and mortality from other causes. Similarly, the mortality rate is increased in individuals with syncope due to orthostatic hypotension related to age and the associated comorbid conditions (Table 21-1). The likelihood of hospitalization and mortality risk are higher in older adults.

### PATHOPHYSIOLOGY

The upright posture imposes a unique physiologic stress upon humans; most, although not all, syncopal episodes occur from a standing position. Standing results in pooling of 500–1000 mL of blood in the lower extremities, buttocks, and splanchnic circulation. The dependent pooling leads to a decrease in venous return to the heart and reduced ventricular filling that result in diminished cardiac output and blood pressure. These hemodynamic changes provoke a compensatory reflex response, initiated by the baroreceptors in the carotid sinus and aortic arch, resulting in increased sympathetic outflow and decreased vagal nerve activity (Fig. 21-1). The reflex increases peripheral resistance, venous return to the heart, and cardiac output and thus limits the fall in blood pressure. If this response fails, as is the case chronically in orthostatic hypotension and transiently in neurally mediated syncope, hypotension and cerebral hypoperfusion occur.

Syncope is a consequence of global cerebral hypoperfusion and thus represents a failure of cerebral blood flow autoregulatory mechanisms. Myogenic factors, local metabolites, and to a lesser extent autonomic neurovascular control are responsible for the autoregulation of cerebral blood flow (Chap. 307). The latency of the autoregulatory response is 5–10 s. Typically, cerebral blood flow ranges from 50–60 mL/min per 100 g brain tissue and remains relatively constant over perfusion pressures ranging from 50–150 mmHg. Cessation of blood flow for 6–8 s



**FIGURE 21-1** The baroreflex. A decrease in arterial pressure unloads the baroreceptors—the terminals of afferent fibers of the glossopharyngeal and vagus nerves—that are situated in the carotid sinus and aortic arch. This leads to a reduction in the afferent impulses that are relayed from these mechanoreceptors through the glossopharyngeal and vagus nerves to the nucleus of the tractus solitarius (NTS) in the dorsomedial medulla. The reduced baroreceptor afferent activity produces a decrease in vagal nerve input to the sinus node that is mediated via connections of the NTS to the nucleus ambiguus (NA). There is an increase in sympathetic efferent activity that is mediated by the NTS projections to the caudal ventrolateral medulla (CVLM) (an excitatory pathway) and from there to the rostral ventrolateral medulla (RVLM) (an inhibitory pathway). The activation of RVLM presynaptic neurons in response to hypotension is thus predominantly due to disinhibition. In response to a sustained fall in blood pressure, vasopressin release is mediated by projections from the A1 noradrenergic cell group in the ventrolateral medulla. This projection activates vasopressin-synthesizing neurons in the magnocellular portion of the paraventricular nucleus (PVN) and the supraoptic nucleus (SON) of the hypothalamus. Blue denotes sympathetic neurons, and green denotes parasympathetic neurons. (From R Freeman: Neurogenic orthostatic hypotension. *N Engl J Med* 358:615, 2008. Copyright © 2008 Massachusetts Medical Society. Reprinted with permission.)

will result in loss of consciousness, while impairment of consciousness ensues when blood flow decreases to 25 mL/min per 100 g brain tissue.

From the clinical standpoint, a fall in systemic systolic blood pressure to ~50 mmHg or lower will result in syncope. A decrease in cardiac output and/or systemic vascular resistance—the determinants of blood pressure—thus underlies the pathophysiology of syncope. Common causes of impaired cardiac output include decreased effective circulating blood volume, increased thoracic pressure, massive pulmonary embolus, cardiac brady- and tachyarrhythmias, valvular heart disease, and myocardial dysfunction. Systemic vascular resistance may be decreased by central and peripheral autonomic nervous system diseases, sympatholytic medications, and transiently during neurally mediated syncope. Increased cerebral vascular resistance, most frequently due to hypocapnia induced by hyperventilation, may also contribute to the pathophysiology of syncope.

Two patterns of electroencephalographic (EEG) changes occur in syncopal subjects. The first is a “slow-flat-slow” pattern (Fig. 21-2) in which normal background activity is replaced with high-amplitude slow delta waves. This is followed by sudden flattening of the EEG—a cessation or attenuation of cortical activity—followed by the return of slow waves, and then normal activity. A second pattern, the “slow pattern,” is characterized by increasing and decreasing slow wave activity only. The EEG flattening that occurs in the slow-flat-slow pattern is a marker of more severe cerebral hypoperfusion. Despite the presence of myoclonic movements and other motor activity during some syncopal events, EEG seizure discharges are not detected.

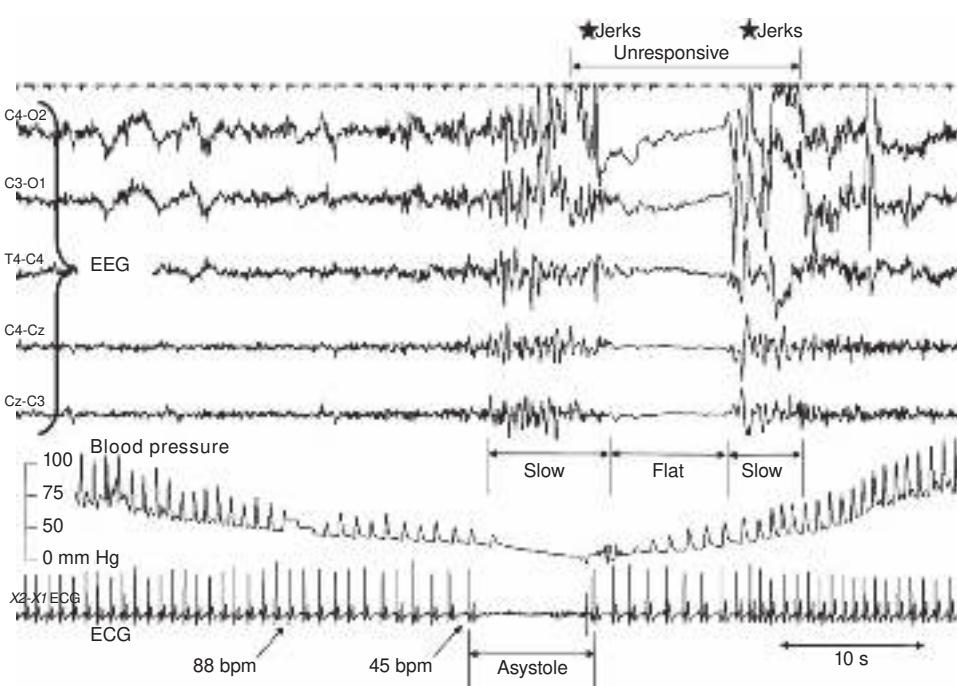
## CLASSIFICATION

### ■ NEURALLY MEDIATED SYNCOPE

Neurally mediated (reflex; vasovagal) syncope is the final pathway of a complex central and peripheral nervous system reflex arc. There is a transient change in autonomic efferent activity with increased parasympathetic outflow, plus sympathoinhibition, resulting in bradycardia, vasodilation, and/or reduced vasoconstrictor tone (the vasodepressor response) and reduced cardiac output. The resulting fall in systemic blood pressure can then reduce cerebral blood flow to below the compensatory limits of autoregulation (Fig. 21-3). In order to develop neurally mediated syncope, a functioning autonomic nervous system is necessary, in contrast to syncope resulting from autonomic failure (discussed below).

Multiple triggers of the afferent limb of the reflex arc can result in neurally mediated syncope. In some situations, these can be clearly defined, e.g., orthostatic stress and stimulus of the carotid sinus, the gastrointestinal tract, or the bladder. Often, however, the trigger is less easily recognized and the cause is multifactorial. Under these circumstances, it is likely that different afferent pathways converge on the central autonomic network within the medulla that integrates the neural impulses and mediates the vasodepressor-bradycardic response.

**Classification of Neurally Mediated Syncope** Neurally mediated syncope may be subdivided based on the afferent pathway and provocative trigger. Vasovagal syncope (the common faint) is provoked

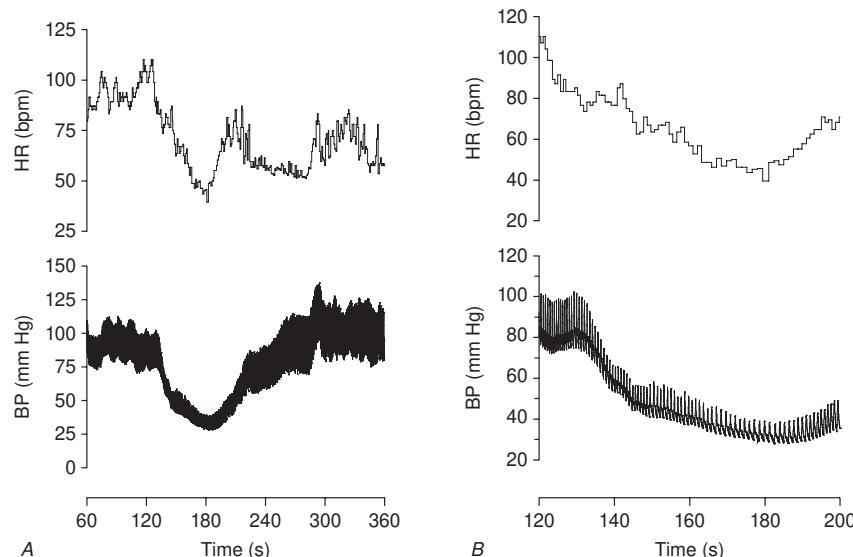


**FIGURE 21-2** The electroencephalogram (EEG) in vasovagal syncope. A 1-min segment of a tilt-table test with typical vasovagal syncope demonstrating the “slow-flat-slow” EEG pattern. Finger beat-to-beat blood pressure, electrocardiogram (ECG), and selected EEG channels are shown. EEG slowing starts when systolic blood pressure drops to ~50 mmHg; heart rate is then ~45 beats/min (bpm). Asystole occurred, lasting about 8 s. The EEG flattens for a similar period, but with a delay. A transient loss of consciousness, lasting 14 s, was observed. There were muscle jerks just before and just after the flat period of the EEG. (From W Wieling et al: Symptoms and signs of syncope: a review of the link between physiology and clinical clues. *Brain* 132:2630, 2009. Reprinted (and translated) by permission of Oxford University Press on behalf of the Guarantors of Brain.)

by intense emotion, pain, and/or orthostatic stress, whereas the situational reflex syncopes have specific localized stimuli that provoke the reflex vasodilation and bradycardia that leads to syncope. The underlying mechanisms have been identified and pathophysiology delineated for most of these situational reflex syncopes. The afferent trigger may originate in the pulmonary system, gastrointestinal system, urogenital system, heart, and carotid sinus in the carotid artery (Table 21-2). Hyperventilation leading to hypocapnia and cerebral vasoconstriction, and raised intrathoracic pressure that impairs venous return to the

heart, play a central role in many of the situational reflex syncopes. The afferent pathway of the reflex arc differs among these disorders, but the efferent response via the vagus and sympathetic pathways is similar.

Alternately, neurally mediated syncope may be subdivided based on the predominant efferent pathway. Vasodepressor syncope describes syncope predominantly due to efferent, sympathetic, vasoconstrictor failure; cardioinhibitory syncope describes syncope predominantly associated with bradycardia or asystole due to increased vagal outflow;



**FIGURE 21-3** A. The paroxysmal hypotensive-bradycardic response that is characteristic of neurally mediated syncope. Noninvasive beat-to-beat blood pressure and heart rate are shown >5 min (from 60 to 360 s) of an upright tilt on a tilt table. B. The same tracing expanded to show 80 s of the episode (from 80 to 200 s). BP, blood pressure; bpm, beats per minute; HR, heart rate.

TABLE 21-2 Causes of Syncope

## A. Neurally Mediated Syncope

## Vasovagal syncope

Provoked fear, pain, anxiety, intense emotion, sight of blood, unpleasant sights and odors, orthostatic stress

## Situational reflex syncope

## Pulmonary

Cough syncope, wind instrument player's syncope, weightlifter's syncope, "mess trick"<sup>a</sup> and "fainting lark,"<sup>b</sup> sneeze syncope, airway instrumentation

## Urogenital

Postmicturition syncope, urogenital tract instrumentation, prostatic massage

## Gastrointestinal

Swallow syncope, glossopharyngeal neuralgia, esophageal stimulation, gastrointestinal tract instrumentation, rectal examination, defecation syncope

## Cardiac

Bezold-Jarisch reflex, cardiac outflow obstruction

## Carotid sinus

Carotid sinus sensitivity, carotid sinus massage

## Ocular

Ocular pressure, ocular examination, ocular surgery

## B. Orthostatic Hypotension

Primary autonomic failure due to idiopathic central and peripheral neurodegenerative diseases—the "synucleinopathies"

## Lewy body diseases

Parkinson's disease

Lewy body dementia

Pure autonomic failure

## Multiple system atrophy (Shy-Drager syndrome)

Secondary autonomic failure due to autonomic peripheral neuropathies

## Diabetes

Hereditary amyloidosis (familial amyloid polyneuropathy)

Primary amyloidosis (AL amyloidosis; immunoglobulin light chain associated)

Hereditary sensory and autonomic neuropathies (HSAN) (especially type III—familial dysautonomia)

Idiopathic immune-mediated autonomic neuropathy

Autoimmune autonomic ganglionopathy

Sjögren's syndrome

Paraneoplastic autonomic neuropathy

HIV neuropathy

Postprandial hypotension

Iatrogenic (drug-induced)

Volume depletion

## C. Cardiac Syncope

## Arrhythmias

Sinus node dysfunction

Atrioventricular dysfunction

Supraventricular tachycardias

Ventricular tachycardias

Inherited channelopathies

Cardiac structural disease

Valvular disease

Myocardial ischemia

Obstructive and other cardiomyopathies

Atrial myxoma

Pericardial effusions and tamponade

and mixed syncope describes syncope in which there are both vagal and sympathetic reflex changes.

**Features of Neurally Mediated Syncope** In addition to symptoms of orthostatic intolerance such as dizziness, lightheadedness, and fatigue, premonitory features of autonomic activation may be present in patients with neurally mediated syncope. These include diaphoresis, pallor, palpitations, nausea, hyperventilation, and yawning. During the syncopal event, proximal and distal myoclonus (typically arrhythmic and multifocal) may occur, raising the possibility of a seizure. The eyes typically remain open and usually deviate upward. Pupils are usually dilated. Roving eye movements may occur. Grunting, moaning, snorting, and stertorous breathing may be present. Urinary incontinence may occur. Fecal incontinence is very rare, however. Postictal confusion is also rare, although visual and auditory hallucinations and near-death and out-of-body experiences are sometimes reported.

Although some predisposing factors and provocative stimuli are well established (for example, motionless upright posture, warm ambient temperature, intravascular volume depletion, alcohol ingestion, hypoxemia, anemia, pain, the sight of blood, venipuncture, and intense emotion), the underlying basis for the widely different thresholds for syncope among individuals exposed to the same provocative stimulus is not known. A genetic basis for neurally mediated syncope may exist; several studies have reported an increased incidence of syncope in first-degree relatives of fainters, but no gene or genetic marker has been identified, and environmental, social, and cultural factors have not been excluded by these studies.

## TREATMENT

## Neurally Mediated Syncope

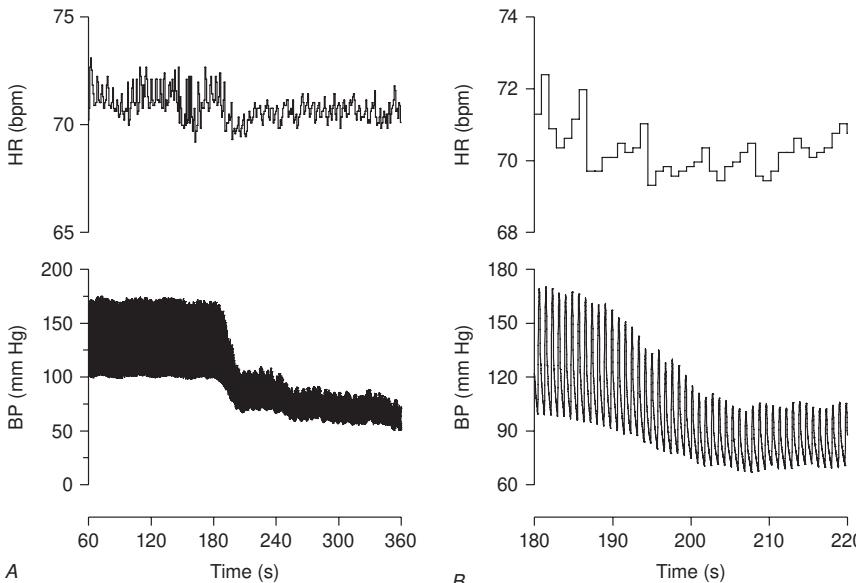
Reassurance, education, avoidance of provocative stimuli, and plasma volume expansion with fluid and salt are the cornerstones of the management of neurally mediated syncope. Isometric counterpressure maneuvers of the limbs (tensing of the abdominal and leg muscles, handgrip and arm tensing, and leg crossing) may raise blood pressure by increasing central blood volume and cardiac output. Of these, abdominal muscle tensing is the most effective. By maintaining pressure in the autoregulatory zone, these maneuvers, which may be particularly helpful in patients with a long prodrome, avoid or delay the onset of syncope. Randomized controlled trials support this intervention.

Fludrocortisone, vasoconstricting agents, and  $\beta$ -adrenoreceptor antagonists are widely used by experts to treat refractory patients, although there is no consistent evidence from randomized controlled trials for any pharmacotherapy to treat neurally mediated syncope. Because vasodilation, decreased central blood volume, decreased stroke volume and cardiac output are the dominant pathophysiologic syncopal mechanisms in most patients, use of a cardiac pacemaker is rarely beneficial. A systematic review of the literature examining whether cardiac pacing reduces risk of recurrent syncope and relevant clinical outcomes in adults with neurally mediated syncope, concluded that the existing evidence does not support the use of routine cardiac pacing. Possible exceptions are (1) older patients (>40 years), with at least three prior episodes associated with asystole (of at least 3 s associated with syncope or at least 6 s associated with presyncope) documented by an implantable loop recorder; and (2) patients with prominent cardioinhibition due to carotid sinus syndrome. In these patients, dual-chamber pacing may be helpful, although this continues to be an area of uncertainty.

## ■ ORTHOSTATIC HYPOTENSION

Orthostatic hypotension, defined as a reduction in systolic blood pressure of at least 20 mmHg or diastolic blood pressure of at least 10 mmHg after 3 min of standing or head-up tilt on a tilt table, is a manifestation of sympathetic vasoconstrictor (autonomic) failure (Fig. 21-4). In many (but not all) cases, there is no compensatory

<sup>a</sup>Hyperventilation for ~1 min, followed by sudden chest compression. <sup>b</sup>Hyperventilation (~20 breaths) in a squatting position, rapid rise to standing, then Valsalva maneuver.



**FIGURE 21-4** *A*, The gradual fall in blood pressure without a compensatory heart rate increase that is characteristic of orthostatic hypotension due to autonomic failure. Blood pressure and heart rate are shown >5 min (from 60 to 360 s) of an upright tilt on a tilt table. *B*, The same tracing expanded to show 40 s of the episode (from 180 to 220 s). BP, blood pressure; bpm, beats per minute; HR, heart rate.

increase in heart rate despite hypotension; with partial autonomic failure, heart rate may increase to some degree but is insufficient to maintain cardiac output. A variant of orthostatic hypotension is “delayed” orthostatic hypotension, which occurs beyond 3 min of standing; this may reflect a mild or early form of sympathetic adrenergic dysfunction. In some cases, orthostatic hypotension occurs within 15 s of standing (so-called initial orthostatic hypotension), a finding that may reflect a transient mismatch between cardiac output and peripheral vascular resistance and does not represent autonomic failure.

Characteristic symptoms of orthostatic hypotension include light-headedness, dizziness, and presyncope (near-faintness) occurring in response to sudden postural change. However, symptoms may be absent or nonspecific, such as generalized weakness, fatigue, cognitive slowing, leg buckling, or headache. Visual blurring may occur, likely due to retinal or occipital lobe ischemia. Neck pain, typically in the suboccipital posterior cervical, and shoulder region (the “coat-hanger headache”), most likely due to neck muscle ischemia, may be the only symptom. Patients may report orthostatic dyspnea (thought to reflect ventilation-perfusion mismatch due to inadequate perfusion of ventilated lung apices) or angina (attributed to impaired myocardial perfusion even with normal coronary arteries). Symptoms may be exacerbated by exertion, prolonged standing, increased ambient temperature, or meals. Syncope is usually preceded by warning symptoms, but may occur suddenly, suggesting the possibility of a seizure or cardiac cause. Some patients have profound decreases in blood pressure, sometimes without symptoms but placing them at risk for falls and injuries if the autoregulatory threshold is crossed with ensuing cerebral hypoperfusion.

Supine hypertension is common in patients with orthostatic hypotension due to autonomic failure, affecting >50% of patients in some series. Orthostatic hypotension may present after initiation of therapy for hypertension, and supine hypertension may follow treatment of orthostatic hypotension. However, in other cases, the association of the two conditions is unrelated to therapy; it may in part be explained by baroreflex dysfunction in the presence of residual sympathetic outflow, particularly in patients with central autonomic degeneration.

**Causes of Neurogenic Orthostatic Hypotension** Causes of neurogenic orthostatic hypotension include central and peripheral

autonomic nervous system dysfunction ([Chap. 440](#)). Autonomic dysfunction of other organ systems (including the bladder, bowels, sexual organs, and sudomotor system) of varying severity frequently accompanies orthostatic hypotension in these disorders (Table 21-2).

The primary autonomic degenerative disorders are multiple system atrophy (Shy-Drager syndrome; [Chap. 440](#)), Parkinson’s disease ([Chap. 435](#)), dementia with Lewy bodies ([Chap. 434](#)), and pure autonomic failure ([Chap. 440](#)). These are often grouped together as “synucleinopathies” due to the presence of  $\alpha$ -synuclein, a protein that aggregates predominantly in the cytoplasm of neurons in the Lewy body disorders (Parkinson’s disease, dementia with Lewy bodies, and pure autonomic failure) and in the glia in multiple system atrophy.

Peripheral autonomic dysfunction may also accompany small-fiber peripheral neuropathies such as those associated with diabetes mellitus, acquired and hereditary amyloidosis, immune-mediated neuropathies, and hereditary sensory and autonomic neuropathies (HSAN; particularly HSAN type III, familial dysautonomia)

([Chaps. 446 and 447](#)). Less frequently, orthostatic hypotension is associated with the peripheral neuropathies that accompany vitamin  $B_{12}$  deficiency, neurotoxin exposure, HIV and other infections, and porphyria.

Patients with autonomic failure and the elderly are susceptible to falls in blood pressure associated with meals. The magnitude of the blood pressure fall is exacerbated by large meals, meals high in carbohydrate, and alcohol intake. The mechanism of postprandial syncope is not fully elucidated.

Orthostatic hypotension is often iatrogenic. Drugs from several classes may lower peripheral resistance (e.g.,  $\alpha$ -adrenoreceptor antagonists used to treat hypertension and prostatic hypertrophy; antihypertensive agents of several classes; nitrates and other vasodilators; tricyclic agents and phenothiazines). Iatrogenic volume depletion due to diuresis and volume depletion due to medical causes (hemorrhage, vomiting, diarrhea, or decreased fluid intake) may also result in decreased effective circulatory volume, orthostatic hypotension, and syncope.

## TREATMENT

### Orthostatic Hypotension

The first step is to remove reversible causes—usually vasoactive medications (see [Table 440-6](#)). Next, nonpharmacologic interventions should be introduced. These include patient education regarding staged moves from supine to upright; warnings about the hypotensive effects of large meals; instructions about the isometric counterpressure maneuvers that increase intravascular pressure (see above); and raising the head of the bed to reduce supine hypertension and nocturnal diuresis. Intravascular volume should be expanded by increasing dietary fluid and salt. If these nonpharmacologic measures fail, pharmacologic intervention with fludrocortisone acetate and vasoconstricting agents such as midodrine and -dihydroxyphenylserine should be introduced. Some patients with intractable symptoms require additional therapy with supplementary agents that include pyridostigmine, atomoxetine, yohimbine, octreotide, desmopressin acetate (DDAVP), and erythropoietin ([Chap. 440](#)).

## CARDIAC SYNCOPE

Cardiac (or cardiovascular) syncope is caused by arrhythmias and structural heart disease. These may occur in combination because structural disease renders the heart more vulnerable to abnormal electrical activity.

**Arrhythmias** Bradyarrhythmias that cause syncope include those due to severe sinus node dysfunction (e.g., sinus arrest or sinoatrial block) and atrioventricular (AV) block (e.g., Mobitz type II, high-grade, and complete AV block). The bradyarrhythmias due to sinus node dysfunction are often associated with an atrial tachyarrhythmia, a disorder known as the tachycardia-bradycardia syndrome. A prolonged pause following the termination of a tachycardic episode is a frequent cause of syncope in patients with the tachycardia-bradycardia syndrome. Medications of several classes may also cause bradyarrhythmias of sufficient severity to cause syncope. Syncope due to bradycardia or asystole has been referred to as a Stokes-Adams attack.

Ventricular tachyarrhythmias frequently cause syncope. The likelihood of syncope with ventricular tachycardia is in part dependent on the ventricular rate; rates <200 beats/min are less likely to cause syncope. The compromised hemodynamic function during ventricular tachycardia is caused by ineffective ventricular contraction, reduced diastolic filling due to abbreviated filling periods, loss of AV synchrony, and concurrent myocardial ischemia.

Several disorders associated with cardiac electrophysiologic instability and arrhythmogenesis are due to mutations in ion channel subunit genes. These include the long QT syndrome, Brugada syndrome, and catecholaminergic polymorphic ventricular tachycardia. The long QT syndrome is a genetically heterogeneous disorder associated with prolonged cardiac repolarization and a predisposition to ventricular arrhythmias. Syncope and sudden death in patients with long QT syndrome result from a unique polymorphic ventricular tachycardia called *torsades des pointes* that degenerates into ventricular fibrillation. The long QT syndrome has been linked to genes encoding K<sup>+</sup> channel α-subunits, K<sup>+</sup> channel β-subunits, voltage-gated Na<sup>+</sup> channel, and a scaffolding protein, ankyrin B (ANK2). Brugada syndrome is characterized by idiopathic ventricular fibrillation in association with right ventricular electrocardiogram (ECG) abnormalities without structural heart disease. This disorder is also genetically heterogeneous, although it is most frequently linked to mutations in the Na<sup>+</sup> channel α-subunit, SCN5A. Catecholaminergic polymorphic tachycardia is an inherited, genetically heterogeneous disorder associated with exercise- or stress-induced ventricular arrhythmias, syncope, or sudden death. Acquired QT interval prolongation, most commonly due to drugs, may also result in ventricular arrhythmias and syncope. **These disorders are discussed in detail in Chap. 255.**

**Structural Disease** Structural heart disease (e.g., valvular disease, myocardial ischemia, hypertrophic and other cardiomyopathies, cardiac masses such as atrial myxoma, and pericardial effusions) may lead to syncope by compromising cardiac output. Structural disease may also contribute to other pathophysiologic mechanisms of syncope. For example, cardiac structural disease may predispose to arrhythmogenesis; aggressive treatment of cardiac failure with diuretics and/or vasodilators may lead to orthostatic hypotension; and inappropriate reflex vasodilation may occur with structural disorders such as aortic stenosis and hypertrophic cardiomyopathy, possibly provoked by increased ventricular contractility.

## TREATMENT

### Cardiac Syncope

Treatment of cardiac disease depends on the underlying disorder. Therapies for arrhythmias include cardiac pacing for sinus node disease and AV block, and ablation, antiarrhythmic drugs, and cardioverter-defibrillators for atrial and ventricular tachyarrhythmias. These disorders are best managed by physicians with specialized skills in this area.

## APPROACH TO THE PATIENT

### Syncope

#### DIFFERENTIAL DIAGNOSIS

Syncope is easily diagnosed when the characteristic features are present; however, several disorders with transient real or apparent loss of consciousness may create diagnostic confusion.

Generalized and partial seizures may be confused with syncope; however, there are a number of differentiating features. Whereas tonic-clonic movements are the hallmark of a generalized seizure, myoclonic and other movements also may occur in up to 90% of syncopal episodes. Myoclonic jerks associated with syncope may be multifocal or generalized. They are typically arrhythmic and of short duration (<30 s). Mild flexor and extensor posturing also may occur. Partial or partial-complex seizures with secondary generalization are usually preceded by an aura, commonly an unpleasant smell; fear; anxiety; abdominal discomfort; or other visceral sensations. These phenomena should be differentiated from the premonitory features of syncope.

Autonomic manifestations of seizures (autonomic epilepsy) may provide a more difficult diagnostic challenge. Autonomic seizures have cardiovascular, gastrointestinal, pulmonary, urogenital, pupillary, and cutaneous manifestations that are similar to the premonitory features of syncope. Furthermore, the cardiovascular manifestations of autonomic epilepsy include clinically significant tachycardias and bradycardias that may be of sufficient magnitude to cause loss of consciousness. The presence of accompanying non-autonomic auras may help differentiate these episodes from syncope.

Loss of consciousness associated with a seizure usually lasts >5 min and is associated with prolonged postictal drowsiness and disorientation, whereas reorientation occurs almost immediately after a syncopal event. Muscle aches may occur after both syncope and seizures, although they tend to last longer and be more severe following a seizure. Seizures, unlike syncope, are rarely provoked by emotions or pain. Incontinence of urine may occur with both seizures and syncope; however, fecal incontinence occurs very rarely with syncope.

Hypoglycemia may cause transient loss of consciousness, typically in individuals with type 1 or type 2 diabetes (*Chap. 403*) treated with insulin. The clinical features associated with impending or actual hypoglycemia include tremor, palpitations, anxiety, diaphoresis, hunger, and paresthesias. These symptoms are due to autonomic activation to counter the falling blood glucose. Hunger, in particular, is not a typical premonitory feature of syncope. Hypoglycemia also impairs neuronal function, leading to fatigue, weakness, dizziness, and cognitive and behavioral symptoms. Diagnostic difficulties may occur in individuals in strict glycemic control; repeated hypoglycemia impairs the counterregulatory response and leads to a loss of the characteristic warning symptoms that are the hallmark of hypoglycemia.

Patients with cataplexy (*Chap. 31*) experience an abrupt partial or complete loss of muscular tone triggered by strong emotions, typically anger or laughter. Unlike syncope, consciousness is maintained throughout the attacks, which typically last between 30 s and 2 min. There are no premonitory symptoms. Cataplexy occurs in 60%–75% of patients with narcolepsy.

The clinical interview and interrogation of eyewitnesses usually allow differentiation of syncope from falls due to vestibular dysfunction, cerebellar disease, extrapyramidal system dysfunction, and other gait disorders. A diagnosis of syncope can be particularly challenging in patients with dementia who experience repeated falls and are unable to provide a clear history of the episodes. If the fall is accompanied by head trauma, a postconcussive syndrome, amnesia for the precipitating events, and/or a loss or alteration of consciousness, this may also contribute to diagnostic difficulty.

Apparent loss of consciousness can be a manifestation of psychiatric disorders such as generalized anxiety, panic disorders, major

depression, and somatization disorder. These possibilities should be considered in individuals who faint frequently without prodromal symptoms. Such patients are rarely injured despite numerous falls. There are no clinically significant hemodynamic changes concurrent with these episodes. In contrast, transient loss of consciousness due to vasovagal syncope precipitated by fear, stress, anxiety, and emotional distress is accompanied by hypotension, bradycardia, or both.

### INITIAL EVALUATION

The goals of the initial evaluation are to determine whether the transient loss of consciousness was due to syncope; to identify the cause; and to assess risk for future episodes and serious harm (Table 21-1). The initial evaluation should include a detailed history, thorough questioning of eyewitnesses, and a complete physical and neurologic examination. Blood pressure and heart rate should be measured in the supine position and after 3 min of standing to determine whether orthostatic hypotension is present. High-risk features on history include: the new onset of chest discomfort, abdominal pain, shortness of breath or headache; syncope during exertion or while supine; sudden onset of palpitations followed by syncope; severe coronary artery or structural heart disease.

High-risk features on examination include an unexplained systolic BP of <90 mmHg; suggestion of gastrointestinal hemorrhage; persistent bradycardia (<40 beats/min); and an undiagnosed systolic murmur.

An ECG should be performed if there is suspicion of syncope due to an arrhythmia or underlying cardiac disease. Relevant electrocardiographic abnormalities include bradyarrhythmias or tachyarrhythmias, AV block, acute myocardial ischemia, old myocardial infarction, long QT<sub>c</sub>, and bundle branch block. This initial assessment will lead to the identification of a cause of syncope in ~50% of patients and also allows stratification of patients at risk for cardiac mortality.

**Laboratory Tests** Baseline laboratory blood tests are rarely helpful in identifying the cause of syncope. Blood tests should be performed when specific disorders, e.g., myocardial infarction, anemia, and secondary autonomic failure, are suspected (Table 21-2).

**Autonomic Nervous System Testing (Chap. 440)** Autonomic testing, including tilt-table testing, can be performed in specialized centers. Autonomic testing is helpful to uncover objective evidence of autonomic failure and also to demonstrate a predisposition to neurally mediated syncope. Autonomic testing includes assessments of parasympathetic autonomic nervous system function (e.g., heart rate variability to deep respiration and a Valsalva maneuver), sympathetic cholinergic function (e.g., thermoregulatory sweat response and quantitative sudomotor axon reflex test), and sympathetic adrenergic function (e.g., blood pressure response to a Valsalva maneuver and a tilt-table test with beat-to-beat blood pressure measurement). The hemodynamic abnormalities demonstrated on the tilt-table test (Figs. 21-3 and 21-4) may be useful in distinguishing orthostatic hypotension due to autonomic failure from the hypotensive bradycardic response of neurally mediated syncope. Similarly, the tilt-table test may help identify patients with syncope due to immediate or delayed orthostatic hypotension.

Carotid sinus massage should be considered in patients with symptoms suggestive of carotid sinus syncope and in patients >40 years with recurrent syncope of unknown etiology. This test should only be carried out under continuous ECG and blood pressure monitoring and should be avoided in patients with carotid bruits, possible or known plaques, or stenosis.

**Cardiac Evaluation** ECG monitoring is indicated for patients with a high pretest probability of arrhythmia causing syncope. Patients should be monitored in the hospital if the likelihood of a life-threatening arrhythmia is high, e.g., patients with severe coronary artery or structural heart disease, nonsustained ventricular

tachycardia, supraventricular tachycardia, paroxysmal atrial fibrillation, trifascicular heart block, prolonged QT interval, Brugada syndrome ECG pattern, syncope during exertion, syncope while seated or supine, and family history of sudden cardiac death (Table 21-1). Outpatient Holter monitoring is recommended for patients who experience frequent syncopal episodes (e.g., one or more per week), whereas loop recorders, which continually record and erase cardiac rhythm, are indicated for patients with suspected arrhythmias with low risk of sudden cardiac death. Loop recorders may be external (e.g., for evaluation of episodes that occur at a frequency of >1 per month) or implantable (e.g., if syncope occurs less frequently).

Echocardiography should be performed in patients with a history of cardiac disease or if abnormalities are found on physical examination or the ECG. Echocardiographic diagnoses that may be responsible for syncope include aortic stenosis, hypertrophic cardiomyopathy, cardiac tumors, aortic dissection, and pericardial tamponade. Echocardiography also has a role in risk stratification based on the left ventricular ejection fraction.

Treadmill exercise testing with ECG and blood pressure monitoring should be performed in patients who have experienced syncope during or shortly after exercise. Treadmill testing may help identify exercise-induced arrhythmias (e.g., tachycardia-related AV block) and exercise-induced exaggerated vasodilation.

Electrophysiologic studies are indicated in patients with structural heart disease and ECG abnormalities in whom noninvasive investigations have failed to yield a diagnosis. Electrophysiologic studies have low sensitivity and specificity and should only be performed when a high pretest probability exists. Currently, these tests are rarely performed to evaluate patients with syncope.

**Psychiatric Evaluation** Screening for psychiatric disorders may be appropriate in patients with recurrent unexplained syncope episodes. Tilt-table testing, with demonstration of symptoms in the absence of hemodynamic change, may be useful in reproducing syncope in patients with suspected psychogenic syncope.

### FURTHER READING

- B M et al: 2018 ESC Guidelines for the diagnosis and management of syncope. Eur Heart J 39:1883, 2018.
- C WP et al: Electrodiagnostic assessment of the autonomic nervous system: a consensus statement endorsed by the American Autonomic Society, American Academy of Neurology, and the International Federation of Clinical Neurophysiology. Clin Neurophysiol 132:666, 2021.
- F R et al: Consensus statement on the definition of orthostatic hypotension, neurally mediated syncope and the postural tachycardia syndrome. Auton Neurosci 161:46, 2011.
- F R et al: Orthostatic Hypotension: JACC State-of-the-Art Review. J Am Coll Cardiol 72:1294, 2018.
- G CH et al: The recommendations of a consensus panel for the screening, diagnosis, and treatment of neurogenic orthostatic hypotension and associated supine hypertension. J Neurol 264:1567, 2017.
- S RS, R SR: Pacing and vasovagal syncope: back to our physiologic roots. Clin Auton Res 27:213, 2017.
- S WK et al: 2017 ACC/AHA/HRS Guideline for the Evaluation and Management of Patients With Syncope: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines and the Heart Rhythm Society. Circulation 136:e60, 2017.
- V PD et al: Pacing as a treatment for reflex-mediated (vasovagal, situational, or carotid sinus hypersensitivity) syncope: a systematic review for the 2017 ACC/AHA/HRS guideline for the evaluation and management of patients with syncope: A report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines and the Heart Rhythm Society. J Am Coll Cardiol 70:664, 2017.



Dizziness is an imprecise symptom used to describe a variety of common sensations that include vertigo, light-headedness, faintness, and imbalance. *Vertigo* refers to a sense of spinning or other motion that may be physiological, occurring during or after a sustained head rotation, or pathological, due to vestibular dysfunction. The term *light-headedness* is classically applied to presyncopal sensations resulting from brain hypoperfusion but as used by patients has little specificity, as it may also refer to other symptoms such as disequilibrium and imbalance. A challenge to diagnosis is that patients often have difficulty distinguishing among these various symptoms, and the words they choose do not reliably indicate the underlying etiology.

There are many causes of dizziness. Vestibular dizziness (vertigo or imbalance) may be due to peripheral disorders that affect the labyrinths or vestibular nerves, or it may result from disruption of central vestibular pathways. It may be paroxysmal or due to a fixed unilateral or bilateral vestibular deficit. Acute unilateral lesions cause vertigo due to a sudden imbalance in vestibular inputs from the two labyrinths. Bilateral lesions cause imbalance and instability of vision when the head moves (*oscillopsia*) due to loss of normal vestibular reflexes.

Presyncopal dizziness occurs when cardiac dysrhythmia, orthostatic hypotension, medication effects, or another cause leads to brain hypoperfusion. Such presyncopal sensations vary in duration; they may increase in severity until loss of consciousness occurs, or they may resolve before loss of consciousness if the cerebral ischemia is corrected. Faintness and syncope, which are discussed in detail in *Chap. 21*, should always be considered when one is evaluating patients with brief episodes of dizziness or dizziness that occurs with upright posture. Other causes of dizziness include nonvestibular imbalance, gait disorders (e.g., loss of proprioception from sensory neuropathy, parkinsonism), and anxiety.

When evaluating patients with dizziness, questions to consider include the following: (1) Is it dangerous (e.g., arrhythmia, transient ischemic attack/stroke)? (2) Is it vestibular? (3) If vestibular, is it peripheral or central? A careful history and examination often provide sufficient information to answer these questions and determine whether additional studies or referral to a specialist is necessary.

## APPROACH TO THE PATIENT

### Dizziness

#### HISTORY

When a patient presents with dizziness, the first step is to delineate more precisely the nature of the symptom. In the case of vestibular disorders, the physical symptoms depend on whether the lesion is unilateral or bilateral, and whether it is acute or chronic. Vertigo, an illusion of self or environmental motion, implies an acute asymmetry of vestibular inputs from the two labyrinths or in their central pathways. Symmetric bilateral vestibular hypofunction causes imbalance but no vertigo. Because of the ambiguity in patients' descriptions of their symptoms, diagnosis based simply on symptom characteristics is typically unreliable. Thus the history should focus closely on other features, including whether this is the first attack, the duration of this and any prior episodes, provoking factors, and accompanying symptoms.

Dizziness can be divided into episodes that last for seconds, minutes, hours, or days. Common causes of brief dizziness (seconds) include benign paroxysmal positional vertigo (BPPV) and orthostatic hypotension, both of which typically are provoked by changes in head and/or body position relative to gravity. Attacks of vestibular migraine and Ménière's disease often last hours. When episodes are of intermediate duration (minutes), transient ischemic

attacks of the posterior circulation should be considered, although migraine and other causes are also possible.

Symptoms that accompany vertigo may be helpful in distinguishing peripheral vestibular lesions from central causes. Unilateral hearing loss and other acute aural symptoms (ear pain, pressure, fullness, new tinnitus) typically point to a peripheral cause. Because the auditory pathways quickly become bilateral upon entering the brainstem, central lesions are unlikely to cause unilateral hearing loss unless the lesion lies near the root entry zone of the auditory nerve. Symptoms such as double vision, numbness, and limb ataxia suggest a brainstem or cerebellar lesion.

#### EXAMINATION

Because dizziness and imbalance can be a manifestation of a variety of neurologic disorders, the neurologic examination is important in the evaluation of these patients. Focus should be given to assessment of eye movements, vestibular function, and hearing. The range of eye movements and whether they are equal in each eye should be observed. Peripheral eye movement disorders (e.g., cranial neuropathies, eye muscle weakness) are usually disconjugate (different in the two eyes). One should check pursuit (the ability to follow a smoothly moving target) and saccades (the ability to look back and forth accurately between two targets). Poor pursuit or inaccurate (dysmetric) saccades usually indicate central pathology, often involving the cerebellum. Alignment of the two eyes can be checked with a cover test: while the patient is looking at a target, alternately cover the eyes and observe for corrective saccades. A vertical misalignment may indicate a brainstem or cerebellar lesion. Finally, one should look for spontaneous nystagmus, an involuntary back-and-forth movement of the eyes. Nystagmus is most often of the jerk type, in which a slow drift (slow phase) in one direction alternates with a rapid saccadic movement (quick phase or fast phase) in the opposite direction that resets the position of the eyes in the orbits. Except in the case of acute vestibulopathy (e.g., vestibular neuritis), if primary position nystagmus is easily seen in the light, it is probably due to a central cause. Two forms of nystagmus that are characteristic of lesions of the cerebellar pathways are vertical nystagmus with downward fast phases (downbeat nystagmus) and horizontal nystagmus that changes direction with gaze (gaze-evoked nystagmus). By contrast, peripheral lesions typically cause unidirectional horizontal nystagmus. Use of Frenzel eyeglasses (self-illuminated goggles with convex lenses that blur the patient's vision but allow the examiner to see the eyes greatly magnified) or infrared video goggles can aid in the detection of peripheral vestibular nystagmus, because they reduce the patient's ability to use visual fixation to suppress nystagmus. *Table 22-1* outlines key findings that help distinguish peripheral from central causes of vertigo.

The most useful bedside test of peripheral vestibular function is the head impulse test, in which the vestibulo-ocular reflex (VOR) is assessed with small-amplitude (~20 degrees) rapid head rotations. While the patient fixates on a target, the head is rotated quickly to the left or right. If the VOR is deficient, the rotation is followed by a catch-up saccade in the opposite direction (e.g., a leftward saccade

**TABLE 22-1** Features of Peripheral and Central Vertigo

- Nystagmus from an acute peripheral lesion is unidirectional, with fast phases beating away from the ear with the lesion. Nystagmus that changes direction with gaze is due to a central lesion.
- Transient mixed vertical-torsional nystagmus occurs in benign paroxysmal positional vertigo (BPPV), but pure vertical or pure torsional nystagmus is a central sign.
- Nystagmus from a peripheral lesion may be inhibited by visual fixation, whereas central nystagmus is not suppressed.
- Absence of a head impulse sign in a patient with acute prolonged vertigo should suggest a central cause.
- Unilateral hearing loss suggests peripheral vertigo. Findings such as diplopia, dysarthria, and limb ataxia suggest a central disorder.

after a rightward rotation). The head impulse test can identify both unilateral (catch-up saccades after rotations toward the weak side) and bilateral (catch-up saccades after rotations in both directions) vestibular hypofunction.

All patients with episodic dizziness, especially if provoked by positional change, should be tested with the Dix-Hallpike maneuver. The patient begins in a sitting position with the head turned 45 degrees; holding the back of the head, the examiner then lowers the patient into a supine position with the head extended backward by about 20 degrees while watching the eyes. Posterior canal BPPV can be diagnosed confidently if transient upbeat-torsional nystagmus is seen. If no nystagmus is observed after 15–20 s, the patient is raised to the sitting position, and the procedure is repeated with the head turned to the other side. Again, Frenzel goggles may improve the sensitivity of the test.

**Dynamic visual acuity** is a functional test that can be useful in assessing vestibular function. Visual acuity is measured with the head still and when the head is rotated back and forth by the examiner (about 1–2 Hz). A drop in visual acuity during head motion of more than one line on a near card or Snellen chart is abnormal and indicates vestibular dysfunction.

#### ANCILLARY TESTING

The choice of ancillary tests should be guided by the history and examination findings. Audiometry should be performed whenever a vestibular disorder is suspected. Unilateral sensorineural hearing loss supports a peripheral disorder (e.g., vestibular schwannoma). Predominantly low-frequency hearing loss is characteristic of Ménière's disease. Videonystagmography includes recordings of spontaneous nystagmus (if present) and measurement of positional nystagmus. Caloric testing compares the responses of the two horizontal semicircular canals, while video head-impulse testing measures the integrity of each of the six semicircular canals. Vestibular evoked potentials assess otolith reflexes. The test battery often includes recording of saccades and pursuit to evaluate central ocular motor function. Neuroimaging is important if a central vestibular disorder is suspected. In addition, patients with unexplained unilateral hearing loss or vestibular hypofunction should undergo MRI of the internal auditory canals, including administration of gadolinium, to rule out a schwannoma.

#### ■ DIFFERENTIAL DIAGNOSIS AND TREATMENT

Treatment of vestibular symptoms should be driven by the underlying diagnosis. Simply treating dizziness with vestibular suppressant medications is often not helpful and may make the symptoms worse and prolong recovery. The diagnostic and specific treatment approaches for the most commonly encountered vestibular disorders are discussed below.

#### ■ ACUTE PROLONGED VERTIGO VESTIBULAR NEURITIS

An acute unilateral vestibular lesion causes constant vertigo, nausea, vomiting, oscillopsia (motion of the visual scene), and imbalance. These symptoms are due to a sudden asymmetry of inputs from the two labyrinths or in their central connections, simulating a continuous rotation of the head. Unlike BPPV, continuous vertigo persists even when the head remains still.

When a patient presents with an acute vestibular syndrome, the most important question is whether the lesion is central (e.g., a cerebellar or brainstem infarct or hemorrhage), which may be life-threatening, or peripheral, affecting the vestibular nerve or labyrinth (vestibular neuritis). Attention should be given to any symptoms or signs that point to central dysfunction (diplopia, weakness or numbness, dysarthria). The pattern of spontaneous nystagmus, if present, may be helpful (Table 22-1). If the head impulse test is normal, an acute peripheral vestibular lesion is unlikely. A central lesion cannot always be excluded with certainty based on symptoms and examination alone; thus older patients with vascular risk factors who present with an acute vestibular

syndrome should be evaluated for the possibility of stroke even when there are no specific findings that indicate a central lesion.

Most patients with vestibular neuritis recover spontaneously, although chronic dizziness, motion sensitivity, and disequilibrium may persist. The role of early glucocorticoid therapy is uncertain, as studies have yielded disparate results. Antiviral medications are of no proven benefit and are not typically given unless there is evidence to suggest herpes zoster oticus (Ramsay Hunt syndrome). Vestibular suppressant medications may reduce acute symptoms but should be avoided after the first several days because they may impede central compensation and recovery. Patients should be encouraged to resume a normal level of activity as soon as possible, and directed vestibular rehabilitation therapy may accelerate improvement.

#### ■ BENIGN PAROXYSMAL POSITIONAL VERTIGO

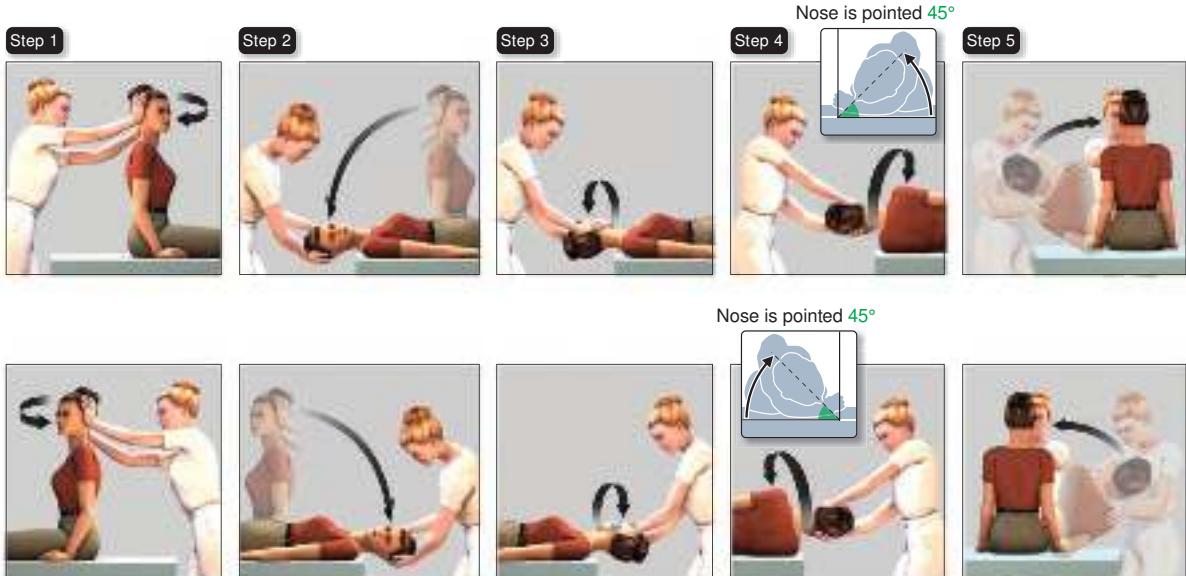
BPPV is a common cause of recurrent vertigo. Episodes are brief (<1 min and typically 15–20 s) and are always provoked by changes in head position relative to gravity, such as lying down, rising from a supine position, and extending the head to look upward. Rolling over in bed is a common trigger that may help to distinguish BPPV from orthostatic hypotension. The attacks are caused by free-floating otoconia (calcium carbonate crystals) that have been dislodged from the utricular macula and have moved into one of the semicircular canals, usually the posterior canal. When head position changes, gravity causes the otoconia to move within the canal, producing vertigo and nystagmus. With posterior canal BPPV, the nystagmus beats upward and torsionally (the upper poles of the eyes beat toward the affected lower ear). Less commonly, the otoconia enter the horizontal canal, resulting in a horizontal nystagmus when the patient is lying with either ear down. Superior (also called anterior) canal involvement is rare. BPPV is treated with repositioning maneuvers that use gravity to remove the otoconia from the semicircular canal. For posterior canal BPPV, the Epley maneuver (Fig. 22-1) is the most commonly used procedure. For more refractory cases of BPPV, patients can be taught a variant of this maneuver that they can perform alone at home. A demonstration of the Epley maneuver is available online (<http://www.dizziness-and-balance.com/disorders/bppv/bppv.html>).

#### ■ VESTIBULAR MIGRAINE

Vestibular migraine is a common yet underdiagnosed cause of episodic vertigo. Vertigo sometimes precedes a typical migraine headache but more often occurs without headache or with only a mild headache. Some patients who have had frequent migraine headaches in the past present later in life with vestibular migraine as the predominant problem. In vestibular migraine, the duration of vertigo may be from minutes to hours, and some migraineurs also experience more prolonged periods of disequilibrium (lasting days to weeks). Motion sensitivity and sensitivity to visual motion (e.g., movies) are common. Even in the absence of headache, other migraine features may be present, such as photophobia, phonophobia, or a visual aura. Although data from controlled studies are generally lacking, vestibular migraine typically is treated with medications that are used for prophylaxis of migraine headaches (Chap. 430). Antiemetics may be helpful to relieve symptoms at the time of an attack.

#### ■ MÉNIÈRE'S DISEASE

Attacks of Ménière's disease consist of vertigo and hearing loss, as well as pain, pressure, and/or fullness in the affected ear. Low-frequency hearing loss and aural symptoms are key features that distinguish Ménière's disease from other peripheral vestibulopathies and from vestibular migraine. Audiometry at the time of an attack shows a characteristic asymmetric low-frequency hearing loss; hearing commonly improves between attacks, although permanent hearing loss may eventually occur. Ménière's disease is associated with excess endolymph fluid in the inner ear; hence the term *endolymphatic hydrops*. The exact pathophysiological mechanism, however, remains unclear. Patients suspected of having Ménière's disease should be referred to an otolaryngologist for further evaluation. Diuretics and sodium restriction are typically the initial treatments. If attacks persist, injections of



**FIGURE 22-1** Modified Epley maneuver for treatment of benign paroxysmal positional vertigo of the right (top panels) and left (bottom panels) posterior semicircular canals. Step 1. With the patient seated, turn the head 45 degrees toward the affected ear. Step 2. Keeping the head turned, lower the patient to the head-hanging position and hold for at least 30 s and until nystagmus disappears. Step 3. Without lifting the head, turn it 90 degrees toward the other side. Hold for another 30 s. Step 4. Rotate the patient onto her side while turning the head another 90 degrees, so that the nose is pointed down 45 degrees. Hold again for 30 s. Step 5. Have the patient sit up on the side of the table. After a brief rest, the maneuver should be repeated to confirm successful treatment. (Reproduced with permission from Chicago dizziness and Hearing (CDH). Figure adapted from <http://www.dizziness-and-balance.com/disorders/bppv/movies/Epley-480x640.avi>)

glucocorticoids or gentamicin into the middle ear may be considered. Nonablative surgical options include decompression and shunting of the endolymphatic sac. Full ablative procedures (vestibular nerve section, labyrinthectomy) are seldom required.

### ■ VESTIBULAR SCHWANNOMA

Vestibular schwannomas (sometimes termed *acoustic neuromas*) and other tumors at the cerebellopontine angle cause slowly progressive unilateral sensorineural hearing loss and vestibular hypofunction. These patients typically do not have vertigo, because the gradual vestibular deficit is compensated centrally as it develops. The diagnosis often is not made until there is sufficient hearing loss to be noticed. The vestibular examination will show a deficient response to the head impulse test when the head is rotated toward the affected side, but nystagmus will not be prominent. As noted above, patients with unexplained unilateral sensorineuronal hearing loss or vestibular hypofunction require MRI of the internal auditory canals to look for a schwannoma.

### ■ BILATERAL VESTIBULAR HYPOFUNCTION

Patients with bilateral loss of vestibular function also typically do not have vertigo, because vestibular function is lost on both sides simultaneously, and there is no asymmetry of vestibular input. Symptoms include loss of balance, particularly in the dark, where vestibular input is most critical, and oscillopsia during head movement, such as while walking or riding in a car. Bilateral vestibular hypofunction may be (1) idiopathic and progressive, (2) part of a neurodegenerative disorder, or (3) iatrogenic due to medication ototoxicity (most commonly gentamicin or other aminoglycoside antibiotics). Other causes include bilateral vestibular schwannomas (neurofibromatosis type 2), autoimmune disease, superficial siderosis, and meningeal-based infection or tumor. It also may occur in patients with peripheral polyneuropathy; in these patients, both vestibular loss and impaired proprioception may contribute to poor balance. Finally, unilateral processes such as vestibular neuritis and Ménière's disease may involve both ears sequentially, resulting in bilateral vestibulopathy.

Examination findings include diminished *dynamic visual acuity* (see above) due to loss of stable vision when the head is moving, abnormal head impulse responses in both directions, and a Romberg

sign. Responses to caloric testing are reduced. Patients with bilateral vestibular hypofunction should be referred for vestibular rehabilitation therapy. Vestibular suppressant medications should not be used, as they will increase the imbalance. Evaluation by a neurologist is important not only to confirm the diagnosis but also to consider any other associated neurologic abnormalities that may clarify the etiology.

### ■ CENTRAL VESTIBULAR DISORDERS

Central lesions causing vertigo typically involve vestibular pathways in the brainstem and/or cerebellum. They may be due to discrete lesions, such as from ischemic or hemorrhagic stroke (Chaps. 426–428), demyelination (Chap. 444), or tumors (Chap. 90), or they may be due to neurodegenerative conditions that include the vestibulocerebellum (Chaps. 431–434). Subacute cerebellar degeneration may be due to immune, including paraneoplastic, processes (Chaps. 94 and 439). Table 22-1 outlines important features of the history and examination that help to identify central vestibular disorders. Acute central vertigo is a medical emergency, due to the possibility of life-threatening stroke or hemorrhage. All patients with suspected central vestibular disorders should undergo brain MRI, and the patient should be referred for full neurologic evaluation.

### ■ PSYCHOSOMATIC AND FUNCTIONAL DIZZINESS

Psychological factors play an important role in chronic dizziness. First, dizziness may be a somatic manifestation of a psychiatric condition such as major depression, anxiety, or panic disorder (Chap. 452). Second, patients may develop anxiety and autonomic symptoms as a consequence or comorbidity of an independent vestibular disorder. One particular form of this has been termed variously *phobic postural vertigo*, *psychophysiological vertigo*, or *chronic subjective dizziness*, but is now referred to as *persistent postural-perceptual dizziness (PPPD)*. These patients have a chronic feeling (3 months or longer) of fluctuating dizziness and disequilibrium that is present at rest but worse while standing. There is an increased sensitivity to self-motion and visual motion (e.g., watching movies), and a particular intensification of symptoms when moving through complex visual environments such as supermarkets. Although there may be a past history of an acute vestibular disorder (e.g., vestibular neuritis), the neuro-otologic examination

TABLE 22-2 Treatment of Vertigo

AGENT <sup>a</sup>	DOSE <sup>b</sup>
Antihistamines	
Meclizine	25–50 mg 3 times daily
Dimenhydrinate	50 mg 1–2 times daily
Promethazine	25 mg 2–3 times daily (also can be given rectally and IM)
Benzodiazepines	
Diazepam	2.5 mg 1–3 times daily
Clonazepam	0.25 mg 1–3 times daily
Anticholinergic	
Scopolamine transdermal <sup>c</sup>	Patch
Physical therapy	
Repositioning maneuvers <sup>d</sup>	
Vestibular rehabilitation	
Other	
Diuretics and/or low-sodium (1000 mg/d) diet <sup>e</sup>	
Antimigrainous drugs <sup>f</sup>	
Selective serotonin reuptake inhibitors <sup>g</sup>	

<sup>a</sup>All listed drugs are approved by the US Food and Drug Administration, but most are not approved for the treatment of vertigo. <sup>b</sup>Usual oral (unless otherwise stated) starting dose in adults; a higher maintenance dose can be reached by a gradual increase. <sup>c</sup>For motion sickness only. <sup>d</sup>For benign paroxysmal positional vertigo. <sup>e</sup>For Ménière's disease. <sup>f</sup>For vestibular migraine. <sup>g</sup>For persistent postural-perceptual vertigo and anxiety.

and vestibular testing are normal or indicative of a compensated vestibular deficit, indicating that the ongoing subjective dizziness cannot be explained by a primary vestibular pathology. Anxiety disorders are particularly common in patients with chronic dizziness; when present, they contribute substantially to the morbidity. Treatment approaches for PPPD include pharmacological therapy with selective serotonin reuptake inhibitors (SSRIs), cognitive-behavioral psychotherapy, and vestibular rehabilitation. Vestibular suppressant medications generally should be avoided.

## TREATMENT

### Vertigo

Table 22-2 provides a list of commonly used medications for suppression of vertigo. As noted, these medications should be reserved for short-term control of active vertigo, such as during the first few days of acute vestibular neuritis, or for acute attacks of Ménière's disease. They are less helpful for chronic dizziness and, as previously stated, may hinder central compensation. An exception is that benzodiazepines may attenuate psychosomatic dizziness and the associated anxiety, although SSRIs are generally preferable in such patients.

Vestibular rehabilitation therapy promotes central adaptation processes that compensate for vestibular loss and also may help habituate motion sensitivity and other symptoms of psychosomatic dizziness. The general approach is to use a graded series of exercises that progressively challenge gaze stabilization and balance.

### FURTHER READING

- A G et al: Drugs inducing hearing loss, tinnitus, dizziness and vertigo: An updated guide. *Eur Rev Med Pharmacol Sci* 24:7946, 2020.
- H TC et al: Vestibular migraine: An update on current understanding and future directions. *Cephalgia* 40:107, 2020.
- K JS, Z DS: Benign paroxysmal positional vertigo. *N Engl J Med* 370:1138, 2014.
- P S et al: Persistent postural-perceptual dizziness (PPPD): a common, characteristic and treatable cause of chronic dizziness. *Pract Neurol* 18:5, 2018.

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## Fatigue

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Fatigue is one of the most common symptoms in clinical medicine. It is a prominent manifestation of a number of systemic, neurologic, and psychiatric syndromes, although a precise cause will not be identified in a substantial minority of patients. Fatigue refers to the subjective experience of physical and mental weariness, sluggishness, low energy, and exhaustion. In the context of clinical medicine, fatigue is most practically defined as difficulty initiating or maintaining voluntary mental or physical activity. Nearly everyone who has ever been ill with a self-limited infection has experienced this near-universal symptom, and fatigue is usually brought to medical attention only when it is either of unclear cause, fails to remit, or the severity is out of proportion with what would be expected for the associated trigger.

*Fatigue* should be distinguished from *muscle weakness*, a reduction of neuromuscular power (Chap. 24); most patients complaining of fatigue are not truly weak when direct muscle power is tested. Fatigue is also distinct from *somnolence*, which refers to sleepiness in the context of disturbed sleep-wake physiology (Chap. 31), and from *dyspnea on exertion*, although patients may use the word fatigue to describe any of these symptoms. The task facing clinicians when a patient presents with fatigue is to identify the underlying cause and develop a therapeutic alliance, the goal of which is to spare patients expensive and fruitless diagnostic workups and steer them toward effective therapy.

### ■ EPIDEMIOLOGY AND GLOBAL CONSIDERATIONS

Variability in the definitions of fatigue and the survey instruments used in different studies makes it difficult to arrive at precise figures about the global burden of fatigue. The point prevalence of fatigue was 6.7% and the lifetime prevalence was 25% in a large National Institute of Mental Health survey of the U.S. general population. In primary care clinics in Europe and the United States, between 10 and 25% of patients surveyed endorsed symptoms of prolonged (present for >1 month) or chronic (present for >6 months) fatigue, but in only a minority was fatigue the primary reason for seeking medical attention. In a community survey of women in India, 12% reported chronic fatigue. By contrast, the prevalence of chronic fatigue syndrome (Chap. 450), as defined by the U.S. Centers for Disease Control and Prevention, is low.

### ■ DIFFERENTIAL DIAGNOSIS

**Psychiatric Disease** Fatigue is a common somatic manifestation of many major psychiatric syndromes, including depression, anxiety, and somatoform disorders (Chap. 452). Psychiatric symptoms are reported in more than three-quarters of patients with unexplained chronic fatigue. Even in patients with systemic or neurologic disorders in which fatigue is independently recognized as a symptom, comorbid psychiatric disease may still be an important contributor.

**Neurologic Disease** Patients complaining of fatigue often say they feel weak, but upon careful examination, objective muscle weakness is rarely discernible. If found, muscle weakness must then be localized to the central nervous system, peripheral nervous system, neuromuscular junction, or muscle, and appropriate follow-up studies obtained (Chap. 24). *Fatigability* of muscle power is a cardinal manifestation of some neuromuscular disorders such as myasthenia gravis and is distinguished from *fatigue* by finding clinically evident diminution of the amount of force that a muscle generates upon repeated contraction (Chap. 448). Fatigue is one of the most common and bothersome symptoms reported in multiple sclerosis (MS) (Chap. 444), affecting nearly 90% of patients; fatigue in MS can persist between MS attacks and does not necessarily correlate with magnetic resonance imaging (MRI) disease activity. Fatigue is also increasingly identified as a troublesome feature of many neurodegenerative diseases, including Parkinson's disease (Chap. 435), amyotrophic lateral sclerosis

(Chap. 437), and central nervous system dysautonomias (Chap. 440). Fatigue after stroke (Chap. 426) is a well-described but poorly understood entity with a widely varying prevalence. Episodic fatigue can be a premonitory symptom of migraine (Chap. 430). Fatigue is also a frequent consequence of traumatic brain injury (Chap. 443), often occurring in association with depression and sleep disorders.

**Sleep Disorders** Obstructive sleep apnea is an important cause of excessive daytime sleepiness in association with fatigue and should be investigated using overnight polysomnography, particularly in those with prominent snoring, obesity, or other predictors of obstructive sleep apnea (Chap. 297). Whether the cumulative sleep deprivation that is common in modern society contributes to clinically apparent fatigue is not known (Chap. 31).

**Endocrine Disorders** Fatigue, sometimes in association with true muscle weakness, can be a heralding symptom of hypothyroidism (Chap. 383), particularly in the context of hair loss, dry skin, cold intolerance, constipation, and weight gain. Fatigue associated with heat intolerance, sweating, and palpitations is typical of hyperthyroidism (Chap. 384). Adrenal insufficiency (Chap. 386) can also manifest with unexplained fatigue as a primary or prominent symptom, often with anorexia, weight loss, nausea, myalgias, and arthralgias; hyponatremia, hyperkalemia, and hyperpigmentation may be present at time of diagnosis. Mild hypercalcemia can cause fatigue, which may be relatively vague, whereas severe hypercalcemia can lead to lethargy, stupor, and coma (Chap. 410). Both hypoglycemia and hyperglycemia can cause lethargy, often in association with confusion; diabetes mellitus, and in particular type 1 diabetes, is also associated with fatigue independent of glucose levels (Chap. 403). Fatigue may also accompany Cushing's disease, hypoaldosteronism, and hypogonadism. Low vitamin D status has also been associated with fatigue.

**Liver and Kidney Disease** Both chronic liver failure and chronic kidney disease can cause fatigue. Over 80% of hemodialysis patients complain of fatigue, which makes it one of the most common symptoms reported by patients in chronic kidney disease (Chap. 311).

**Obesity** Obesity (Chap. 401) is associated with fatigue and sleepiness independent of the presence of obstructive sleep apnea. Obese patients undergoing bariatric surgery experience improvement in daytime sleepiness sooner than would be expected if the improvement were solely the result of weight loss and resolution of sleep apnea. A number of other factors common in obese patients are likely contributors as well, including physical inactivity, diabetes, and depression.

**Physical Inactivity** Physical inactivity is associated with fatigue, and increasing physical activity can improve fatigue in some patients.

**Malnutrition** Although fatigue can be a presenting feature of malnutrition (Chap. 334), nutritional status may also be an important comorbidity and contributor to fatigue in other chronic illnesses, including cancer-associated fatigue.

**Infection** Both acute and chronic infections commonly lead to fatigue as part of the broader infectious syndrome. Evaluation for undiagnosed infection as the cause of unexplained fatigue, and particularly prolonged or chronic fatigue, should be guided by the history, physical examination, and infectious risk factors, with particular attention to risk for tuberculosis, HIV, chronic hepatitis, and endocarditis. Infectious mononucleosis may cause prolonged fatigue that persists for weeks to months following the acute illness, but infection with the Epstein-Barr virus is only very rarely the cause of unexplained chronic fatigue. Postinfectious fatigue may also occur following a variety of acute infections. For example, a substantial minority of patients who have recovered from SARS-CoV-1, SARS-CoV-2, and Ebola virus complain of persistent fatigue.

**Drugs** Many medications, drugs, drug withdrawal, and chronic alcohol use can all lead to fatigue. Medications that are more likely to

be causative include antidepressants, antipsychotics, anxiolytics, opiates, antispasticity agents, antiseizure agents, and beta blockers.

**Cardiovascular and Pulmonary Disorders** Fatigue is one of the most taxing symptoms reported by patients with congestive heart failure and chronic obstructive pulmonary disease and negatively affects quality of life. In a population-based cohort study in Norfolk, United Kingdom, fatigue was associated with an increased hazard of all-cause mortality in the general population, but particularly for deaths related to cardiovascular disease.

**Malignancy** Fatigue, particularly in association with unexplained weight loss, can be a sign of occult malignancy, but cancer is rarely identified in patients with unexplained chronic fatigue in the absence of other telltale signs or symptoms. Cancer-related fatigue is experienced by 40% of patients at the time of diagnosis and by >80% at some time in the disease course.

**Hematologic Disorders** Chronic or progressive anemia may present with fatigue, sometimes in association with exertional tachycardia and breathlessness. Anemia may also contribute to fatigue in chronic illness. Low serum ferritin in the absence of anemia may also cause fatigue that is reversible with iron replacement.

**Immune-Mediated Disorders** Fatigue is a prominent complaint in many chronic inflammatory disorders, including systemic lupus erythematosus, polymyalgia rheumatica, rheumatoid arthritis, inflammatory bowel disease, antineutrophil cytoplasmic antibody (ANCA)-associated vasculitis, sarcoidosis, and Sjögren's syndrome, but is not usually an isolated symptom. Fatigue is also associated with primary immunodeficiency diseases.

**Pregnancy** Fatigue is very commonly reported by women during all stages of pregnancy and postpartum.

**Disorders of Unclear Cause** Myalgic encephalomyelitis (ME)/chronic fatigue syndrome (CFS) (Chap. 450) and fibromyalgia (Chap. 373) incorporate chronic fatigue as part of the syndromic definition when fatigue is present in association with other criteria, as discussed in the respective chapters. Chronic multisymptom illness, also known as Gulf-War syndrome, is another symptom complex with prominent fatigue; it is most commonly, although not exclusively, observed in veterans of the 1991 Gulf War conflict (Chap. S7). Idiopathic chronic fatigue is used to describe the syndrome of unexplained chronic fatigue in the absence of enough additional clinical features to meet the diagnostic criteria for ME/CFS.

## APPROACH TO THE PATIENT

### Fatigue

A detailed history focusing on the quality, pattern, time course, associated symptoms, and alleviating factors of fatigue is necessary to define the syndrome and help direct further evaluation and treatment. It is important to determine if fatigue is the appropriate designation, whether symptoms are acute or chronic, and if the impairment is primarily mental, physical, or a combination of the two. The review of systems should attempt to distinguish fatigue from excessive sleepiness, dyspnea on exertion, exercise intolerance, and muscle weakness. The presence of fever, chills, night sweats, or weight loss should raise suspicion for an occult infection or malignancy. A careful review of prescription, over-the-counter, herbal, and recreational drug and alcohol use is required. Circumstances surrounding the onset of symptoms and potential triggers should be investigated. The social history is important, with attention paid to life stressors and adverse experiences, workhours, the social support network, and domestic affairs including a screen for intimate partner violence. Sleep habits and sleep hygiene should be questioned. The impact of fatigue on daily functioning is important to understand the patient's experience and gauge recovery and the success of treatment.

The physical examination of patients with fatigue is guided by the history and differential diagnosis. A detailed mental status examination should be performed with particular attention to symptoms of depression and anxiety. A formal neurologic examination is required to determine whether objective muscle weakness is present. This is usually a straightforward exercise, although occasionally patients with fatigue have difficulty sustaining effort against resistance and sometimes report that generating full power requires substantial mental effort. On confrontational testing, full power may be generated for only a brief period before the patient suddenly gives way to the examiner. This type of weakness is often referred to as *breakaway weakness* and may or may not be associated with pain. This is contrasted with weakness due to lesions in the motor tracts or lower motor unit, in which the patient's resistance can be overcome in a smooth and steady fashion and full power can never be generated. Occasionally, a patient may demonstrate fatigable weakness, in which power is full when first tested but becomes weak upon repeat evaluation without interval rest. Fatigable weakness, which usually indicates a problem of neuromuscular transmission, never has the sudden breakaway quality that one occasionally observes in patients with fatigue. If the presence or absence of muscle weakness cannot be determined with the physical examination, electromyography with nerve conduction studies can be a helpful ancillary test.

The general physical examination should screen for signs of cardiopulmonary disease, malignancy, lymphadenopathy, organomegaly, infection, liver failure, kidney disease, malnutrition, endocrine abnormalities, and connective tissue disease. In patients with associated widespread musculoskeletal pain, assessment of tender points may help to reveal fibromyalgia. Although the diagnostic yield of the general physical examination may be relatively low in the context of evaluation of unexplained chronic fatigue, elucidating the cause of only 2% of cases in one prospective analysis, the yield of a detailed neuropsychiatric and mental status evaluation is likely to be much higher, revealing a potential explanation for fatigue in up to 75–80% of patients in some series. Furthermore, a complete physical examination demonstrates a serious and systematic approach to the patient's complaint and helps build trust and a therapeutic alliance.

Laboratory testing is likely to identify the cause of chronic fatigue in only about 5% of cases. Beyond a few standard screening tests, laboratory evaluation should be guided by the history and physical examination; extensive testing is likely to lead to incidental findings that require explanation and unnecessary follow-up investigation, and should be avoided in lieu of frequent clinical follow-up. A reasonable approach to screening includes a complete blood count with differential (to screen for anemia, infection, and malignancy), electrolytes (including sodium, potassium, and calcium), glucose, renal function, liver function, and thyroid function. Testing for HIV and adrenal function can also be considered. Published guidelines for chronic fatigue syndrome also recommend an erythrocyte sedimentation rate (ESR) as part of the evaluation for mimics, but unless the value is very high, such nonspecific testing in the absence of other features is unlikely to clarify the situation. Routine screening with an antinuclear antibody (ANA) test is also unlikely to be informative in isolation and is frequently positive at low titers in otherwise healthy adults. Additional unfocused studies, such as whole-body imaging scans, are usually not indicated; in addition to their inconvenience, potential risk, and cost, they often reveal unrelated incidental findings that can prolong the workup unnecessarily.

## TREATMENT

### Fatigue

The first priority is to address the underlying disorder or disorders that account for fatigue, because this can be curative in select contexts and palliative in others. Unfortunately, in many chronic

illnesses, fatigue may be refractory to traditional disease-modifying therapies, but it is nevertheless important in such cases to evaluate for other potential contributors because the cause may be multifactorial. Antidepressants (Chap. 452) may be helpful for treatment of chronic fatigue when symptoms of depression are present and are generally most effective as part of a multimodal approach. However, antidepressants can also cause fatigue and should be discontinued if they are not clearly effective. Cognitive-behavioral therapy has also been demonstrated to be helpful in ME/CFS as well as cancer-associated fatigue. Both cognitive-behavioral therapy and graded exercise therapy, in which physical exercise, most typically walking, is gradually increased with attention to target heart rates to avoid overexertion, were shown to modestly improve walking times and self-reported fatigue measures when compared to standard medical care in patients in the United Kingdom with chronic fatigue. These benefits were maintained after a median follow-up of 2.5 years. Psychostimulants such as amphetamines, modafinil, and armodafinil can help increase alertness and concentration and reduce excessive daytime sleepiness in certain clinical contexts, which may in turn help with symptoms of fatigue in a minority of patients, but they have generally proven to be unhelpful in randomized trials for treating fatigue in posttraumatic brain injury, Parkinson's disease, cancer, and MS. In patients with low vitamin D status, vitamin D replacement may lead to improvement in fatigue.

Development of more effective therapy for fatigue is hampered by limited knowledge of the biologic basis of this symptom, including how fatigue is detected and registered in the nervous system. Proinflammatory cytokines, such as interleukin 1 $\alpha$  and 1 $\beta$  and tumor necrosis factor  $\alpha$ , might mediate fatigue in some patients. While preliminary studies of biologic therapies that inhibit cytokines have suggested a benefit against fatigue in some patients with inflammatory conditions, this approach has largely not led to improvement in clinical trials that focused on fatigue as the primary endpoint. Nonetheless, specific targeting with cytokine antagonists could represent a possible future approach for some patients.

## ■ PROGNOSIS

Acute fatigue significant enough to require medical evaluation is more likely to lead to an identifiable medical, neurologic, or psychiatric cause than is unexplained chronic fatigue. Evaluation of unexplained chronic fatigue most commonly leads to diagnosis of a psychiatric condition or remains unexplained. Identification of a previously undiagnosed serious or life-threatening culprit etiology is rare, even with longitudinal follow-up of patients with unexplained chronic fatigue. Complete resolution is uncommon, at least over the short term, but multidisciplinary treatment approaches can lead to symptomatic improvements that substantially improve quality of life.

## ■ FURTHER READING

- B N et al: Fatigue is associated with excess mortality in the general population: Results from the EPIC-Norfolk study. *BMC Med* 14:122, 2016.
- D JC et al: Approach to fatigue: Best practice. *Med Clin North Am* 105:137, 2021.
- R ME et al: Interleukin-1 as a mediator of fatigue in disease: A narrative review. *J Neuroinflammation* 14:16, 2017.
- S M et al: Rehabilitative treatments for chronic fatigue syndrome: Long-term follow-up from the PACE trial. *Lancet Psychiatry* 2:1067, 2015.
- W PD et al: Comparison of adaptive pacing therapy, cognitive behaviour therapy, graded exercise therapy, and specialist medical care for chronic fatigue syndrome (PACE): A randomised trial. *Lancet* 377:823, 2011.



Normal motor function involves integrated muscle activity that is modulated by the activity of the cerebral cortex, basal ganglia, cerebellum, red nucleus, brainstem reticular formation, lateral vestibular nucleus, and spinal cord. Motor system dysfunction leads to weakness or paralysis, discussed in this chapter, or to ataxia (Chap. 439) or abnormal movements (Chap. 436). Weakness is a reduction in the power that can be exerted by one or more muscles. It must be distinguished from increased *fatigability* (i.e., the inability to sustain the performance of an activity that should be normal for a person of the same age, sex, and size), limitation in function due to pain or articular stiffness, or impaired motor activity because severe *proprioceptive sensory loss* prevents adequate feedback information about the direction and power of movements. It is also distinct from *bradykinesia* (in which increased time is required for full power to be exerted) and *apraxia*, a disorder of planning and initiating a skilled or learned movement unrelated to a significant motor or sensory deficit (Chap. 30).

*Paralysis* or the suffix “-plegia” indicates weakness so severe that a muscle cannot be contracted at all, whereas *paresis* refers to less severe weakness. The prefix “hemi-” refers to one-half of the body, “para-” to both legs, and “quadri-” to all four limbs.

The *distribution* of weakness helps to localize the underlying lesion. Weakness from involvement of upper motor neurons occurs particularly in the extensors and abductors of the upper limb and the flexors of the lower limb. Lower motor neuron weakness depends on whether involvement is at the level of the anterior horn cells, nerve root, limb plexus, or peripheral nerve—only muscles supplied by the affected structure are weak. Myopathic weakness is generally most marked in proximal muscles. Weakness from impaired neuromuscular transmission has no specific pattern of involvement.

Weakness often is accompanied by other neurologic abnormalities that help indicate the site of the responsible lesion (Table 24-1).

*Tone* is the resistance of a muscle to passive stretch. Increased tone may be of several types. *Spasticity* is the increase in tone associated with disease of upper motor neurons. It is velocity dependent, has a sudden release after reaching a maximum (the “clasp-knife” phenomenon), and predominantly affects the antigravity muscles (i.e., upper-limb flexors and lower-limb extensors). *Rigidity* is hypertonia that is present throughout the range of motion (a “lead pipe” or “plastic” stiffness) and affects flexors and extensors equally; it sometimes has a cogwheel quality that is enhanced by voluntary movement of the contralateral limb (reinforcement). Rigidity occurs with certain extrapyramidal disorders, such as Parkinson’s disease. *Paratonia* (or *gegenhalten*) is increased tone that varies irregularly in a manner seemingly related to the degree of relaxation, is present throughout the range of motion, and affects flexors and extensors equally; it usually results from disease of the frontal lobes. Weakness with *decreased tone* (*flaccidity*) or normal tone occurs with disorders of *motor units*. A motor unit consists of a single lower motor neuron and all the muscle fibers that it innervates.

*Muscle bulk* generally is not affected by upper motor neuron lesions, although mild disuse atrophy eventually may occur. By contrast, atrophy is often conspicuous when a lower motor neuron lesion is responsible for weakness and also may occur with advanced muscle disease.

*Muscle stretch (tendon) reflexes* are usually increased with upper motor neuron lesions but may be decreased or absent for a variable period immediately after onset of an acute lesion. Hyperreflexia is usually—but not invariably—accompanied by loss of *cutaneous reflexes* (such as superficial abdominals; Chap. 422) and, in particular, by an extensor plantar (Babinski) response. The muscle stretch reflexes are depressed with lower motor neuron lesions directly involving specific reflex arcs. They generally are preserved in patients with myopathic weakness except in advanced stages, when they sometimes are attenuated. In disorders of the neuromuscular junction, reflex responses may be affected by preceding voluntary activity of affected muscles; such activity may lead to enhancement of initially depressed reflexes in Lambert-Eaton myasthenic syndrome and, conversely, to depression of initially normal reflexes in myasthenia gravis (Chap. 448).

The distinction of *neuropathic* (lower motor neuron) from *myopathic* weakness is sometimes difficult clinically, although distal weakness is likely to be neuropathic, and symmetric proximal weakness myopathic. *Fasciculations* (visible or palpable twitches within a muscle due to the spontaneous discharge of a motor unit) and early atrophy indicate that weakness is neuropathic.

## ■ PATHOGENESIS

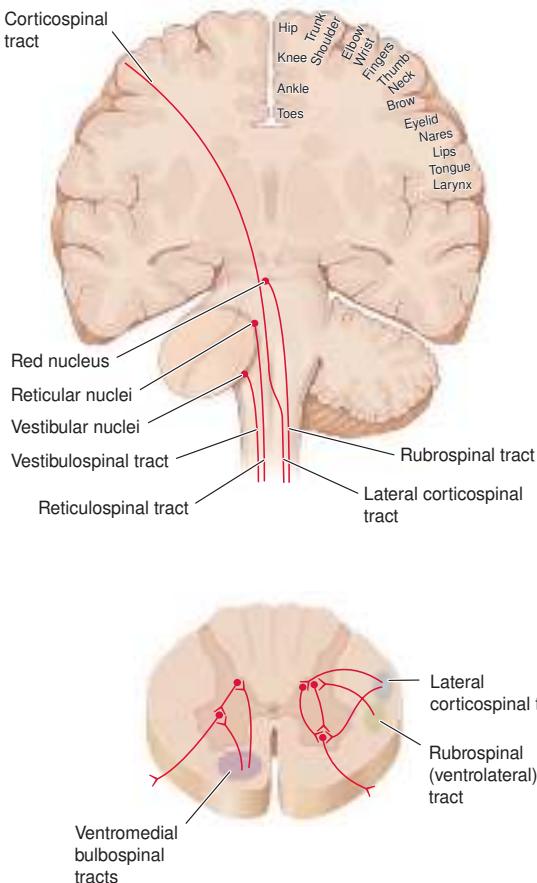
**Upper Motor Neuron Weakness** Lesions of the upper motor neurons or their descending axons to the spinal cord (Fig. 24-1) produce weakness through decreased activation of lower motor neurons. In general, distal muscle groups are affected more severely than proximal ones, and axial movements are spared unless the lesion is severe and bilateral. Spasticity is typical but may not be present acutely. Rapid repetitive movements are slowed and coarse, but normal rhythmicity is maintained. With corticobulbar involvement, weakness occurs in the lower face and tongue; extraocular, upper facial, pharyngeal, and jaw muscles are typically spared. Bilateral corticobulbar lesions produce a *pseudobulbar palsy*: dysarthria, dysphagia, dysphonia, and emotional lability accompany bilateral facial weakness and a brisk jaw jerk. Electromyogram (EMG) (Chap. 446) shows that with weakness of the upper motor neuron type, motor units have a diminished maximal discharge frequency.

**Lower Motor Neuron Weakness** This pattern results from disorders of lower motor neurons in the brainstem motor nuclei and the anterior horn of the spinal cord or from dysfunction of the axons of these neurons as they pass to skeletal muscle (Fig. 24-2). Weakness is due to a decrease in the number of muscle fibers that can be activated through a loss of  $\alpha$  motor neurons or disruption of their connections to muscle. Loss of  $\gamma$  motor neurons does not cause weakness but decreases tension on the muscle spindles, which decreases muscle tone and attenuates the stretch reflexes. An absent stretch reflex suggests involvement of spindle afferent fibers.

When a motor unit becomes diseased, especially in anterior horn cell diseases, it may discharge spontaneously, producing *fasciculations*. When  $\alpha$  motor neurons or their axons degenerate, the denervated muscle fibers also may discharge spontaneously. These single muscle

TABLE 24-1 Signs That Distinguish the Origin of Weakness

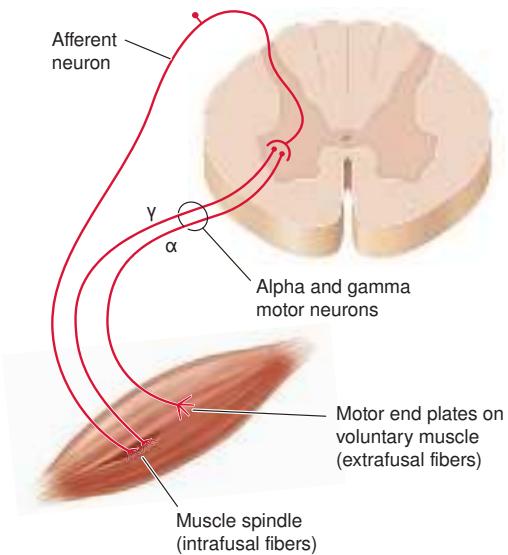
SIGN	UPPER MOTOR NEURON	LOWER MOTOR NEURON	MYOPATHIC	PSYCHOGENIC
Atrophy	None	Severe	Mild	None
Fasciculations	None	Common	None	None
Tone	Spastic	Decreased	Normal/decreased	Variable/paratonia
Distribution of weakness	Pyramidal/regional	Distal/segmental	Proximal	Variable/inconsistent with daily activities
Muscle stretch reflexes	Hyperactive	Hypoactive/absent	Normal/hypoactive	Normal
Babinski sign	Present	Absent	Absent	Absent



**FIGURE 24-1** The corticospinal and bulbospinal upper motor neuron pathways. Upper motor neurons have their cell bodies in layer V of the primary motor cortex (the precentral gyrus, or Brodmann area 4) and in the premotor and supplemental motor cortex (area 6). The upper motor neurons in the primary motor cortex are somatotopically organized (right side of figure). Axons of the upper motor neurons descend through the subcortical white matter and the posterior limb of the internal capsule. Axons of the pyramidal or corticospinal system descend through the brainstem in the cerebral peduncle of the midbrain, the basis pontis, and the medullary pyramids. At the cervicomedullary junction, most corticospinal axons decussate into the contralateral corticospinal tract of the lateral spinal cord, but 10–30% remain ipsilateral in the anterior spinal cord. Corticospinal neurons synapse on premotor interneurons, but some—especially in the cervical enlargement and those connecting with motor neurons to distal limb muscles—make direct monosynaptic connections with lower motor neurons. They innervate most densely the lower motor neurons of hand muscles and are involved in the execution of learned, fine movements. Corticobulbar neurons are similar to corticospinal neurons but innervate brainstem motor nuclei. Bulbospinal upper motor neurons influence strength and tone but are not part of the pyramidal system. The descending ventromedial bulbospinal pathways originate in the tectum of the midbrain (tectospinal pathway), the vestibular nuclei (vestibulospinal pathway), and the reticular formation (reticulospinal pathway). These pathways influence axial and proximal muscles and are involved in the maintenance of posture and integrated movements of the limbs and trunk. The descending ventrolateral bulbospinal pathways, which originate predominantly in the red nucleus (rubrospinal pathway), facilitate distal limb muscles. The bulbospinal system sometimes is referred to as the extrapyramidal upper motor neuron system. In all figures, nerve cell bodies and axon terminals are shown, respectively, as closed circles and forks.

fiber discharges, or *fibrillation potentials*, cannot be seen but can be recorded with EMG. Weakness leads to delayed or reduced recruitment of motor units, with fewer than normal activated at a particular discharge frequency.

**Neuromuscular Junction Weakness** Disorders of the neuromuscular junction produce weakness of variable degree and distribution. The number of muscle fibers that are activated varies over time, depending on the state of rest of the neuromuscular junctions. Strength



**FIGURE 24-2** Lower motor neurons are divided into  $\alpha$  and  $\gamma$  types. The larger  $\alpha$  motor neurons are more numerous and innervate the extrafusal muscle fibers of the motor unit. Loss of  $\alpha$  motor neurons or disruption of their axons produces lower motor neuron weakness. The smaller, less numerous  $\gamma$  motor neurons innervate the intrafusal muscle fibers of the muscle spindle and contribute to normal tone and stretch reflexes. The  $\alpha$  motor neuron receives direct excitatory input from corticomotoneurons and primary muscle spindle afferents. The  $\alpha$  and  $\gamma$  motor neurons also receive excitatory input from other descending upper motor neuron pathways, segmental sensory inputs, and interneurons. The  $\alpha$  motor neurons receive direct inhibition from Renshaw cell interneurons, and other interneurons indirectly inhibit the  $\alpha$  and  $\gamma$  motor neurons. A muscle stretch (tendon) reflex requires the function of all the illustrated structures. A tap on a tendon stretches muscle spindles (which are tonically activated by  $\gamma$  motor neurons) and activates the primary spindle afferent neurons. These neurons stimulate the  $\alpha$  motor neurons in the spinal cord, producing a brief muscle contraction, which is the familiar tendon reflex.

is influenced by preceding activity of the affected muscle. In myasthenia gravis, for example, sustained or repeated contractions of affected muscle decline in strength despite continuing effort (Chap. 440). Thus, fatigable weakness is suggestive of disorders of the neuromuscular junction, which cause functional loss of muscle fibers due to failure of their activation.

**Myopathic Weakness** Myopathic weakness is produced by a decrease in the number or contractile force of muscle fibers activated within motor units. With muscular dystrophies, inflammatory myopathies, or myopathies with muscle fiber necrosis, the number of muscle fibers is reduced within many motor units. On EMG, the size of each motor unit action potential is decreased, and motor units must be recruited more rapidly than normal to produce the desired power. Some myopathies produce weakness through loss of contractile force of muscle fibers or through relatively selective involvement of type II (fast) fibers. These myopathies may not affect the size of individual motor unit action potentials and are detected by a discrepancy between the electrical activity and force of a muscle.

**Psychogenic Weakness** Weakness may occur without a recognizable organic basis. It tends to be variable, inconsistent, and with a pattern of distribution that cannot be explained on a neuroanatomic basis. On formal testing, antagonists may contract when the patient is supposedly activating the agonist muscle. The severity of weakness is out of keeping with the patient's daily activities.

## DISTRIBUTION OF WEAKNESS

**Hemiparesis** Hemiparesis results from an upper motor neuron lesion above the midcervical spinal cord; most such lesions are above the foramen magnum. The presence of other neurologic deficits helps localize the lesion. Thus language disorders, for example, point to a

cortical lesion. Homonymous visual field defects reflect either a cortical or a subcortical hemispheric lesion. A “pure motor” hemiparesis of the face, arm, and leg often is due to a small, discrete lesion in the posterior limb of the internal capsule, cerebral peduncle in the midbrain, or upper pons. Some brainstem lesions produce “crossed paralyses,” consisting of ipsilateral cranial nerve signs and contralateral hemiparesis (Chap. 426). The absence of cranial nerve signs or facial weakness suggests that a hemiparesis is due to a lesion in the high cervical spinal cord, especially if associated with Brown-Séquard syndrome, consisting of loss of joint position and vibration sense on the side of the weakness, and loss of pain and temperature sense on the opposite side (Chap. 442).

*Acute or episodic hemiparesis* usually results from focal structural lesions, particularly vascular etiologies, rapidly expanding lesions, or an inflammatory process. *Subacute hemiparesis* that evolves over days or weeks may relate to subdural hematoma, infectious or inflammatory disorders (e.g., cerebral abscess, fungal granuloma or meningitis, parasitic infection, multiple sclerosis, sarcoidosis), or primary or metastatic neoplasms. AIDS may present with subacute hemiparesis due to toxoplasmosis or primary central nervous system (CNS) lymphoma. *Chronic hemiparesis* that evolves over months usually is due to a neoplasm or vascular malformation, a chronic subdural hematoma, or a degenerative disease.

Investigation of hemiparesis (Fig. 24-3) of acute origin usually starts with a CT scan of the brain and laboratory studies. If the CT is normal, or in subacute or chronic cases of hemiparesis, MRI of the brain and/or cervical spine (including the foramen magnum) is performed, depending on the clinical accompaniments.

**Paraparesis** *Acute paraparesis* is caused most commonly by an intraspinal lesion, but its spinal origin may not be recognized initially if the legs are flaccid and areflexic. Usually, however, there is sensory loss in the legs with an upper level on the trunk; a dissociated sensory loss (loss of pain and temperature but not touch, position, and vibration sense) suggestive of a central cord syndrome; or hyperreflexia in the legs with normal reflexes in the arms (Chap. 442). Imaging the

spinal cord (Fig. 24-3) may reveal compressive lesions, infarction ( proprioception usually is spared), arteriovenous fistulas or other vascular anomalies, or transverse myelitis (Chap. 442).

Diseases of the cerebral hemispheres that produce acute paraparesis include anterior cerebral artery ischemia (shoulder shrug also is affected), superior sagittal sinus or cortical venous thrombosis, and acute hydrocephalus.

Paraparesis may also result from a cauda equina syndrome, for example, after trauma to the low back, a midline disk herniation, or an intraspinal tumor. The sphincters are commonly affected, whereas hip flexion often is spared, as is sensation over the anterolateral thighs. Rarely, paraparesis is caused by a rapidly evolving anterior horn cell disease (such as poliovirus or West Nile virus infection), peripheral neuropathy (such as Guillain-Barré syndrome; Chap. 447), or myopathy (Chap. 449).

*Subacute or chronic spastic paraparesis* is caused by upper motor neuron disease. When associated with lower-limb sensory loss and sphincter involvement, a chronic spinal cord disorder should be considered (Chap. 442). If hemispheric signs are present, a parasagittal meningioma or chronic hydrocephalus is likely. The absence of spasticity in a long-standing paraparesis suggests a lower motor neuron or myopathic etiology.

Investigations typically begin with spinal MRI, but when upper motor neuron signs are associated with drowsiness, confusion, seizures, or other hemispheric signs, brain MRI should also be performed, sometimes as the initial investigation. Electrophysiologic studies are diagnostically helpful when clinical findings suggest an underlying neuromuscular disorder.

**Quadriplegia or Generalized Weakness** Generalized weakness may be due to disorders of the CNS or the motor unit. Although the terms often are used interchangeably, *quadriplegia* is commonly used when an upper motor neuron cause is suspected, and *generalized weakness* is used when a disease of the motor units is likely. Weakness from CNS disorders usually is associated with changes in consciousness or cognition and accompanied by spasticity, hyperreflexia, and sensory disturbances.

Most neuromuscular causes of generalized weakness are associated with normal mental function, hypotonia, and hypoactive muscle stretch reflexes. The major causes of intermittent weakness are listed in Table 24-2. A patient with generalized fatigability without objective weakness may have chronic fatigue syndrome (Chap. 450).

**ACUTE QUADRIPLAESIS** Quadriplegia with onset over minutes may result from disorders of upper motor neurons (such as from anoxia, hypotension, brainstem or cervical cord ischemia, trauma, and systemic metabolic abnormalities) or muscle (electrolyte disturbances, certain inborn errors of muscle energy metabolism, toxins, and periodic paralyses). Onset over hours to weeks may, in addition to these disorders, be due to lower motor neuron disorders such as Guillain-Barré syndrome (Chap. 447).

In obtunded patients, evaluation begins with a CT or MRI scan of the brain. If upper motor neuron signs are present but the patient is alert, the initial test is usually an MRI of the cervical cord. If weakness is lower motor neuron, myopathic, or uncertain in origin, the clinical approach begins with blood studies to determine the level of muscle enzymes and electrolytes and with EMG and nerve conduction studies.

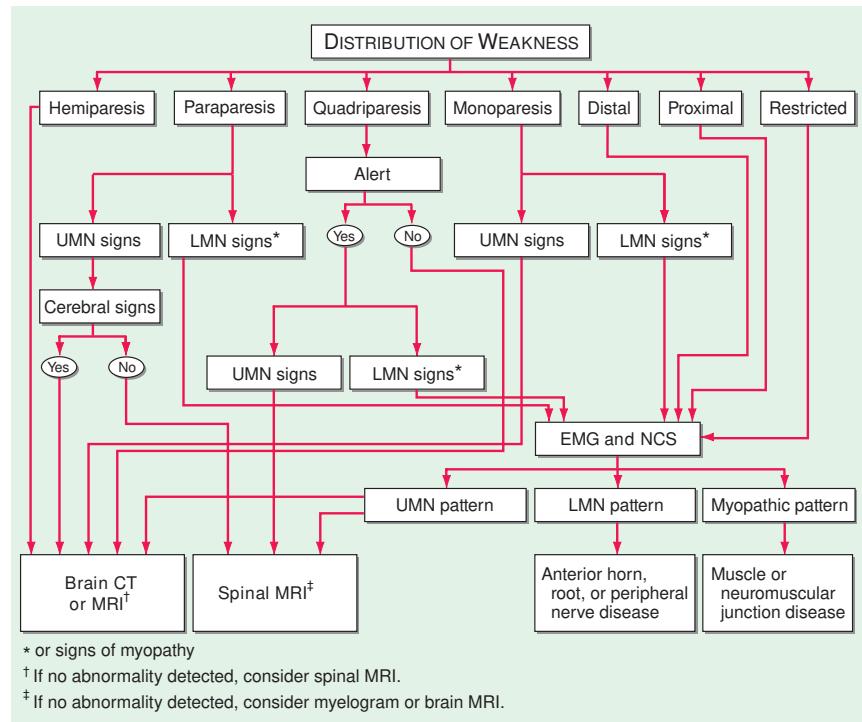


FIGURE 24-3 An algorithm for the initial workup of a patient with weakness. CT, computed tomography; EMG, electromyography; LMN, lower motor neuron; MRI, magnetic resonance imaging; NCS, nerve conduction studies; UMN, upper motor neuron.

**TABLE 24-2 Causes of Episodic Generalized Weakness**

1. Electrolyte disturbances, e.g., hypokalemia, hyperkalemia, hypercalcemia, hypernatremia, hyponatremia, hypophosphatemia, hypermagnesemia
2. Muscle disorders
  - a. Channelopathies (periodic paralyses)
  - b. Metabolic defects of muscle (impaired carbohydrate or fatty acid utilization; abnormal mitochondrial function)
3. Neuromuscular junction disorders
  - a. Myasthenia gravis
  - b. Lambert-Eaton myasthenic syndrome
4. Central nervous system disorders
  - a. Transient ischemic attacks of the brainstem
  - b. Transient global cerebral ischemia
  - c. Multiple sclerosis
5. Lack of voluntary effort
  - a. Anxiety
  - b. Pain or discomfort
  - c. Somatization disorder

**SUBACUTE OR CHRONIC QUADRIPARESIS** Quadripareisis due to upper motor neuron disease may develop over weeks to years from chronic myelopathies, multiple sclerosis, brain or spinal tumors, chronic subdural hematomas, and various metabolic, toxic, and infectious disorders. It may also result from lower motor neuron disease, a chronic neuropathy (in which weakness is often most profound distally), or myopathic weakness (typically proximal).

When quadripareisis develops acutely in obtunded patients, evaluation begins with a CT scan of the brain. If upper motor neuron signs have developed acutely but the patient is alert, the initial test is usually an MRI of the cervical cord. When onset has been gradual, disorders of the cerebral hemispheres, brainstem, and cervical spinal cord can usually be distinguished clinically, and imaging is directed first at the clinically suspected site of pathology. If weakness is lower motor neuron, myopathic, or uncertain in origin, laboratory studies can determine the levels of muscle enzymes and electrolytes, and EMG and nerve conduction studies help to localize the pathologic process (*Chap. 449*).

**Monoparesis** Monoparesis usually is due to lower motor neuron disease, with or without associated sensory involvement. Upper motor neuron weakness occasionally presents as a monoparesis of distal and nonantigravity muscles. Myopathic weakness rarely is limited to one limb.

**ACUTE MONOPARESIS** If weakness is predominantly distal and of upper motor neuron type and is not associated with sensory impairment or pain, focal cortical ischemia is likely (*Chap. 427*); diagnostic possibilities are similar to those for acute hemiparesis. Sensory loss and pain usually accompany acute lower motor neuron weakness; the weakness commonly localizes to a single nerve root or peripheral nerve, but occasionally reflects plexus involvement. If lower motor neuron weakness is likely, evaluation begins with EMG and nerve conduction studies.

**SUBACUTE OR CHRONIC MONOPARESIS** Weakness and atrophy that develop over weeks or months are usually of lower motor neuron origin. When associated with sensory symptoms, a peripheral cause (nerve, root, or plexus) is likely; otherwise, anterior horn cell disease should be considered. In either case, an electrodiagnostic study is indicated. If weakness is of the upper motor neuron type, a discrete cortical (precentral gyrus) or cord lesion may be responsible, and appropriate imaging is performed.

**Distal Weakness** Involvement of two or more limbs distally suggests lower motor neuron or peripheral nerve disease. Acute distal lower-limb weakness results occasionally from an acute toxic polyneuropathy or cauda equina syndrome. Distal symmetric weakness usually develops over weeks, months, or years and, when associated with numbness, is due to peripheral neuropathy (*Chap. 446*). Anterior horn

cell disease may begin distally but is typically asymmetric and without accompanying numbness (*Chap. 437*). Rarely, myopathies present with distal weakness (*Chap. 449*). Electrodiagnostic studies help localize the disorder (Fig. 24-3).

**Proximal Weakness** Myopathy often produces symmetric weakness of the pelvic or shoulder girdle muscles (*Chap. 449*). Diseases of the neuromuscular junction, such as myasthenia gravis (*Chap. 448*), may present with symmetric proximal weakness often associated with ptosis, diplopia, or bulbar weakness and fluctuate in severity during the day. In anterior horn cell disease, proximal weakness is usually asymmetric, but it may be symmetric especially in genetic forms. Numbness does not occur with any of these diseases. The evaluation usually begins with determination of the serum creatine kinase level and electrophysiologic studies.

**Weakness in a Restricted Distribution** Weakness may not fit any of these patterns, being limited, for example, to the extraocular, hemifacial, bulbar, or respiratory muscles. If it is unilateral, restricted weakness usually is due to lower motor neuron or peripheral nerve disease, such as in a facial palsy. Weakness of part of a limb is commonly due to a peripheral nerve lesion such as an entrapment neuropathy. Relatively symmetric weakness of extraocular or bulbar muscles frequently is due to a myopathy (*Chap. 449*) or neuromuscular junction disorder (*Chap. 448*). Bilateral facial palsy with areflexia suggests Guillain-Barré syndrome (*Chap. 447*). Worsening of relatively symmetric weakness with fatigue is characteristic of neuromuscular junction disorders. Asymmetric bulbar weakness usually is due to motor neuron disease. Weakness limited to respiratory muscles is uncommon and usually is due to motor neuron disease, myasthenia gravis, or polymyositis/dermatomyositis (*Chap. 365*).

## A

The editors acknowledge the contributions of Michael J. Aminoff to earlier editions of this chapter.

## ■ FURTHER READING

- B P et al: *Localization in Clinical Neurology*, 7th ed. Philadelphia, Lippincott William & Wilkins, 2016.
- C WW, B RJ: *DeJong's The Neurological Examination*, 8th ed. Philadelphia, Lippincott William & Wilkins, 2019.
- G B : *Aids to the Examination of the Peripheral Nervous System*, 4th ed. Edinburgh, Saunders, 2000.

## 25

# Numbness, Tingling, and Sensory Loss

Stephen L. Hauser



Normal somatic sensation reflects a continuous monitoring process, little of which reaches consciousness under ordinary conditions. By contrast, disordered sensation, particularly when experienced as painful, is alarming and dominates the patient's attention. Physicians should be able to recognize abnormal sensations by how they are described, know their type and likely site of origin, and understand their implications. Pain is considered separately in *Chap. 13*.

## ■ POSITIVE AND NEGATIVE SYMPTOMS

Abnormal sensory symptoms can be divided into two categories: positive and negative. The prototypical positive symptom is tingling (pins and needles); other positive sensory phenomena include itch and altered sensations that are described as pricking, bandlike, lightning-like shooting feelings (lancinations), aching, knifelike, twisting, drawing,

pulling, tightening, burning, searing, electrical, or raw feelings. Such symptoms are often painful.

Positive phenomena usually result from trains of impulses generated at sites of lowered threshold or heightened excitability along a peripheral or central sensory pathway. The nature and severity of the abnormal sensation depend on the number, rate, timing, and distribution of ectopic impulses and the type and function of nervous tissue in which they arise. Because positive phenomena represent excessive activity in sensory pathways, they are not necessarily associated with a sensory deficit (loss) on examination.

Negative phenomena represent loss of sensory function and are characterized by diminished or absent feeling that often is experienced as numbness and by abnormal findings on sensory examination. In disorders affecting peripheral sensation, at least one-half of the afferent axons innervating a particular site are probably lost or functionless before a sensory deficit can be demonstrated by clinical examination. If the rate of loss is slow, however, lack of cutaneous feeling may be unnoticed by the patient and difficult to demonstrate on examination, even though few sensory fibers are functioning; if it is rapid, both positive and negative phenomena are usually conspicuous. Subclinical degrees of sensory dysfunction may be revealed by sensory nerve conduction studies or somatosensory-evoked potentials.

Whereas sensory symptoms may be either positive or negative, sensory signs on examination are always a measure of negative phenomena.

## ■ TERMINOLOGY

Paresthesias and dysesthesias are general terms used to denote positive sensory symptoms. The term *paresthesia* typically refers to tingling or pins-and-needles sensations but may include a wide variety of other abnormal sensations, except pain; it sometimes implies that the abnormal sensations are perceived spontaneously. The more general term *dysesthesia* denotes all types of abnormal sensations, including painful ones, regardless of whether a stimulus is evident.

Another set of terms refers to sensory abnormalities found on examination. *Hypesthesia* or *hypoesthesia* refers to a reduction of cutaneous sensation to a specific type of testing such as pressure, light touch, and warm or cold stimuli; *anesthesia*, to a complete absence of skin sensation to the same stimuli plus pinprick; and *hypalgesia* or *analgesia*, to reduced or absent pain perception (nociception). *Hyperesthesia* means pain or increased sensitivity in response to touch. Similarly, *allodynia* describes the situation in which a nonpainful stimulus, once perceived, is experienced as painful, even excruciating. An example is elicitation of a painful sensation by application of a vibrating tuning fork. *Hyperalgesia* denotes severe pain in response to a mildly noxious stimulus, and *hyperpathia*, a broad term, encompasses all the phenomena described by hyperesthesia, allodynia, and hyperalgesia. With hyperpathia, the threshold for a sensory stimulus is increased and perception is delayed, but once felt, it is unduly painful.

Disorders of deep sensation arising from muscle spindles, tendons, and joints affect proprioception (position sense). Manifestations include imbalance (particularly with eyes closed or in the dark), clumsiness of precision movements, and unsteadiness of gait, which are referred to collectively as *sensory ataxia*. Other findings on examination usually, but not invariably, include reduced or absent joint position and vibratory sensibility and absent deep tendon reflexes in the affected limbs. The Romberg sign is positive, which means that the patient sways markedly or topples when asked to stand with feet close together and eyes closed. In severe states of deafferentation involving deep sensation, the patient cannot walk or stand unaided or even sit unsupported. Continuous involuntary movements (*pseudoathetosis*) of the outstretched hands and fingers occur, particularly with eyes closed.

## ■ ANATOMY OF SENSATION

Cutaneous receptors are classified by the type of stimulus that optimally excites them. They consist of naked nerve endings (nociceptors, which respond to tissue-damaging stimuli, and thermoreceptors, which respond to noninjurious thermal stimuli) and encapsulated terminals (several types of mechanoreceptor, activated by physical

deformation of the skin or stretch of muscles). Each type of receptor has its own set of sensitivities to specific stimuli, size and distinctness of receptive fields, and adaptational qualities.

Afferent peripheral nerve fibers conveying somatosensory information from the limbs and trunk traverse the dorsal roots and enter the dorsal horn of the spinal cord (Fig. 25-1); the cell bodies of first-order neurons are located in the dorsal root ganglia (DRG). In an analogous fashion, sensations from the face and head are conveyed through the trigeminal system (Fig. 441-2). Once fiber tracts enter the spinal cord, the polysynaptic projections of the smaller fibers (unmyelinated and small myelinated), which subserve mainly nociception, itch, temperature sensibility, and touch, cross and ascend in the opposite anterior and lateral columns of the spinal cord, through the brainstem, to the ventral posterolateral (VPL) nucleus of the thalamus and ultimately project to the postcentral gyrus of the parietal cortex and other cortical areas (Chap. 13). This is the *spinothalamic pathway* or *anterolateral system*. The larger fibers, which subserve tactile and position sense and kinesthesia, project rostrally in the posterior and posterolateral columns on the same side of the spinal cord and make their first synapse in the gracile or cuneate nucleus of the lower medulla. Axons of second-order neurons decussate and ascend in the medial lemniscus located medially in the medulla and in the tegmentum of the pons and midbrain and synapse in the VPL nucleus; third-order neurons project to parietal cortex as well as to other cortical areas. This large-fiber system is referred to as the *posterior column-medial lemniscal pathway* (lemniscal, for short). Although the fiber types and functions that make up the spinothalamic and lemniscal systems are relatively well known, many other fibers, particularly those associated with touch, pressure, and position sense, ascend in a diffusely distributed pattern both ipsilaterally and contralaterally in the anterolateral quadrants of the spinal cord. This explains why a complete lesion of the posterior columns of the spinal cord may be associated with little sensory deficit on examination.

## APPROACH TO THE PATIENT

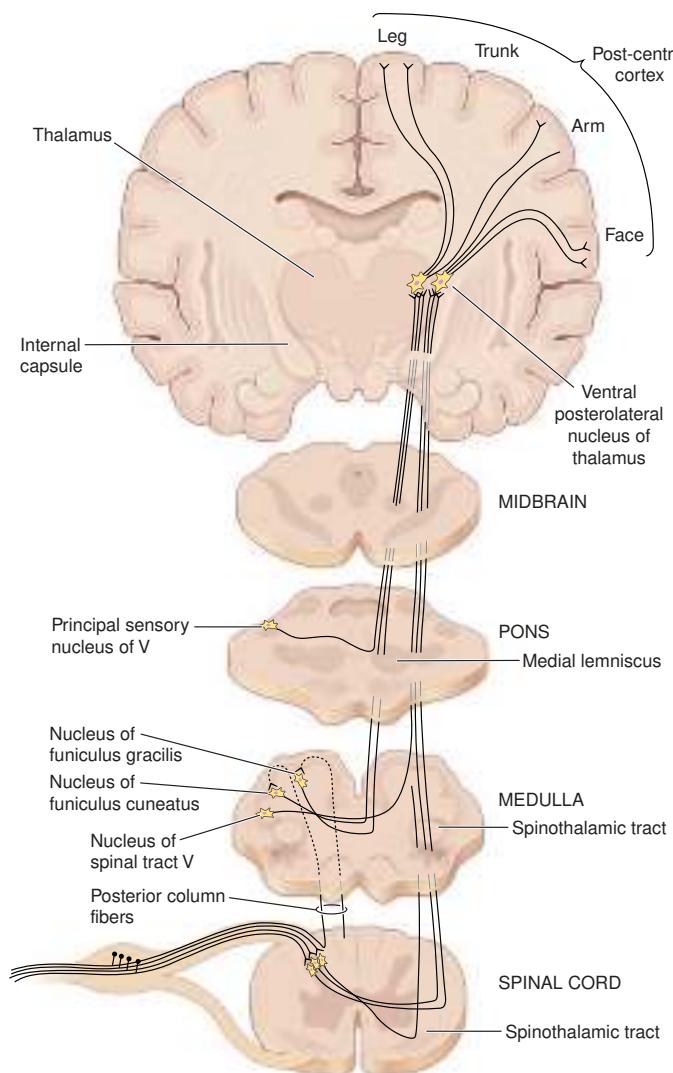
### Clinical Examination of Sensation

The main components of the sensory examination are tests of primary sensation (pain, touch, vibration, joint position, and thermal sensation) (Table 25-1). The examiner must depend on patient responses, and this complicates interpretation. Further, examination may be limited in some patients. In a stuporous patient, for example, sensory examination is reduced to observing the briskness of withdrawal in response to a pinch or another noxious stimulus. Comparison of responses on the two sides of the body is essential. In an alert but uncooperative patient, it may not be possible to examine cutaneous sensation, but some idea of proprioceptive function may be gained by noting the patient's best performance of movements requiring balance and precision.

In patients with sensory complaints, testing should begin in the center of the affected region and proceed radially until sensation is perceived as normal. The distribution of any abnormality is defined and compared to root and peripheral nerve territories (Figs. 25-2 and 25-3). Some patients present with sensory symptoms that do not fit an anatomic localization and are accompanied by either no abnormalities or gross inconsistencies on examination. The examiner should consider in such cases the possibility of a psychologic cause (see "Psychogenic Symptoms," below). Sensory examination of a patient who has no neurologic complaints can be brief and consist of pinprick, touch, and vibration testing in the hands and feet plus evaluation of stance and gait, including the Romberg maneuver (Chap. V6). Evaluation of stance and gait also tests the integrity of motor and cerebellar systems.

### PRIMARY SENSATION

The sense of pain usually is tested with a clean pin, which is then discarded. The patient is asked to close the eyes and focus on the pricking or unpleasant quality of the stimulus, not just the pressure



**FIGURE 25-1** The main somatosensory pathways. The spinothalamic tract (pain, thermal sense) and the posterior column–lemniscal system (touch, pressure, joint position) are shown. Offshoots from the ascending anterolateral fasciculus (spinothalamic tract) to nuclei in the medulla, pons, and mesencephalon and nuclear terminations of the tract are indicated. (Reproduced with permission from AH Ropper, MA Samuels: Adams and Victor's Principles of Neurology, 9th ed. New York, McGraw-Hill, 2009.)

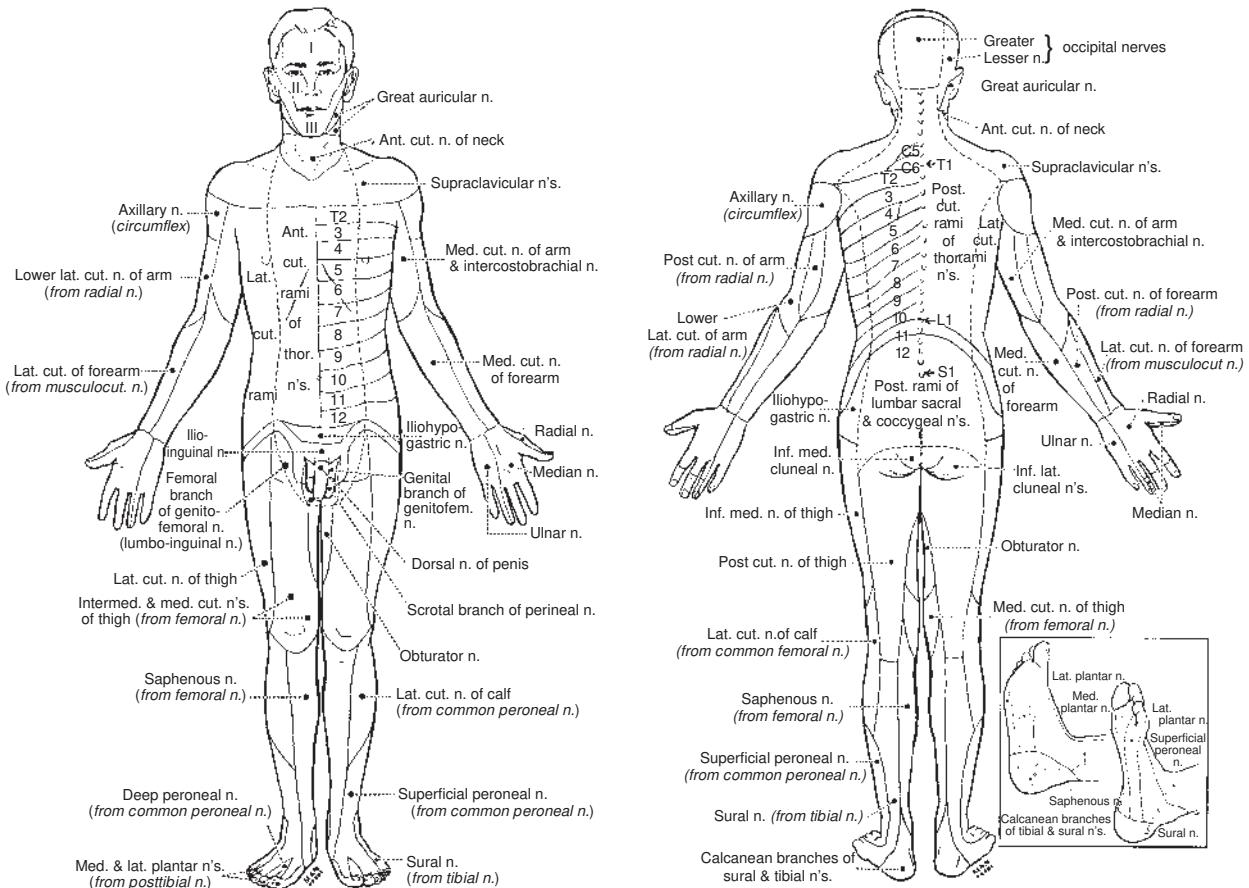
or touch sensation elicited. Areas of hypalgesia should be mapped by proceeding radially from the most hypalgesic site. Temperature sensation to both hot and cold is best tested with small containers filled with water of the desired temperature. An alternative way to test cold sensation is to touch a metal object, such as a tuning fork

at room temperature, to the skin. For testing warm temperatures, the tuning fork or another metal object may be held under warm water of the desired temperature and then used. The appreciation of both cold and warmth should be tested because different receptors respond to each. Touch usually is tested with a wisp of cotton,

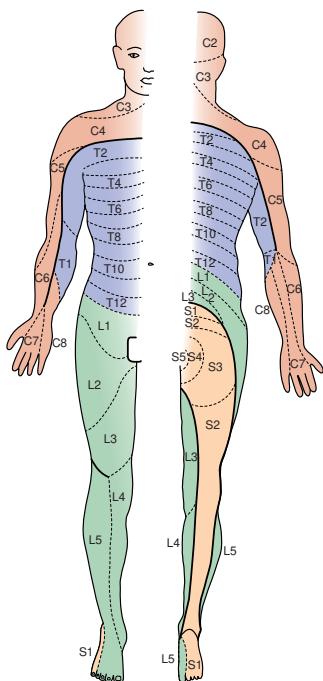
**TABLE 25-1** Testing Primary Sensation

SENSE	TEST DEVICE	ENDINGS ACTIVATED	FIBER SIZE MEDIATING	CENTRAL PATHWAY
Pain	Pinprick	Cutaneous nociceptors	Small	SpTh, also D
Temperature, heat	Warm metal object	Cutaneous thermoreceptors for hot	Small	SpTh
Temperature, cold	Cold metal object	Cutaneous thermoreceptors for cold	Small	SpTh
Touch	Cotton wisp, fine brush	Cutaneous mechanoreceptors, also naked endings	Large and small	Lem, also D and SpTh
Vibration	Tuning fork, 128 Hz	Mechanoreceptors, especially pacinian corpuscles	Large	Lem, also D
Joint position	Passive movement of specific joints	Joint capsule and tendon endings, muscle spindles	Large	Lem, also D

*Abbreviations:* D, diffuse ascending projections in ipsilateral and contralateral anterolateral columns; Lem, posterior column and lemniscal projection, ipsilateral; SpTh, spinothalamic projection, contralateral.



**FIGURE 25-2** The cutaneous fields of peripheral nerves. (Reproduced with permission from W Haymaker, B Woodhall: *Peripheral Nerve Injuries*, 2nd ed. Philadelphia, Saunders, 1953.)



**FIGURE 25-3** Distribution of the sensory spinal roots on the surface of the body (dermatomes). (Reproduced with permission from D Sinclair: *Mechanisms of Cutaneous Sensation*. Oxford, UK, Oxford University Press, 1981 through PLS Clear.)

minimizing pressure on the skin. In general, it is better to avoid testing touch on hairy skin because of the profusion of the sensory endings that surround each hair follicle. The patient is tested with the eyes closed and should respond as soon as the stimulus is perceived, indicating its location.

Joint position testing is a measure of proprioception. With the patient's eyes closed, joint position is tested in the distal interphalangeal joint of the great toe and fingers. The digit is held by its sides, distal to the joint being tested, and moved passively while more proximal joints are stabilized—the patient indicates the change in position or direction of movement. If errors are made, more proximal joints are tested. A test of proximal joint position sense, primarily at the shoulder, is performed by asking the patient to bring the two index fingers together with arms extended and eyes closed. Normal individuals can do this accurately, with errors of 1 cm or less.

The sense of vibration is tested with an oscillating tuning fork that vibrates at 128 Hz. Vibration is tested over bony points, beginning distally; in the feet, it is tested over the dorsal surface of the distal phalanx of the big toes and at the malleoli of the ankles, and in the hands, it is tested dorsally at the distal phalanx of the fingers. If abnormalities are found, more proximal sites should be examined. Vibratory thresholds at the same site in the patient and the examiner may be compared for control purposes.

#### CORTICAL SENSATION

The most commonly used tests of cortical function are two-point discrimination, touch localization, and bilateral simultaneous stimulation, and tests for graphesthesia and stereognosis. Abnormalities

of these sensory tests, in the presence of normal primary sensation in an alert cooperative patient, signify a lesion of the parietal cortex or thalamocortical projections. If primary sensation is altered, these cortical discriminative functions usually will be abnormal also. Comparisons should always be made between analogous sites on the two sides of the body because the deficit with a specific parietal lesion is likely to be unilateral.

*Two-point discrimination* can be tested with calipers, the points of which may be set from 2 mm to several centimeters apart and then applied simultaneously to the test site. On the fingertips, a normal individual can distinguish about a 3-mm separation of points.

*Touch localization* is performed by light pressure for an instant with the examiner's fingertip or a wisp of cotton wool; the patient, whose eyes are closed, is required to identify the site of touch. *Bilateral simultaneous stimulation* at analogous sites (e.g., the dorsum of both hands) can be carried out to determine whether the perception of touch is extinguished consistently on one side (*extinction* or *neglect*). *Graphesthesia* refers to the capacity to recognize, with eyes closed, letters or numbers drawn by the examiner's fingertip on the palm of the hand. Once again, interside comparison is of prime importance. Inability to recognize numbers or letters is termed *agraphesthesia*.

*Stereognosis* refers to the ability to identify common objects by palpation, recognizing their shape, texture, and size. Common standard objects such as keys, paper clips, and coins are best used. Patients with normal stereognosis should be able to distinguish a dime from a penny and a nickel from a quarter without looking. Patients should feel the object with only one hand at a time. If they are unable to identify it in one hand, it should be placed in the other for comparison. Individuals who are unable to identify common objects and coins in one hand but can do so in the other are said to have *astereognosis* of the abnormal hand.

#### QUANTITATIVE SENSORY TESTING

Effective sensory testing devices are commercially available. Quantitative sensory testing is particularly useful for serial evaluation of cutaneous sensation in clinical trials. Threshold testing for touch and vibratory and thermal sensation is the most widely used application.

#### ELECTRODIAGNOSTIC STUDIES AND NERVE BIOPSY

Nerve conduction studies and nerve biopsy are important means of investigating the peripheral nervous system, but they do not evaluate the function or structure of cutaneous receptors and free nerve endings or of unmyelinated or thinly myelinated nerve fibers in the nerve trunks. Skin biopsy can be used to evaluate these structures in the dermis and epidermis.

### ■ LOCALIZATION OF SENSORY ABNORMALITIES

Sensory symptoms and signs can result from lesions at many different levels of the nervous system from the parietal cortex to the peripheral sensory receptor. Noting their distribution and nature is the most important way to localize their source. Their extent, configuration, symmetry, quality, and severity are the key observations.

Dysesthesias without sensory findings by examination may be difficult to interpret. To illustrate, tingling dysesthesias in an acral distribution (hands and feet) can be systemic in origin, for example, secondary to hyperventilation, or induced by a medication such as acetazolamide. Distal dysesthesias can also be an early event in an evolving polyneuropathy or may herald a myopathy, such as from vitamin B<sub>12</sub> deficiency. Sometimes, distal dysesthesias have no definable basis. In contrast, dysesthesias that correspond in distribution to that of a particular peripheral nerve structure denote a lesion at that site. For instance, dysesthesias restricted to the fifth digit and the adjacent one-half of the fourth finger on one hand reliably point to disorder of the ulnar nerve, most commonly at the elbow.

**Nerve and Root** In focal nerve trunk lesions, sensory abnormalities are readily mapped and generally have discrete boundaries

(Figs. 25-2 and 25-3). Root ("radicular") lesions frequently are accompanied by deep, aching pain along the course of the related nerve trunk. With compression of a fifth lumbar (L5) or first sacral (S1) root, as from a ruptured intervertebral disk, sciatica (radicular pain relating to the sciatic nerve trunk) is a common manifestation (Chap. 17). With a lesion affecting a single root, sensory deficits may be minimal or absent because adjacent root territories overlap extensively.

Isolated mononeuropathies may cause symptoms beyond the territory supplied by the affected nerve, but abnormalities on examination typically are confined to expected anatomic boundaries. In multiple mononeuropathies, symptoms and signs occur in discrete territories supplied by different individual nerves and—as more nerves are affected—may simulate a polyneuropathy if deficits become confluent. With polyneuropathies, sensory deficits are generally graded, distal, and symmetric in distribution (Chap. 446). Dysesthesias, followed by numbness, begin in the toes and ascend symmetrically. When dysesthesias reach the knees, they usually also have appeared in the fingertips. The process is nerve length-dependent, and the deficit is often described as "stocking glove" in type. Involvement of both hands and feet also occurs with lesions of the upper cervical cord or the brainstem, but an upper level of the sensory disturbance may then be found on the trunk and other evidence of a central lesion may be present, such as sphincter involvement or signs of an upper motor neuron lesion (Chap. 24). Although most polyneuropathies are pансensory and affect all modalities of sensation, selective sensory dysfunction according to nerve fiber size may occur. Small-fiber polyneuropathies are characterized by burning, painful dysesthesias with reduced pinprick and thermal sensation but with sparing of proprioception, motor function, and deep tendon reflexes. Touch is involved variably; when it is spared, the sensory pattern is referred to as exhibiting *sensory dissociation*. Sensory dissociation may occur also with spinal cord lesions (Chap. 442). Large-fiber polyneuropathies are characterized by vibration and position sense deficits, imbalance, absent tendon reflexes, and variable motor dysfunction but preservation of most cutaneous sensation. Dysesthesias, if present at all, tend to be tingling or bandlike in quality.

Sensory neuronopathy (or ganglionopathy) is characterized by widespread but asymmetric sensory loss occurring in a non-length-dependent manner so that it may occur proximally or distally, and in the arms, legs, or both. Pain and numbness progress to sensory ataxia and impairment of all sensory modalities over time. This condition is usually paraneoplastic or idiopathic in origin (Chaps. 94 and 445) or related to an autoimmune disease, particularly Sjögren's syndrome (Chap. 361).

**Spinal Cord** (See also Chap. 442) If the spinal cord is transected, all sensation is lost below the level of transection. Bladder and bowel function also are lost, as is motor function. Lateral hemisection of the spinal cord produces the Brown-Séquard syndrome, with absent pain and temperature sensation contralaterally and loss of proprioceptive sensation and power ipsilaterally below the lesion (see Figs. 25-1 and 442-1); ipsilateral pain or hyperesthesia may also occur.

Numbness or paresthesias in both feet may arise from a spinal cord lesion; this is especially likely when the upper level of the sensory loss extends to the trunk. When all extremities are affected, the lesion is probably in the cervical region or brainstem unless a peripheral neuropathy is responsible. The presence of upper motor neuron signs (Chap. 24) supports a central lesion; a hyperesthetic band on the trunk may suggest the level of involvement.

A dissociated sensory loss can reflect spinothalamic tract involvement in the spinal cord, especially if the deficit is unilateral and has an upper level on the torso. Bilateral spinothalamic tract involvement occurs with lesions affecting the center of the spinal cord, such as in syringomyelia. There is a dissociated sensory loss with impairment of pinprick and temperature appreciation but relative preservation of light touch, position sense, and vibration appreciation.

Dysfunction of the posterior columns in the spinal cord or of the posterior root entry zone may lead to a bandlike sensation around the trunk or a feeling of tight pressure in one or more limbs. Flexion

of the neck sometimes leads to an electric shock-like sensation that radiates down the back and into the legs (Lhermitte's sign) in patients with a cervical lesion affecting the posterior columns, such as from multiple sclerosis, cervical spondylosis, or following irradiation to the cervical region.

**Brainstem** Crossed patterns of sensory disturbance, in which one side of the face and the opposite side of the body are affected, localize to the lateral medulla. Here a small lesion may damage both the ipsilateral descending trigeminal tract and the ascending spinothalamic fibers subserving the opposite arm, leg, and hemitorso (see "Lateral medullary syndrome" in Fig. 426-7). A lesion in the tegmentum of the pons and midbrain, where the lemniscal and spinothalamic tracts merge, causes pansensory loss contralaterally.

**Thalamus** Hemisensory disturbance with tingling numbness from head to foot is often thalamic in origin but also can arise from the anterior parietal region. If abrupt in onset, the lesion is likely to be due to a small stroke (lacunar infarction), particularly if localized to the thalamus. Occasionally, with lesions affecting the VPL nucleus or adjacent white matter, a syndrome of thalamic pain, also called *Déjerine-Roussy syndrome*, may ensue. The persistent, unrelenting unilateral pain often is described in dramatic terms.

**Cortex** With lesions of the parietal lobe involving either the cortex or subjacent white matter, the most prominent symptoms are contralateral hemineglect, hemi-inattention, and a tendency not to use the affected hand and arm. On cortical sensory testing (e.g., two-point discrimination, graphesthesia), abnormalities are often found but primary sensation is usually intact. Anterior parietal infarction may present as a pseudothalamic syndrome with contralateral loss of primary sensation from head to toe. Dysesthesias or a sense of numbness and, rarely, a painful state may also occur.

**Focal Sensory Seizures** These seizures generally are due to lesions in the area of the postcentral or precentral gyrus. The principal symptom of focal sensory seizures is tingling, but additional, more complex sensations may occur, such as a rushing feeling, a sense of warmth, or a sense of movement without detectable motion. Symptoms typically are unilateral; commonly begin in the arm or hand, face, or foot; and often spread in a manner that reflects the cortical representation of different bodily parts, as in a Jacksonian march. Their duration is variable; seizures may be transient, lasting only for seconds, or persist for an hour or more. Focal motor features may supervene, often becoming generalized with loss of consciousness and tonic-clonic jerking.

**Psychogenic Symptoms** Sensory symptoms may have a psychogenic basis. Such symptoms may be generalized or have an anatomic boundary that is difficult to explain neurologically, for example, circumferentially at the groin or shoulder or around a specific joint. Pain is common, but the nature and intensity of any sensory disturbances are variable. The diagnosis should not be one of exclusion but based on suggestive findings that are otherwise difficult to explain, such as midline splitting of impaired vibration, pinprick, or light touch appreciation; variability or poor reproducibility of sensory deficits; or normal performance of tasks requiring sensory input that is seemingly abnormal on formal testing, such as good performance with eyes closed of the finger-to-nose test despite an apparent loss of position sense in the upper limb. The side with abnormal sensation may be confused when the limbs are placed in an unusual position, such as crossed behind the back. Sensory complaints should not be regarded as psychogenic simply because they are unusual.

## TREATMENT

Management is based on treatment of the underlying condition. Symptomatic treatment of acute and chronic pain is discussed in Chap. 13. Dysesthesias, when severe and persistent, may respond to anticonvulsants (carbamazepine, 100–1000 mg/d; gabapentin, 300–3600 mg/d; or pregabalin, 50–300 mg/d), antidepressants (amitriptyline, 25–150 mg/d; nortriptyline, 25–150 mg/d; desipramine, 100–300 mg/d; or venlafaxine, 75–225 mg/d).

A

The editors acknowledge the contributions of Michael J. Aminoff to earlier editions of this chapter.

## FURTHER READING

- B P et al: *Localization in Clinical Neurology*, 7th ed. Philadelphia, Lippincott William & Wilkins, 2016.
- C WW, B RJ: *DeJong's the Neurologic Examination*, 8th ed. Philadelphia, Wolters Kluwer, 2020.
- W S: *Clinical Neuroanatomy*, 29th ed. New York, McGraw Hill Education, 2020.

26

# Gait Disorders, Imbalance, and Falls

Jessica M. Baker



## PREVALENCE, MORBIDITY, AND MORTALITY

Gait and balance problems are common in the elderly and contribute to the risk of falls and injury. Gait disorders have been described in 15% of individuals aged >65. By age 80, one person in four will use a mechanical aid to assist with ambulation. Among those aged ≥85, the prevalence of gait abnormality approaches 40%. In epidemiologic studies, gait disorders are consistently identified as a major risk factor for falls and injury.

## ANATOMY AND PHYSIOLOGY

An upright bipedal gait depends on the successful integration of postural control and locomotion. These functions are widely distributed in the central nervous system. The biomechanics of bipedal walking are complex, and the performance is easily compromised by a neurologic deficit at any level. Command and control centers in the brainstem, cerebellum, and forebrain modify the action of spinal pattern generators to promote stepping. While a form of "fictive locomotion" can be elicited from quadrupedal animals after spinal transection, this capacity is limited in primates. Step generation in primates is dependent on locomotor centers in the pontine tegmentum, midbrain, and subthalamic region. Locomotor synergies are executed through the reticular formation and descending pathways in the ventromedial spinal cord. Cerebral control provides a goal and purpose for walking and is involved in avoidance of obstacles and adaptation of locomotor programs to context and terrain.

Postural control requires the maintenance of the center of mass over the base of support through the gait cycle. Unconscious postural adjustments maintain standing balance: long latency responses are measurable in the leg muscles, beginning 110 milliseconds after a perturbation. Forward motion of the center of mass provides propulsive force for stepping, but failure to maintain the center of mass within stability limits results in falls. The anatomic substrate for dynamic balance has not been well defined, but the vestibular nucleus and midline cerebellum contribute to balance control in animals. Patients with damage to these structures have impaired balance while standing and walking.

Standing balance depends on good-quality sensory information about the position of the body center with respect to the environment, support surface, and gravitational forces. Sensory information for postural control is primarily generated by the visual system, the vestibular system, and proprioceptive receptors in the muscle spindles and joints. A healthy redundancy of sensory afferent information is generally available, but loss of two of the three pathways is sufficient to compromise standing balance. Balance disorders in older individuals

sometimes result from multiple insults in the peripheral sensory systems (e.g., visual loss, vestibular deficit, peripheral neuropathy) that critically degrade the quality of afferent information needed for balance stability.

Older patients with cognitive impairment appear to be particularly prone to falls and injury. There is a growing body of literature on the use of attentional resources to manage gait and balance. Walking is generally considered to be unconscious and automatic, but the ability to walk while attending to a cognitive task (*dual-task walking*) may be compromised in the elderly. Older patients with deficits in executive function may have particular difficulty in managing the attentional resources needed for dynamic balance when distracted.

## DISORDERS OF GAIT

Disorders of gait may be attributed to neurologic and nonneurologic causes, although significant overlap often exists. The *antalgic gait* results from avoidance of pain associated with weight bearing and is commonly seen in osteoarthritis. Asymmetry is a common feature of gait disorders due to contractures and other orthopedic deformities. Impaired vision rounds out the list of common nonneurologic causes of gait disorders.

Neurologic gait disorders are disabling and equally important to address. The heterogeneity of gait disorders observed in clinical practice reflects the large network of neural systems involved in the task. Walking is vulnerable to neurologic disease at every level. Gait disorders have been classified descriptively on the basis of abnormal physiology and biomechanics. One problem with this approach is that many failing gaits look fundamentally similar. This overlap reflects common patterns of adaptation to threatened balance stability and declining performance. *The gait disorder observed clinically must be viewed as the product of a neurologic deficit and a functional adaptation.* Unique features of the failing gait are often overwhelmed by the adaptive response. Some common patterns of abnormal gait are summarized next. Gait disorders can also be classified by etiology (Table 26-1).

### ■ CAUTIOUS GAIT

The term *cautious gait* is used to describe the patient who walks with an abbreviated stride, widened base, and lowered center of mass, as if walking on a slippery surface. Arms are often held abducted. This disorder is both common and nonspecific. It is, in essence, an adaptation to a perceived postural threat. There may be an associated fear of falling. This disorder can be observed in more than one-third of older

patients with gait impairment. Physical therapy often improves walking to the degree that follow-up observation may reveal a more specific underlying disorder.

### ■ STIFF LEGGED GAIT

Spastic gait is characterized by stiffness in the legs, an imbalance of muscle tone, and a tendency to circumduct and scuff the feet. The disorder reflects compromise of corticospinal command and overactivity of spinal reflexes. The patient may walk on the toes. In extreme instances, the legs cross due to increased tone in the adductors ("scissoring" gait). Upper motor neuron signs are present on physical examination. The disorder may be cerebral or spinal in origin.

Myelopathy from cervical spondylosis is a common cause of spastic or spastic-ataxic gait in the elderly. Demyelinating disease and trauma are the leading causes of myelopathy in younger patients. In chronic progressive myelopathy of unknown cause, a workup with laboratory and imaging tests may establish a diagnosis. A structural lesion, such as a tumor or a spinal vascular malformation, should be excluded with appropriate testing. *Spinal cord disorders are discussed in detail in Chap. 442.*

With cerebral spasticity, asymmetry is common, the upper extremities are usually involved, and dysarthria is often an associated feature. Common causes include vascular disease (stroke), multiple sclerosis, motor neuron disease, and perinatal nervous system injury (cerebral palsy).

Other stiff-legged gaits include dystonia (Chap. 436) and stiff-person syndrome (Chap. 94). Dystonia is a disorder characterized by sustained muscle contractions resulting in repetitive twisting movements and abnormal posture. It often has a genetic basis. Dystonic spasms can produce plantar flexion and inversion of the feet, sometimes with torsion of the trunk. In autoimmune stiff-person syndrome, exaggerated lordosis of the lumbar spine and overactivation of antagonist muscles restrict trunk and lower-limb movement and result in a wooden or fixed posture.

### ■ PARKINSONISM, FREEZING GAIT, AND OTHER MOVEMENT DISORDERS

Parkinson's disease (Chap. 435) is common, affecting 1% of the population >65 years of age. The stooped posture, shuffling gait, and decreased arm swing are characteristic and distinctive features. Patients sometimes accelerate (festinate) with walking, display retropulsion, or exhibit a tendency to turn en bloc. The step-to-step variability

TABLE 26-1 Prevalence of Neurologic Gait Disorders

NEUROLOGIC GAIT DISORDER	NO. (%) <sup>a</sup>	TOTAL NUMBER <sup>b</sup>	CAUSES (NO.)
Single neurologic gait disorder	81 (69%)		
Sensory ataxic	22 (18%)	46	Peripheral sensory neuropathy (46)
Parkinsonian	19 (16%)	34	Parkinson's disease (18), drug-induced parkinsonism (8), dementia with parkinsonism (4), parkinsonism (4)
Higher level	9 (8%)	31	Vascular encephalopathy (20), normal pressure hydrocephalus (1), severe dementia (7), hypoxic ischemic encephalopathy (1), unknown (1)
Cerebellar ataxic	7 (6%)	10	Cerebellar stroke (3), cerebellar lesion due to multiple sclerosis (1), severe essential tremor (3), postvaccinal cerebellitis (1), chronic alcohol abuse (1), multiple system atrophy (1)
Cautious	7 (6%)	7	Idiopathic, associated fear of falling (7)
Paretic/hypotonic	6 (5%)	14	Neurogenic claudication (7), diabetic neuropathy (1), nerve lesion due to trauma or surgery (4), distal paraparesis after Guillain-Barré syndrome (1), unknown (2)
Spastic	6 (5%)	7	Ischemic stroke (3), intracerebral hemorrhage (3), congenital (1)
Vestibular ataxic	4 (3%)	6	Bilateral vestibulopathy (3), recent vestibular neuritis (1), recent Ménière's attack (1), acoustic neuroma with surgery (1)
Dyskinetic	1 (1%)	4	Levodopa-induced dyskinesia (3), chorea (1)
Multiple neurologic gait disorders	36 (30%)		
Total	117		

<sup>a</sup>Percentage of individuals with a single gait disorder. <sup>b</sup>Includes individuals with multiple gait disorders.

Note: Of 117 patients with a neurologic gait disorder, 81 had a single neurologic gait disorder; the remainder (36) had multiple neurologic gait disorders.

Source: Reproduced with modifications from P Mahlknecht et al: PLoS One 8:e69627, 2013.

of the parkinsonian gait also contributes to falls, which are a major source of morbidity, particularly later in the disease course. Dopamine replacement improves step length, arm swing, turning speed, and gait initiation. There is increasing evidence that deficits in cholinergic circuits in the pedunculopontine nucleus and cortex contribute to the gait disorder of Parkinson's disease. Cholinesterase inhibitors such as donepezil and rivastigmine have been shown in early studies to significantly decrease gait variability, instability, and fall frequency, even in the absence of cognitive impairment, perhaps through improvement in attention.

**Freezing** is defined as a brief, episodic absence of forward progression of the feet, despite the intention to walk. Freezing may be triggered by approaching a narrow doorway or crowd, may be overcome by visual cuing, and contributes to fall risk. Gait freezing is present in approximately one-quarter of Parkinson's patients within 5 years of onset, and its frequency increases further over time. In treated patients, end-of-dose gait freezing is a common problem that may improve with more frequent administration of dopaminergic drugs or with use of monoamine oxidase type B inhibitors such as rasagiline or selegiline (Chap. 435).

Freezing of gait is also common in other neurodegenerative disorders associated with parkinsonism, including progressive supranuclear palsy (PSP), multiple-system atrophy, and corticobasal degeneration. Patients with these disorders frequently present with axial stiffness, postural instability, and a shuffling, freezing gait while lacking the characteristic pill-rolling tremor of Parkinson's disease. The gait of PSP is typically more erect compared with the stooped posture of typical Parkinson's disease, and falls within the first year also suggest the possibility of PSP. The gait of vascular parkinsonism tends to be broad-based and shuffling with reduced arm swing bilaterally; disproportionate involvement of gait early in the disease course differentiates this entity from Parkinson's disease.

Hyperkinetic movement disorders also produce characteristic and recognizable disturbances in gait. In Huntington's disease (Chap. 436), the unpredictable occurrence of choreic movements gives the gait a dancing quality. Tardive dyskinesia is the cause of many odd, stereotypic gait disorders seen in patients chronically exposed to antipsychotics and other drugs that block the D<sub>2</sub> dopamine receptor. *Orthostatic tremor* is a high-frequency, low-amplitude tremor predominantly involving the lower extremities. Patients often report shakiness or unsteadiness on standing and improvement with sitting or walking. Falls are common. The tremor is often only appreciable by palpating the legs while standing.

## ■ FRONTAL GAIT DISORDER

Frontal gait disorder, also known as higher-level gait disorder, is common in the elderly and has a variety of causes. The term is used to describe a shuffling, freezing gait with imbalance, and other signs of higher cerebral dysfunction. Typical features include a wide base of support, a short stride, shuffling along the floor, and difficulty with starts and turns. Many patients exhibit a difficulty with gait initiation that is descriptively characterized as the "slipping clutch" syndrome or gait ignition failure. The term *lower-body parkinsonism* is also used to describe such patients. Strength is generally preserved, and patients are able to

make stepping movements when not standing and maintaining their balance at the same time. This disorder is best considered a higher-level motor control disorder, as opposed to an apraxia (Chap. 30), though the term *gait apraxia* persists in the literature.

The most common cause of frontal gait disorder is vascular disease, particularly subcortical small-vessel disease in the deep frontal white matter and centrum ovale. Over three-quarters of patients with subcortical vascular dementia demonstrate gait abnormalities; decreased arm swing and a stooped posture are particularly prevalent features. The clinical syndrome also includes dysarthria, pseudobulbar affect (emotional disinhibition), increased tone, and hyperreflexia in the lower limbs.

Normal pressure (communicating) hydrocephalus (NPH) in adults also presents with a similar gait disorder (Chap. 431). Other features of the diagnostic triad (mental changes, incontinence) may be absent in a substantial number of patients. MRI demonstrates ventricular enlargement, an enlarged flow void about the aqueduct, periventricular white matter change, and high-convexity tightness (disproportionate widening of the sylvian fissures versus the cortical sulci). A lumbar puncture or dynamic test is necessary to confirm a diagnosis of NPH. Neurodegenerative dementias and mass lesions of the frontal lobes cause a similar clinical picture and can be differentiated from vascular disease and hydrocephalus by neuroimaging.

## ■ CEREBELLAR GAIT ATAXIA

Disorders of the cerebellum (Chap. 439) have a dramatic impact on gait and balance. Cerebellar gait ataxia is characterized by a wide base of support, lateral instability of the trunk, erratic foot placement, and decompensation of balance when attempting to walk on a narrow base. Difficulty maintaining balance when turning is often an early feature. Patients are unable to walk tandem heel to toe and display truncal sway in narrow-based or tandem stance. They show considerable variation in their tendency to fall in daily life.

Causes of cerebellar ataxia in older patients include stroke, trauma, tumor, and neurodegenerative disease such as multiple-system atrophy (Chap. 440) and various forms of hereditary cerebellar degeneration (Chap. 439). A short expansion at the site of the fragile X mutation (*fragile X premutation*) has been associated with gait ataxia in older men. Alcohol causes an acute and chronic cerebellar ataxia. In patients with ataxia due to cerebellar degeneration, MRI demonstrates the extent and topography of cerebellar atrophy.

## ■ SENSORY ATAXIA

As reviewed earlier in this chapter, balance depends on high-quality afferent information from the visual and the vestibular systems and proprioception. When this information is lost or degraded, balance during locomotion is impaired and instability results. The sensory ataxia of tabetic neurosyphilis is a classic example. The contemporary equivalent is the patient with neuropathy affecting large fibers. Vitamin B<sub>12</sub> deficiency is a treatable cause of large-fiber sensory loss in the spinal cord and peripheral nervous system. Joint position and vibration sense are diminished in the lower limbs. The stance in such patients is destabilized by eye closure; they often look down at their feet when walking and do poorly in the dark. Table 26-2 compares sensory ataxia with cerebellar ataxia and frontal gait disorder.

TABLE 26-2 Features of Cerebellar Ataxia, Sensory Ataxia, and Frontal Gait Disorders

FEATURE	CEREBELLAR ATAXIA	SENSORY ATAXIA	FRONTAL GAIT
Base of support	Wide-based	Narrow base, looks down	Wide-based
Velocity	Variable	Slow	Very slow
Stride	Irregular, lurching	Regular with path deviation	Short, shuffling
Romberg test	+/-	Unsteady, falls	+/-
Heel → shin	Abnormal	+/-	Normal
Initiation	Normal	Normal	Hesitant
Turns	Unsteady	+/-	Hesitant, multistep
Postural instability	+	+++	+++/ Poor postural synergies rising from a chair
Falls	Late event	Frequent	Frequent

## ■ NEUROMUSCULAR DISEASE

Patients with neuromuscular disease often have an abnormal gait, occasionally as a presenting feature. With distal weakness (peripheral neuropathy), the step height is increased to compensate for foot drop, and the sole of the foot may slap on the floor during weight acceptance, termed the *steppage gait*. Patients with myopathy or muscular dystrophy more typically exhibit proximal weakness. Weakness of the hip girdle may result in some degree of excess pelvic sway during locomotion. The stooped posture of lumbar spinal stenosis ameliorates pain from the compression of the cauda equina occurring with a more upright posture while walking and may mimic early parkinsonism.

## ■ TOXIC AND METABOLIC DISORDERS

Chronic toxicity from medications and metabolic disturbances can impair motor function and gait. Examination may reveal mental status changes, asterixis, or myoclonus. Static equilibrium is disturbed, and such patients are easily thrown off balance. Disequilibrium is particularly evident in patients with chronic renal disease and those with hepatic failure, in whom asterixis may impair postural support. Sedative drugs, especially neuroleptics and long-acting benzodiazepines, affect postural control and increase the risk for falls. These disorders are especially important to recognize because they are often treatable.

## ■ FUNCTIONAL GAIT DISORDER

Functional neurologic disorders (formerly “psychogenic”) are common in practice, and the presentation often involves gait. Sudden onset, inconsistent deficits, waxing and waning course, incongruence of symptoms with an organic lesion, and improvement with distraction are key features. Phenomenology is variable; extreme slow motion, an inappropriately overcautious gait, odd gyrations of posture with wastage of muscular energy, astasia-abasia (inability to stand and walk), bouncing, and foot stiffness (dystonia) have been described. Falls are rare, and there are often discrepancies between examination findings and the patient’s functional status. Preceding stress or trauma is variably present, and its absence does not preclude the diagnosis of a functional gait disorder. Functional gait disorders may be challenging to diagnose and should be differentiated from the slowness and psychomotor retardation seen in certain patients with major depression.

## APPROACH TO THE PATIENT

### Slowly Progressive Disorder of Gait

When reviewing the history, it is helpful to inquire about the onset and progression of disability. Initial awareness of an unsteady gait often follows a fall. Stepwise evolution or sudden progression suggests vascular disease. Gait disorder may be associated with urinary urgency and incontinence, particularly in patients with cervical spine disease or hydrocephalus. It is always important to review the use of alcohol and medications that affect gait and balance. Information on localization derived from the neurologic examination can be helpful in narrowing the list of possible diagnoses.

Gait observation provides an immediate sense of the patient’s degree of disability. Arthritic and antalgic gaits are recognized by observation, although neurologic and orthopedic problems may coexist. Characteristic patterns of abnormality are sometimes seen, although, as stated previously, failing gaits often look fundamentally similar. Cadence (steps per minute), velocity, and stride length can be recorded by timing a patient over a fixed distance. Watching the patient rise from a chair provides a good functional assessment of balance.

Brain imaging studies may be informative in patients with an undiagnosed disorder of gait. MRI is sensitive for cerebral lesions of vascular or demyelinating disease and is a good screening test for occult hydrocephalus. Patients with recurrent falls are at risk for subdural hematoma. As mentioned earlier, many elderly patients with gait and balance difficulty have white matter abnormalities in the periventricular region and centrum semiovale. While these lesions may be an incidental finding, a substantial burden of white matter disease will ultimately impact cerebral control of locomotion.

## DISORDERS OF BALANCE

### ■ DEFINITION, ETIOLOGY, AND MANIFESTATIONS

*Balance* is the ability to maintain equilibrium—a dynamic state in which one’s center of mass is controlled with respect to the lower extremities, gravity, and the support surface despite external perturbations. The reflexes required to maintain upright posture require input from cerebellar, vestibular, and somatosensory systems; the premotor cortex and corticospinal and rubrospinal tracts mediate output to axial and proximal limb muscles. These responses are physiologically complex, and the anatomic representation they entail is not well understood. Failure can occur at any level and presents as difficulty maintaining posture while standing and walking.

The history and physical examination may differentiate underlying causes of imbalance. Patients with *cerebellar* ataxia do not generally complain of dizziness, although balance is visibly impaired. Neurologic examination reveals a variety of cerebellar signs. Postural compensation may prevent falls early on, but falls are inevitable with disease progression. The progression of neurodegenerative ataxia is often measured by the number of years to loss of stable ambulation.

*Vestibular* disorders (Chap. 22) have symptoms and signs that fall into three categories: (1) vertigo (the subjective inappropriate perception or illusion of movement); (2) nystagmus (involuntary eye movements); and (3) impaired standing balance. Not every patient has all manifestations. Patients with vestibular deficits related to ototoxic drugs may lack vertigo or obvious nystagmus, but their balance is impaired on standing and walking, and they cannot navigate in the dark. Laboratory testing is available to investigate vestibular deficits.

*Somatosensory* deficits also produce imbalance and falls. There is often a subjective sense of insecure balance and fear of falling. Postural control is compromised by eye closure (*Romberg’s sign*); these patients also have difficulty navigating in the dark. A dramatic example is provided by the patient with autoimmune subacute sensory neuropathy, which is sometimes a paraneoplastic disorder (Chap. 94). Compensatory strategies enable such patients to walk in the virtual absence of proprioception, but the task requires active visual monitoring.

Patients with *higher-level disorders of equilibrium* have difficulty maintaining balance in daily life and may present with falls. Their awareness of balance impairment may be reduced. Patients taking sedating medications are in this category.

### ■ FALLS

Falls are common in the elderly; over one-third of people aged >65 who are living in the community fall each year. This number is even higher in nursing homes and hospitals. Elderly people are not only at higher risk for falls but are also more likely to suffer serious complications due to medical comorbidities such as osteoporosis. Hip fractures result in hospitalization, can lead to nursing home admission, and are associated with an increased mortality risk in the subsequent year. Falls may result in brain or spinal injury, the history of which may be difficult for the patient to provide. The proportion of spinal cord injuries due to falls in individuals aged >65 years has doubled in the past decade, perhaps due to increasing activity in this age group. Some falls result in a prolonged time lying on the ground; fractures and CNS injury are a particular concern in this context.

For each person who is physically disabled, there are others whose functional independence is limited by anxiety and fear of falling. Nearly one in five elderly individuals voluntarily restricts his or her activity because of fear of falling. With loss of ambulation, the quality of life diminishes, and rates of morbidity and mortality increase.

### ■ RISK FACTORS FOR FALLS

Risk factors for falls may be *intrinsic* (e.g., gait and balance disorders) or *extrinsic* (e.g., polypharmacy, environmental factors); some risk factors are modifiable. The presence of multiple risk factors is associated with a substantially increased risk of falls. Table 26-3 summarizes a meta-analysis of studies establishing the principal risk factors for falls. Polypharmacy (use of four or more prescription medications) has also been identified as an important risk factor.

RISK FACTOR	MEAN RR (OR)	RANGE
Muscle weakness	4.4	1.5–10.3
History of falls	3.0	1.7–7.0
Gait deficit	2.9	1.3–5.6
Balance deficit	2.9	1.6–5.4
Use assistive device	2.6	1.2–4.6
Visual deficit	2.5	1.6–3.5
Arthritis	2.4	1.9–2.9
Impaired ADL	2.3	1.5–3.1
Depression	2.2	1.7–2.5
Cognitive impairment	1.8	1.0–2.3
Age >80 years	1.7	1.1–2.5

Abbreviations: ADL, activity of daily living; OR, odds ratio from retrospective studies; RR, relative risk from prospective studies.

Source: Reproduced with permission from Guideline for the Prevention of Falls in Older Persons. J Am Geriatr Soc 49:664, 2001.

### ASSESSMENT OF THE PATIENT WITH FALLS

The most productive approach is to identify the high-risk patient prospectively, before there is a serious injury. All community-dwelling adults should be asked annually about falls and whether or not fear of falling limits daily activities. The Timed Up and Go ("TUG") test involves timing a patient as they stand up from a chair, walk 10 feet, turn, and then sit down. Patients with a history of falls or those requiring >12 s to complete the TUG test are at high risk for falls and should undergo further assessment.

**History** The history surrounding a fall is often problematic or incomplete, and the underlying mechanism or cause may be difficult to establish in retrospect. Patients should be queried about any provoking factors (including head turn, standing) or prodromal symptoms, such as dizziness, vertigo, presyncopal symptoms, or focal weakness. A history of baseline mobility and medical comorbidities should be elicited. Patients at particular risk include those with mental status changes or dementia. Medications should be reviewed, with particular attention to benzodiazepines, opioids, antipsychotics, antiepileptics, antidepressants, antiarrhythmics, and diuretics, all of which are associated with an increased risk of falls. It is equally important to distinguish *mechanical falls* (those caused by tripping or slipping) due to purely extrinsic or environmental factors from those in which a modifiable intrinsic factor contributes. *Recurrent falls* may indicate an underlying gait or balance disorder. Falls associated with loss of consciousness (syncope, seizure) may require appropriate cardiac or neurologic evaluation and intervention (Chaps. 21 and 425), although a patient's report of change in consciousness may be unreliable.

**Physical Examination** Examination of the patient with falls should include a basic cardiac examination, including orthostatic blood pressure if indicated by history, and observation of any orthopedic abnormalities. Mental status is easily assessed while obtaining a history from the patient; the remainder of the neurologic examination should include visual acuity, strength and sensation in the lower extremities, muscle tone, and cerebellar function, with particular attention to gait and balance as described earlier in this chapter.

**Fall Patterns** The description of a fall event may provide further clues to the underlying etiology. While there is no standard nosology of falls, some common clinical patterns may emerge and provide a clue.

**DROP ATTACKS AND COLLAPSING FALLS** Drop attacks and collapsing falls are associated with a sudden loss of postural tone. Patients may report that their legs just "gave out" underneath them or that they "collapsed in a heap." Syncope or orthostatic hypotension may be a factor in some such falls. Neurologic causes are relatively rare but include atonic seizures, myoclonus, and intermittent obstruction of the foramen of Monro by a colloid cyst of the third ventricle causing acute obstructive hydrocephalus. An emotional trigger suggests cataplexy.

While collapsing falls are more common among older patients with vascular risk factors, drop attacks should not be confused with vertebrobasilar ischemic attacks.

**TOPPLING FALLS** Some patients maintain tone in antigravity muscles but fall over like a tree trunk, as if postural defenses had disengaged. Causes include cerebellar pathology and lesions of the vestibular system. There may be a consistent direction to such falls. Toppling falls are an early feature of progressive supranuclear palsy, and a late feature of Parkinson's disease, once postural instability has developed. Thalamic lesions causing truncal instability (*thalamic astasia*) may also contribute to this type of fall.

**FALLS DUE TO GAIT FREEZING** Freezing of gait is seen in Parkinson's disease and related disorders. The feet stick to the floor and the center of mass keeps moving, resulting in a disequilibrium from which the patient has difficulty recovering, resulting in a forward fall. Similarly, patients with Parkinson's disease and festinating gait may find their feet unable to keep up and may thus fall forward.

**FALLS RELATED TO SENSORYLOSS** Patients with somatosensory, visual, or vestibular deficits are prone to falls. These patients have particular difficulty dealing with poor illumination or walking on uneven ground. They often report subjective imbalance, apprehension, and fear of falling. These patients may be especially responsive to a rehabilitation-based intervention.

**FALLS RELATED TO WEAKNESS** Patients who lack strength in antigravity muscles have difficulty rising from a chair or maintaining their balance after a perturbation. These patients are often unable to get up after a fall and may have to remain on the floor for a prolonged period until help arrives. If due to deconditioning, this is often treatable. Resistance strength training can increase muscle mass and leg strength, even for people in their eighties and nineties.

## TREATMENT

### Interventions to Reduce the Risk of Falls and Injury

Efforts should be made to define the mechanism underlying falls in a given patient, as specific treatment may be possible once a diagnosis is established. Orthostatic changes in blood pressure and pulse should be recorded. Medications (including over-the-counter) should be reviewed, reevaluating benefits and burdens of medications that might increase fall risk. Treatment of cataracts and avoidance of multifocal lenses could be considered for patients whose falls result from vision impairment. A home visit to look for environmental hazards can be helpful. A variety of modifications may be recommended to improve safety, including improved lighting, installation of grab bars and nonslip surfaces, and use of adaptive equipment.

Home- and group-based exercise programs focusing on leg strength and balance, physical therapy, and use of assistive devices reduce fall risk in individuals with a history of falls or disorders of gait and balance. Rehabilitative interventions aim to improve muscle strength and balance stability and to make the patient more resistant to injury. High-intensity resistance strength training with weights and machines is useful to improve muscle mass, even in frail older patients. Improvements realized in posture and gait should translate to reduced risk of falls and injury. Sensory balance training is another approach to improving balance stability. Measurable gains can be made in a few weeks of training, and benefits can be maintained over 6 months by a 10- to 20-min home exercise program. This strategy is particularly successful in patients with vestibular and somatosensory balance disorders. The National Institute on Aging provides online examples of balance exercises for older adults. A Tai Chi exercise program has been demonstrated to reduce the risk of falls and injury in patients with Parkinson's disease. Cognitive training, including dual-task training, may improve mobility in older adults with cognitive impairment.

A  
I am grateful to Dr. Lewis R. Sudarsky for his substantial contributions to earlier versions of this chapter.

## FURTHER READING

- A G S , B G S ,  
A A O S P F  
P : Guideline for the prevention of falls in older persons.  
J Am Geriatr Soc 49:664, 2001.  
G D, L N: Prevention of falls in community-dwelling older adults. N Engl J Med 382:734, 2020.  
N I A : E P A -  
. Available from <https://www.nia.nih.gov/health/exercise-physical-activity>. Accessed April 25, 2021.  
N JG: Classification of gait and balance disorders. Adv Neurol 87:135, 2001.  
P W, K R: Gait disorders in adults and the elderly. Wien Klin Wochenschr 129:81, 2017.

reversible cognitive disturbance. Hyperactive patients are often easily recognized by their characteristic severe agitation, tremor, hallucinations, and autonomic instability. Patients who are quietly hypoactive are more often overlooked on the medical wards and in the ICU.

The reversibility of delirium is emphasized because many etiologies, such as infection and medication effects, can be treated easily. The long-term cognitive consequences of delirium remain an area of active research. Some episodes of delirium continue for weeks, months, or even years. The persistence of delirium in some patients and its high recurrence rate may be due to inadequate initial treatment of the underlying etiology. In other instances, delirium appears to cause permanent neuronal damage and long-term cognitive decline. Therefore, prevention strategies are important to implement. Even if an episode of delirium completely resolves, there may be lingering effects of the disorder; a patient's recall of events after delirium varies widely, ranging from complete amnesia to repeated reexperiencing of the frightening period of confusion, similar to what is seen in patients with posttraumatic stress disorder.

## RISK FACTORS

An effective primary prevention strategy for delirium begins with identification of high-risk patients. Some hospital systems have initiated comprehensive delirium programs that screen most or all patients upon admission or before elective surgery; positive screens trigger a host of focused prevention measures. Multiple validated scoring systems have been developed as a screen for asymptomatic patients, many of which emphasize well-established risk factors for delirium.

The two most consistently identified risk factors are older age and baseline cognitive dysfunction. Individuals who are aged >65 or exhibit low scores on standardized tests of cognition develop delirium upon hospitalization at a rate approaching 50%. Whether age and baseline cognitive dysfunction are truly independent risk factors is uncertain. Other predisposing factors include sensory deprivation, such as preexisting hearing and visual impairment, as well as indices for poor overall health, including baseline immobility, malnutrition, and underlying medical or neurologic illness.

In-hospital risks for delirium include the use of bladder catheterization, physical restraints, sleep and sensory deprivation, and the addition of three or more new medications. Avoiding such risks remains a key component of delirium prevention as well as treatment. Surgical and anesthetic risk factors for the development of postoperative delirium include procedures such as those involving cardiopulmonary bypass, inadequate or excessive treatment of pain in the immediate postoperative period, and perhaps specific agents such as inhalational anesthetics.

The relationship between delirium and dementia (Chap. 29) is complicated by significant overlap between the two conditions, and it is not always simple to distinguish between them. Dementia and preexisting cognitive dysfunction serve as major risk factors for delirium, and at least two-thirds of cases of delirium occur in patients with coexisting underlying dementia. A form of dementia with parkinsonism, *dementia with Lewy bodies* (Chap. 434), is characterized by a fluctuating course, prominent visual hallucinations, parkinsonism, and an attentional deficit that clinically resembles hyperactive delirium; patients with this condition are particularly vulnerable to delirium. Delirium in the elderly often reflects an insult to a brain that is vulnerable due to an underlying neurodegenerative condition. Therefore, the development of delirium sometimes heralds the onset of a previously unrecognized brain disorder, and after the acute delirious episode has cleared, careful screening for an underlying condition should occur in the outpatient setting.

## EPIDEMIOLOGY

Delirium is common, but its reported incidence has varied widely with the criteria used to define this disorder. Estimates of delirium in hospitalized patients range from 10% to >50%, with higher rates reported for elderly patients and patients undergoing hip surgery. Older patients in the ICU have especially high rates of delirium that approach 75%. The

# 27

## Confusion and Delirium

S. Andrew Josephson, Bruce L. Miller

**Confusion**, a mental and behavioral state of reduced comprehension, coherence, and capacity to reason, is one of the most common problems encountered in medicine, accounting for a large number of emergency department visits, hospital admissions, and inpatient consultations. **Delirium**, a term used to describe an acute confusional state, remains a major cause of morbidity and mortality, costing billions of dollars yearly in health care costs in the United States alone. Despite increased efforts targeting awareness of this condition, delirium often goes unrecognized in the face of evidence that it is usually the cognitive manifestation of serious underlying medical or neurologic illness.

### CLINICAL FEATURES OF DELIRIUM

A multitude of terms are used to describe patients with delirium, including *encephalopathy*, *acute brain failure*, *acute confusional state*, and *postoperative or intensive care unit (ICU) psychosis*. Delirium has many clinical manifestations, but it is defined as a relatively acute decline in cognition that fluctuates over hours or days. The hallmark of delirium is a deficit of attention, although all cognitive domains—including memory, executive function, visuospatial tasks, and language—are variably involved. Associated symptoms that may be present in some cases include altered sleep-wake cycles, perceptual disturbances such as hallucinations or delusions, affect changes, and autonomic findings that include heart rate and blood pressure instability.

Delirium is a clinical diagnosis that is made only at the bedside. Two subtypes have been described—hyperactive and hypoactive—based on differential psychomotor features. The cognitive syndrome associated with severe alcohol withdrawal (i.e., “delirium tremens”) remains the classic example of the hyperactive subtype, featuring prominent hallucinations, agitation, and hyperarousal, often accompanied by life-threatening autonomic instability. In striking contrast is the hypoactive subtype, exemplified by benzodiazepine intoxication, in which patients are withdrawn and quiet, with prominent apathy and psychomotor slowing.

This dichotomy between subtypes of delirium is a useful construct, but patients often fall somewhere along a spectrum between the hyperactive and hypoactive extremes, sometimes fluctuating from one to the other. Therefore, clinicians must recognize this broad range of presentations of delirium to identify all patients with this potentially

condition is not recognized in up to one-third of delirious inpatients, and the diagnosis is especially problematic in the ICU environment, where cognitive dysfunction is often difficult to appreciate in the setting of serious systemic illness and sedation. Delirium in the ICU should be viewed as an important manifestation of organ dysfunction not unlike liver, kidney, or heart failure. Outside the acute hospital setting, delirium occurs in nearly one-quarter of patients in nursing homes and in 50–80% of those at the end of life. These estimates emphasize the remarkably high frequency of this cognitive syndrome in older patients, a population that continues to grow.

An episode of delirium was previously viewed as a transient condition that carried a benign prognosis. It is now recognized as a disorder with substantial morbidity and mortality, and that often represents the first manifestation of a serious underlying illness. Estimates of in-hospital mortality rates among delirious patients range from 25% to 33%, similar to mortality rates due to sepsis. Patients with an in-hospital episode of delirium have a fivefold higher mortality rate in the months after their illness compared with age matched nondelirious hospitalized patients. Delirious hospitalized patients also have a longer length of stay, are more likely to be discharged to a nursing home, have a higher frequency of readmission, and are more likely to experience subsequent episodes of delirium and cognitive decline; as a result, this condition has an enormous economic cost.

## ■ PATHOGENESIS

The pathogenesis and anatomy of delirium are incompletely understood. The attentional deficit that serves as the neuropsychological hallmark of delirium has a diffuse localization within the brainstem, thalamus, prefrontal cortex, and parietal lobes. Rarely, focal lesions such as ischemic strokes have led to delirium in otherwise healthy persons; right parietal and medial dorsal thalamic lesions have been reported most commonly, pointing to the importance of these areas in delirium pathogenesis. In most cases, however, delirium results from widespread disturbances in cortical and subcortical regions of the brain. Electroencephalogram (EEG) usually reveals symmetric slowing, a nonspecific finding that supports diffuse cerebral dysfunction.

Multiple neurotransmitter abnormalities, proinflammatory factors, and specific genes likely play a role in the pathogenesis of delirium. Deficiency of acetylcholine may play a key role, and medications with anticholinergic properties can commonly precipitate delirium. As noted earlier, patients with preexisting dementia are particularly susceptible to episodes of delirium. Alzheimer's disease (Chap. 431), dementia with Lewy bodies (Chap. 434), and Parkinson's disease dementia (Chap. 435) are all associated with cholinergic deficiency due to degeneration of acetylcholine-producing neurons in the basal forebrain. In addition, other neurotransmitters are also likely to be involved in this diffuse cerebral disorder. For example, increases in dopamine can lead to delirium, and patients with Parkinson's disease treated with dopaminergic medications can develop a delirium-like state that features visual hallucinations, fluctuations, and confusion.

Not all individuals exposed to the same insult will develop signs of delirium. A low dose of an anticholinergic medication may have no cognitive effects on a healthy young adult but produce a florid delirium in an elderly person with known underlying dementia, although even healthy young persons develop delirium with very high doses of anticholinergic medications. This concept of delirium developing as the result of an insult in predisposed individuals is currently the most widely accepted pathogenic construct. Therefore, if a previously healthy individual with no known history of cognitive illness develops delirium in the setting of a relatively minor insult such as elective surgery or hospitalization, an unrecognized underlying neurologic illness such as a neurodegenerative disease, multiple previous strokes, or another diffuse cerebral cause should be considered. In this context, delirium can be viewed as a "stress test for the brain" whereby exposure to known inciting factors such as systemic infection and offending drugs can unmask a decreased cerebral reserve and herald a serious underlying and potentially treatable illness. New blood-based biomarkers for specific dementias may soon be available to help predict people at risk for delirium before surgical procedures or hospitalization.

## APPROACH TO THE PATIENT

### Delirium

Because the diagnosis of delirium is clinical and is made at the bedside, a careful history and physical examination are necessary in evaluating patients with possible confusional states. Screening tools can aid physicians and nurses in identifying patients with delirium, including the Confusion Assessment Method (CAM); the Nursing Delirium Screening Scale (NuDESC); the Organic Brain Syndrome Scale; the Delirium Rating Scale; and, in the ICU, the ICU version of the CAM and the Delirium Detection Score. Using the well-validated CAM, a diagnosis of delirium is made if there is (1) an acute onset and fluctuating course and (2) inattention accompanied by either (3) disorganized thinking or (4) an altered level of consciousness (Table 27-1). These scales may not identify the full spectrum of patients with delirium, and all patients who are acutely confused should be presumed delirious regardless of their presentation due to the wide variety of possible clinical features. A course that fluctuates over hours or days and may worsen at night (termed *sundowning*) is typical but not essential for the diagnosis. Observation will usually reveal an altered level of consciousness or a deficit of attention. Other features that are sometimes present include alteration of sleep-wake cycles, thought disturbances such as hallucinations or delusions, autonomic instability, and changes in affect.

### HISTORY

It may be difficult to elicit an accurate history in delirious patients who have altered levels of consciousness or impaired attention. Information from a collateral source such as a spouse or another family member is therefore invaluable. The three most important pieces of history are the patient's baseline cognitive function, the time course of the present illness, and current medications.

Premorbid cognitive function can be assessed through the collateral source or, if needed, via a review of outpatient records. Delirium by definition represents a change that is relatively acute and usually developing over hours to days, from a cognitive baseline. An acute confusional state is nearly impossible to diagnose without some knowledge of baseline cognitive function. Without

TABLE 27-1 The Confusion Assessment Method (CAM) Diagnostic Algorithm<sup>a</sup>

The diagnosis of delirium requires the presence of features 1 and 2 and either feature 3 or 4.

#### Feature 1. Acute Onset and Fluctuating Course

This feature is satisfied by positive responses to the following questions: Is there evidence of an acute change in mental status from the patient's baseline? Did the (abnormal) behavior fluctuate during the day, that is, tend to come and go, or did it increase and decrease in severity?

#### Feature 2. Inattention

This feature is satisfied by a positive response to the following question: Did the patient have difficulty focusing attention, for example, being easily distractible, or have difficulty keeping track of what was being said?

#### Feature 3. Disorganized Thinking

This feature is satisfied by a positive response to the following question: Was the patient's thinking disorganized or incoherent, such as rambling or irrelevant conversation, unclear or illogical flow of ideas, or unpredictable switching from subject to subject?

#### Feature 4. Altered Level of Consciousness

This feature is satisfied by any answer other than "alert" to the following question: Overall, how would you rate the patient's level of consciousness: alert (normal), vigilant (hyperalert), lethargic (drowsy, easily aroused), stupor (difficult to arouse), or coma (unarousable)?

<sup>a</sup>Information is usually obtained from a reliable reporter, such as a family member, caregiver, or nurse.

Source: From Annals of Internal Medicine, SK Inouye et al: Clarifying confusion: The Confusion Assessment Method. A new method for detection of delirium. 113(12):941, 1990. Copyright © 1990 American College of Physicians. All Rights Reserved. Reprinted with the permission of American College of Physicians, Inc.

this information, many patients with dementia or longstanding depression may be mistaken as delirious during a single initial evaluation. Patients with a more hypoactive, apathetic presentation with psychomotor slowing may be identified as being different from baseline only through conversations with family members. A number of validated instruments have been shown to diagnose cognitive dysfunction accurately using a collateral source, including the modified Blessed Dementia Rating Scale and the Clinical Dementia Rating (CDR). Baseline cognitive impairment is common in patients with delirium. Even when no such history of cognitive impairment is elicited, there should still be a high suspicion for a previously unrecognized underlying neurologic disorder.

Establishing the time course of cognitive change is important not only to make a diagnosis of delirium but also to correlate the onset of the illness with potentially treatable etiologies such as recent medication changes or symptoms of systemic infection.

Medications remain a common cause of delirium, especially compounds with anticholinergic or sedative properties. It is estimated that nearly one-third of all cases of delirium are secondary to medications, especially in the elderly. Medication histories should include all prescription as well as over-the-counter and herbal substances taken by the patient and any recent changes in dosing or formulation, including substitution of generics for brand-name medications.

Other important elements of the history include screening for symptoms of organ failure or systemic infection, which often contributes to delirium in the elderly. A history of illicit drug use, alcoholism, or toxin exposure is common in younger delirious patients. Finally, asking the patient and collateral source about other symptoms that may accompany delirium, such as depression, may help identify potential therapeutic targets.

#### PHYSICAL EXAMINATION

The general physical examination in a delirious patient should include careful screening for signs of infection such as fever, tachypnea, pulmonary consolidation, heart murmur, and meningismus. The patient's fluid status should be assessed; both dehydration and fluid overload with resultant hypoxemia have been associated with delirium, and each is usually easily rectified. The appearance of the skin can be helpful, showing jaundice in hepatic encephalopathy, cyanosis in hypoxemia, or needle tracks in patients using intravenous drugs.

The neurologic examination requires a careful assessment of mental status. Patients with delirium often present with a fluctuating course; therefore, the diagnosis can be missed when one relies on a single time point of evaluation. For patients who worsen in the evening (sundowning), assessment only during morning rounds may be falsely reassuring.

An altered level of consciousness ranging from hyperarousal to lethargy to coma is present in most patients with delirium and can be assessed easily at the bedside. In a patient with a relatively normal level of consciousness, a screen for an attentional deficit is in order, because this deficit is the classic neuropsychological hallmark of delirium. Attention can be assessed while taking a history from the patient. Tangential speech, a fragmentary flow of ideas, or inability to follow complex commands often signifies an attentional problem. There are formal neuropsychological tests to assess attention, but a simple bedside test of digit span forward is quick and fairly sensitive. In this task, patients are asked to repeat successively longer random strings of digits beginning with two digits in a row, said to the patient at one per second intervals. Healthy adults can repeat a string of five to seven digits before faltering; a digit span of four or less usually indicates an attentional deficit unless hearing or language barriers are present, and many patients with delirium have digit spans of three or fewer digits.

More formal neuropsychological testing can be helpful in assessing a delirious patient, but it is usually too cumbersome and time-consuming in the inpatient setting. A Mini-Mental State

Examination (MMSE) provides information regarding orientation, language, and visuospatial skills (Chap. 29); however, performance of many tasks on the MMSE, including the spelling of "world" backward and serial subtraction of digits, will be impaired by delirious patients' attentional deficits, rendering the test unreliable.

The remainder of the screening neurologic examination should focus on identifying new focal neurologic deficits. Focal strokes or mass lesions in isolation are rarely the cause of delirium, but patients with underlying extensive cerebrovascular disease or neurodegenerative conditions may not be able to cognitively tolerate even relatively small new insults. Patients should be screened for other signs of neurodegenerative conditions such as parkinsonism, which is seen not only in idiopathic Parkinson's disease but also in other dementing conditions including Alzheimer's disease, dementia with Lewy bodies, and progressive supranuclear palsy. The presence of multifocal myoclonus or asterixis on the motor examination is nonspecific but usually indicates a metabolic or toxic etiology of the delirium.

#### ETIOLOGY

Some etiologies can be easily discerned through a careful history and physical examination, whereas others require confirmation with laboratory studies, imaging, or other ancillary tests. A large, diverse group of insults can lead to delirium, and the cause in many patients is multifactorial. Common etiologies are listed in Table 27-2.

Prescribed, over-the-counter, and herbal medications all can precipitate delirium. Drugs with anticholinergic properties, narcotics, and benzodiazepines are particularly common offenders, but nearly any compound can lead to cognitive dysfunction in a predisposed patient. Whereas an elderly patient with baseline dementia may become delirious upon exposure to a relatively low dose of a medication, in less susceptible individuals, delirium occurs only with very high doses of the same medication. This observation emphasizes the importance of correlating the timing of recent medication changes, including dose and formulation, with the onset of cognitive dysfunction.

In younger patients, illicit drugs and toxins are common causes of delirium. In addition to more classic drugs of abuse, the availability of "bath salts," synthetic cannabis (Chap. 455), methylenedioxymethamphetamine (MDMA, ecstasy),  $\gamma$ -hydroxybutyrate (GHB), and the phencyclidine (PCP)-like agent ketamine has led to an increase in delirious young persons presenting to acute care settings (Chap. 457). Many common prescription drugs such as oral narcotics and benzodiazepines are often abused and readily available on the street. Alcohol abuse leading to high serum levels causes confusion, but more commonly, it is withdrawal from alcohol that leads to a hyperactive delirium (Chap. 453). Alcohol and benzodiazepine withdrawal should be considered in all cases of delirium, including in the elderly, because even patients who drink only a few servings of alcohol every day can experience relatively severe withdrawal symptoms upon hospitalization.

Metabolic abnormalities such as electrolyte disturbances of sodium, calcium, magnesium, or glucose can cause delirium, and mild derangements can lead to substantial cognitive disturbances in susceptible individuals. Other common metabolic etiologies include liver and renal failure, hypercarbia and hypoxemia, vitamin deficiencies of thiamine and  $B_{12}$ , autoimmune disorders including central nervous system (CNS) vasculitis, and endocrinopathies such as thyroid and adrenal disorders.

Systemic infections often cause delirium, especially in the elderly. A common scenario involves the development of an acute cognitive decline in the setting of a urinary tract infection in a patient with baseline dementia. Pneumonia, skin infections such as cellulitis, and frank sepsis also lead to delirium. This so-called septic encephalopathy, often seen in the ICU, is probably due to the release of proinflammatory cytokines and their diffuse cerebral effects. CNS infections such as meningitis, encephalitis, and abscess are less common etiologies of delirium, as are cases of autoimmune or

**TABLE 27-2** Differential Diagnosis of Delirium**Toxins**

Prescription medications: especially those with anticholinergic properties, narcotics, and benzodiazepines  
 Drugs of abuse: alcohol intoxication and alcohol withdrawal, opiates, ecstasy, LSD, GHB, PCP, ketamine, cocaine, "bath salts," marijuana and its synthetic forms  
 Poisons: inhalants, carbon monoxide, ethylene glycol, pesticides

**Metabolic Conditions**

Electrolyte disturbances: hypoglycemia, hyperglycemia, hyponatremia, hypernatremia, hypercalcemia, hypocalcemia, hypomagnesemia  
 Hypothermia and hyperthermia  
 Pulmonary failure: hypoxemia and hypercarbia  
 Liver failure/hepatic encephalopathy  
 Renal failure/uremia  
 Cardiac failure  
 Vitamin deficiencies: B<sub>12</sub>, thiamine, folate, niacin  
 Dehydration and malnutrition  
 Anemia

**Infections**

Systemic infections: urinary tract infections, pneumonia, skin and soft tissue infections, sepsis  
 CNS infections: meningitis, encephalitis, brain abscess

**Endocrine Conditions**

Hyperthyroidism, hypothyroidism  
 Hyperparathyroidism  
 Adrenal insufficiency

**Cerebrovascular Disorders**

Global hypoperfusion states  
 Hypertensive encephalopathy  
 Focal ischemic strokes and hemorrhages (rare): especially nondominant parietal and thalamic lesions

**Autoimmune Disorders**

CNS vasculitis  
 Cerebral lupus  
 Neurologic paraneoplastic and autoimmune encephalitis

**Seizure-Related Disorders**

Nonconvulsive status epilepticus  
 Intermittent seizures with prolonged postictal states

**Neoplastic Disorders**

Diffuse metastases to the brain  
 Giomatosis cerebri  
 Carcinomatous meningitis  
 CNS lymphoma

**Hospitalization**

Terminal end-of-life delirium

**Abbreviations:** CNS, central nervous system; GHB, γ-hydroxybutyrate; LSD, lysergic acid diethylamide; PCP, phencyclidine.

paraneoplastic encephalitis; however, in light of the high morbidity and mortality rates associated with these conditions when they are not treated, clinicians must always maintain a high index of suspicion.

In some susceptible individuals, exposure to the unfamiliar environment of a hospital itself can contribute to delirium. This etiology usually occurs as part of a multifactorial delirium and should be considered a diagnosis of exclusion after all other causes have been thoroughly investigated. Many primary prevention and treatment strategies for delirium involve relatively simple methods to address the aspects of the inpatient setting that are most confusing.

Cerebrovascular etiologies of delirium are usually due to global hypoperfusion in the setting of systemic hypotension from heart failure, septic shock, dehydration, or anemia. Focal strokes in the right parietal lobe and medial dorsal thalamus rarely can lead to a delirious state. A more common scenario involves a new focal stroke or hemorrhage causing confusion in a patient who has decreased cerebral reserve. In these individuals, it is sometimes difficult to distinguish between cognitive dysfunction resulting from the new neurovascular insult itself and delirium due to the infectious, metabolic, and pharmacologic complications that can accompany hospitalization after stroke.

Because a fluctuating course often is seen in delirium, intermittent seizures may be overlooked when one is considering potential etiologies. Both nonconvulsive status epilepticus and recurrent focal or generalized seizures followed by postictal confusion can cause delirium; EEG remains essential for this diagnosis and should be considered whenever the etiology of delirium remains unclear following initial workup. Seizure activity spreading from an electrical focus in a mass or infarct can explain global cognitive dysfunction caused by relatively small lesions.

It is extremely common for patients to experience delirium at the end of life in palliative care settings. This condition must be identified and treated aggressively because it is an important cause of patient and family discomfort at the end of life. It should be remembered that these patients also may be suffering from more common etiologies of delirium such as systemic infection.

**LABORATORY AND DIAGNOSTIC EVALUATION**

A cost-effective approach allows the history and physical examination to guide further tests. No single algorithm will fit all delirious patients due to the staggering number of potential etiologies, but one stepwise approach is detailed in Table 27-3. If a clear precipitant such as an offending medication is identified, further testing may not be required. If, however, no likely etiology is uncovered with initial evaluation, an aggressive search for an underlying cause should be initiated.

Basic screening labs, including a complete blood count, electrolyte panel, and tests of liver and renal function, should be obtained in all patients with delirium. In elderly patients, screening for systemic infection, including chest radiography, urinalysis and culture, and possibly blood cultures, is important. In younger individuals, serum and urine drug and toxicology screening may be appropriate earlier in the workup. Additional laboratory tests addressing other autoimmune, endocrinologic, metabolic, and infectious etiologies should be reserved for patients in whom the diagnosis remains unclear after initial testing.

Multiple studies have demonstrated that brain imaging in patients with delirium is often unhelpful. If, however, the initial workup is unrevealing, most clinicians quickly move toward imaging of the brain to exclude structural causes. A noncontrast computed tomography (CT) scan can identify large masses and hemorrhages but is otherwise unlikely to help determine an etiology of delirium. The ability of magnetic resonance imaging (MRI) to identify most acute ischemic strokes as well as to provide neuroanatomic detail that gives clues to possible infectious, inflammatory, neurodegenerative, and neoplastic conditions makes it the test of choice. Because MRI techniques are limited by availability, speed of imaging, patient's cooperation, and contraindications, many clinicians begin with CT scanning and proceed to MRI if the etiology of delirium remains elusive.

Lumbar puncture (LP) must be obtained immediately after neuroimaging for all patients in whom CNS infection is suspected. Spinal fluid examination can also be useful in identifying autoimmune, other inflammatory, and neoplastic conditions. As a result, LP should be considered in any delirious patient with a negative workup. EEG remains invaluable if seizures are considered or if there is no cause readily identified.

TABLE 27-3 Stepwise Evaluation of a Patient with Delirium

**Initial Evaluation**

- History with special attention to medications (including over-the-counter and herbals)
- General physical examination and neurologic examination
- Complete blood count
- Electrolyte panel including calcium, magnesium, phosphorus
- Liver function tests, including albumin
- Renal function tests

**First-Tier Further Evaluation Guided by Initial Evaluation**

- Systemic infection screen
- Urinalysis and culture
- Chest radiograph
- Blood cultures
- Electrocardiogram
- Arterial blood gas
- Serum and/or urine toxicology screen (perform earlier in young persons)
- Brain imaging with MRI with diffusion and gadolinium (preferred) or CT
- Suspected CNS infection or other inflammatory disorder: lumbar puncture after brain imaging
- Suspected seizure-related etiology: electroencephalogram (EEG) (if high suspicion, should be performed immediately)

**Second-Tier Further Evaluation**

- Vitamin levels: B<sub>12</sub>, folate, thiamine
- Endocrinologic laboratories: thyroid-stimulating hormone (TSH) and free T<sub>4</sub>; cortisol
- Serum ammonia
- Sedimentation rate
- Autoimmune serologies: antinuclear antibodies (ANA), complement levels; p-ANCA, c-ANCA, consider paraneoplastic/autoimmune encephalitis serologies
- Infectious serologies: rapid plasmin reagent (RPR); fungal and viral serologies if high suspicion; HIV antibody
- Lumbar puncture (if not already performed)
- Brain MRI with and without gadolinium (if not already performed)

**Abbreviations:** c-ANCA, cytoplasmic antineutrophil cytoplasmic antibody; CNS, central nervous system; CT, computed tomography; MRI, magnetic resonance imaging; p-ANCA, perinuclear antineutrophil cytoplasmic antibody.

**TREATMENT****Delirium**

Management of delirium begins with treatment of the underlying inciting factor (e.g., patients with systemic infections should be given appropriate antibiotics, and underlying electrolyte disturbances should be judiciously corrected). These treatments often lead to prompt resolution of delirium. Blindly targeting the symptoms of delirium pharmacologically only serves to prolong the time patients remain in the confused state and may mask important diagnostic information.

Relatively simple methods of supportive care can be highly effective (Fig. 27-1). Reorientation by the nursing staff and family combined with visible clocks, calendars, and outside-facing windows can reduce confusion. Sensory isolation should be prevented by providing glasses and hearing aids to patients who need them. Sundowning can be addressed to a large extent through vigilance to appropriate sleep-wake cycles. During the day, a well-lit room should be accompanied by activities or exercises to prevent napping. At night, a quiet, dark environment with limited interruptions by staff can assure proper rest; melatonin can be considered before bed to promote sleep. These sleep-wake cycle interventions are especially important in the ICU setting as the usual constant 24-h activity commonly provokes delirium. Attempting to mimic the home environment as much as possible also has been shown to help treat and even prevent delirium. Visits from friends and

**PROMOTE AM WAKEFULNESS**

Shades up. Lights on.	Write date and staff names on board to orient patient.	Patient out of bed to chair for all 3 meals. Ask for assistance if you need help.	Walk patient 3x/day. Engage patient in conversation.

Each visit, introduce yourself; remind patient where they are, what day and time it is.	Patient is wearing hearing aids/glasses (if needed) to hear and see appropriately.	Provide activities like games and reading materials to keep patient's mind active while awake.	Make sure your patient has water within reach at all times. Dehydration is the #1 complaint in the hospital!

Make sure family members have been provided the pamphlet about delirium and discuss any questions they have. It is ok to refer to the nurse or doctor if you are unsure.	Discuss with the nurse at each shift if the patient truly needs the following: nasal cannula on their nose, Foley catheter, telemetry, and CPO. These "tethers" make it difficult for the patient to move and can contribute to confusion.	

A

**PROMOTE PM SLEEP**

Shades closed. Lights off. TV off. Make room as dark and quiet as possible.	Minimize caffeine intake.	Offer eye mask, ear plugs to help with sleep.

Group your nighttime tasks so that you are entering the room and waking the patient as few times as possible.	If you communicate with the patient during the night, make sure glasses and hearing aids are on. Remember to introduce yourself, remind the patient where they are.

B

**FIGURE 27-1** Delirium management and prevention: a checklist for hospitalized patients. Effective management of delirium relies on broad efforts to promote wakefulness (A) and sleep (B). CPO, continuous pulse oximetry.

family throughout the day minimize the anxiety associated with the constant flow of new faces of staff and physicians. Allowing hospitalized patients to have access to home bedding, clothing, and nightstand objects makes the hospital environment less foreign and therefore less confusing. Simple standard nursing practices such as maintaining proper nutrition and volume status as well as managing pain, incontinence, and skin breakdown also help alleviate discomfort and resulting confusion.

In some instances, patients pose a threat to their own safety or to the safety of staff members, and acute management is required. Bed alarms and personal sitters are more effective and much less disorienting than physical restraints. Chemical restraints should be avoided, but when necessary, very-low-dose typical or atypical antipsychotic medications administered on an as-needed basis can be used, recognizing that clinical trials have consistently shown that these medications are ineffective in treating delirium. Therefore, they should be reserved for patients who display severe agitation and significant potential to harm themselves or staff. The association of antipsychotic use in the elderly with increased mortality rates underscores the importance of using these medications judiciously and only as a last resort. Benzodiazepines often worsen

confusion through their sedative properties. Although many clinicians use benzodiazepines to treat acute confusion, their use should be limited to cases in which delirium is caused by alcohol or benzodiazepine withdrawal.

## ■ PREVENTION

In light of the high morbidity associated with delirium and the tremendously increased health care costs that accompany it, development of an effective strategy to prevent delirium in hospitalized patients is extremely important. Successful identification of high-risk patients is the first step, followed by initiation of appropriate interventions. Increasingly, hospitals are using nursing or physician-administered tools to screen for high-risk individuals, triggering simple standardized protocols used to manage risk factors for delirium, including sleep-wake cycle reversal, immobility, visual impairment, hearing impairment, sleep deprivation, and dehydration. No specific medications have been definitively shown to be effective for delirium prevention, including trials of cholinesterase inhibitors and antipsychotic agents. Melatonin and its agonist ramelteon have shown some promising results in small preliminary trials. Recent studies in the ICU have focused both on identifying sedatives, such as dexmedetomidine, that are less likely to lead to delirium in critically ill patients and on developing protocols for daily awakenings in which infusions of sedative medications are interrupted and the patient is reoriented by the staff. All hospitals and health care systems should work toward decreasing the incidence of delirium and promptly recognizing and treating the disorder when it occurs.

## ■ FURTHER READING

- B EG et al: Evaluation of a multicomponent pathway to address inpatient delirium on a neurosciences ward. *BMC Health Serv Res* 18:106, 2018.
- C JM et al: Efficacy and safety of sedation with dexmedetomidine in critical care patients: A meta-analysis of randomized controlled trials. *Anaesth Crit Care Pain Med* 35:7, 2016.
- G TD et al: Haloperidol and ziprasidone for treatment of delirium in critical illness. *N Engl J Med* 379:2506, 2018.
- G TE et al: Association of delirium with long-term cognitive decline: A meta-analysis. *JAMA Neurol* 77:1, 2020.
- H K et al: Preventive effects of ramelteon on delirium: A randomized placebo-controlled trial. *JAMA Psychiatry* 71:397, 2014.

preferable to use of ambiguous terms such as lethargy, semicomma, or obtundation.

Several conditions that render patients unresponsive and simulate coma are considered separately because of their special significance. The *vegetative state* signifies an awake-appearing but nonresponsive state, usually encountered in a patient who has emerged from coma. In the vegetative state, the eyelids may open periodically, giving the appearance of wakefulness. Respiratory and autonomic functions are retained. Yawning, coughing, swallowing, and limb and head movements persist, but there are few, if any, meaningful responses to the external and internal environment. There are typically accompanying signs that indicate extensive damage in both cerebral hemispheres, e.g., decerebrate or decorticate limb posturing and absent responses to visual stimuli (see below). In the closely related but less severe *minimally conscious state*, the patient displays rudimentary vocal or motor behaviors, often spontaneous, but sometimes in response to touch, visual stimuli, or command. Cardiac arrest with cerebral hypoperfusion and head trauma are the most common causes of the vegetative and minimally conscious states (*Chap. 30*).

The prognosis for regaining meaningful mental faculties once the vegetative state has supervened for several months is poor, and after a year, almost nil; hence the term *persistent vegetative state*. Most reports of dramatic recovery, when investigated carefully, are found to yield to the usual rules for prognosis, but there have been rare instances in which recovery has occurred to a severely disabled condition and, in rare childhood cases, to an even better state. Patients in the minimally conscious state carry a better prognosis for some recovery compared to those in a persistent vegetative state, but even in these patients, dramatic recovery after 12 months is unusual.

The possibility of incorrectly attributing meaningful behavior to patients in the vegetative and minimally conscious states creates problems and anguish for families and physicians. The question of whether some of these patients have the capability for cognition has been investigated by functional MRI and electroencephalogram (EEG) studies that have demonstrated cerebral activation that is temporally consistent in response to verbal and other stimuli, as discussed in more detail below. This finding suggests at a minimum that some of these patients could in the future be able to communicate their needs using technological advances and that further research could shed light on treatment approaches targeting areas of the brain and their connections that seem to be preserved in individual patients.

Several syndromes that affect alertness are prone to be misinterpreted as stupor or coma, and clinicians should be aware of these pitfalls when diagnosing coma at the bedside. Akinetic mutism refers to a partially or fully awake state in which the patient remains virtually immobile and mute but can form impressions and think, as demonstrated by later recounting of events. This condition results from damage in the regions of the medial thalamic nuclei or the frontal lobes (particularly lesions situated deeply or on the orbitofrontal surfaces) or from extreme hydrocephalus. The term *abulia* describes a milder form of akinetic mutism characterized by mental and physical slowness and diminished ability to initiate activity. It is also usually the result of damage to the medial frontal lobes and their connections (*Chap. 30*).

Catatonics is a hypomobile and mute syndrome that occurs usually as part of a major psychosis, typically schizophrenia or major depression. Catatonic patients make few voluntary or responsive movements, although they blink, swallow, and may not appear distressed. There are nevertheless signs that the patient is responsive, although it takes a careful examination to demonstrate these features. For example, eyelid elevation is actively resisted, blinking occurs in response to a visual threat, and the eyes move concomitantly with head rotation, all of which are inconsistent with the presence of a brain lesion causing unresponsiveness. The limbs may retain postures in which they have been placed by the examiner ("waxy flexibility," or catalepsy). With recovery from catatonia, patients often have some memory of events that occurred during their stupor. Catatonia is superficially similar to akinetic mutism, but clinical evidence of cerebral damage such as hyperreflexia and hypertonicity of the limbs is lacking in the former. The special problem of coma in brain death is discussed below.

# 28

## Coma

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Coma is among the most common neurologic emergencies encountered general medicine and requires an organized approach. It accounts for a substantial portion of admissions to emergency wards and occurs on all hospital services.

There exists a continuum of states of reduced alertness, the most severe form being coma, defined as a deep sleeplike state with eyes closed, from which the patient cannot be aroused. Stupor refers to a lower threshold for arousability, in which the patient can be transiently awakened by vigorous stimuli, accompanied by motor behavior that leads to avoidance or withdrawal from noxious stimuli. Drowsiness simulates light sleep and is characterized by easy arousal that may persist for brief periods. Stupor and drowsiness are usually accompanied by some degree of confusion when the patient is alerted (*Chap. 27*). A precise narrative description of the level of arousal and of the type of responses evoked by various stimuli as observed at the bedside is



The locked-in state describes a type of pseudocoma in which an awake but paralyzed patient has no means of producing speech or voluntary limb movement but retains voluntary vertical eye movements and lid elevation, thus allowing the patient to communicate. The pupils are normally reactive. The usual cause is an infarction (e.g., basilar artery thrombosis) or hemorrhage of the bilateral ventral pons that transects all descending motor (corticospinal and corticobulbar) pathways. Another awake but de-efferent state occurs as a result of total paralysis of the musculature in severe cases of neuromuscular weakness such as in Guillain-Barré syndrome (Chap. 447), critical illness neuropathy (Chap. 307), or pharmacologic neuromuscular blockade.

### THE ANATOMY AND PHYSIOLOGY OF COMA

Almost all instances of coma can be traced to either (1) widespread abnormalities of the cerebral hemispheres or (2) reduced activity of the thalamocortical alerting system, the reticular activating system (RAS), which is an assemblage of neurons located diffusely in the upper brainstem and thalamus. The proper functioning of this system, its ascending projections to the cortex, and the cortex itself are required to maintain alertness and coherence of thought. In addition to structural damage to either or both of these systems, suppression of reticulocerebral function commonly occurs by drugs, toxins, or metabolic derangements such as hypoglycemia, anoxia, uremia, and hepatic failure, or by seizures; these types of metabolic causes of coma are far more common than structural injuries.

**Coma Due to Cerebral Mass Lesions and Herniation Syndromes** The skull prevents outward expansion of the brain, and infoldings of the dura create compartments that restrict displacement of brain tissue within the cranium. The two cerebral hemispheres are separated by the falx and the anterior and posterior fossae by the tentorium. Herniation refers to displacement of brain tissue by an intracranial or overlying mass into a contiguous compartment that it normally does not occupy. Coma from mass lesions, and many of its associated signs, are attributable to these tissue shifts, and certain clinical features are characteristic of specific configurations of herniation (Fig. 28-1).

In the most common form of herniation, brain tissue is displaced from the supratentorial to the infratentorial compartment through the tentorial opening, referred to as transtentorial herniation. The cause is often a mass hemispherical lesion, with accompanying contralateral hemiparesis. Uncal transtentorial herniation refers to impaction of the anterior medial temporal gyrus (the uncus) into the tentorial opening just anterior to and adjacent to the midbrain (Fig. 28-1A). The uncus can compress the third nerve as the nerve traverses the subarachnoid space, causing enlargement of the ipsilateral pupil as the first sign (the fibers subserving parasympathetic pupillary function are located

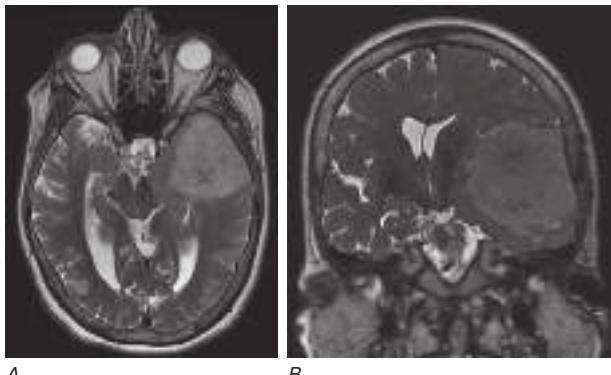


FIGURE 28-2 Axial (A) and coronal (B) T2-weighted magnetic resonance images from a stuporous patient with a left third nerve palsy from a large left-sided meningioma. A. The upper midbrain is compressed and displaced horizontally away from the mass, and there is transtentorial herniation of the medial temporal lobe structures, including the uncus. B. The lateral ventricle opposite to the mass has become enlarged as a result of compression of the third ventricle.

peripherally in the nerve). The coma that typically follows is due to lateral displacement of the midbrain (and therefore the RAS) against the opposite tentorial edge by the displaced parahippocampal gyrus (Fig. 28-2), compressing the opposite cerebral peduncle and producing a Babinski sign and ipsilateral hemiparesis (the Kernohan-Woltman sign). Herniation may also compress the anterior and posterior cerebral arteries as they pass over the tentorial reflections, with resultant brain infarction. These distortions may also entrap portions of the ventricular system, causing hydrocephalus.

Central transtentorial herniation denotes a symmetric downward movement of the thalamic structures through the tentorial opening with compression of the upper midbrain (Fig. 28-1B). Miotic pupils and drowsiness are the heralding signs, in contrast to a unilaterally enlarged pupil of the uncal syndrome. Both uncal and central transtentorial herniations cause progressive compression of the brainstem and RAS, with initial damage to the midbrain, then the pons, and finally the medulla. The result is an approximate sequence of neurologic signs that corresponds to each affected level, with respiratory centers in the brainstem often spared until late in the herniation syndrome. Other forms of herniation include transfalcial herniation (displacement of the cingulate gyrus under the falx and across the midline, Fig. 28-1C) and foraminal herniation (downward forcing of the cerebellar tonsils into the foramen magnum, Fig. 28-1D), which causes early compression of the medulla, respiratory arrest, and death.

**Coma Due to Metabolic, Drug, and Toxic Disorders** Many systemic metabolic abnormalities cause coma by interrupting the delivery of energy substrates (e.g., oxygen, glucose) or by altering neuronal excitability (drugs and alcohol, anesthesia, and epilepsy). These are the most common causes of coma in large case series. The metabolic abnormalities that produce coma may, in milder forms, induce a confusional state (metabolic encephalopathy) in which clouded consciousness and coma are in a continuum.

Cerebral neurons are dependent on cerebral blood flow (CBF) and the delivery of oxygen and glucose. Brain stores of glucose are able to provide energy for ~2 min after blood flow is interrupted, and oxygen stores last 8–10 s after the cessation of blood flow. Simultaneous hypoxia and ischemia exhaust glucose more rapidly. The EEG rhythm in these circumstances becomes diffusely slowed, typical of metabolic encephalopathies, and as substrate delivery worsens, eventually brain electrical activity ceases.

Unlike hypoxia-ischemia, which first causes a metabolic encephalopathy due to reduced energy substrate but ultimately causes neuronal destruction, most metabolic disorders such as hypoglycemia, hyponatremia, hyperosmolarity, hypercapnia, hypercalcemia, and hepatic and renal failure cause no or only minor neuropathologic changes in the

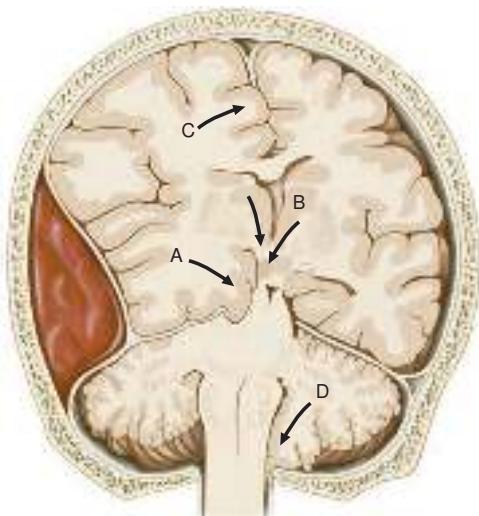


FIGURE 28-1 Types of cerebral herniation: (A) uncal; (B) central; (C) transfalcial; and (D) foraminal.

brain. The reversible effects of these conditions are not fully understood but may result from impaired energy supplies, changes in ion fluxes across neuronal membranes, and neurotransmitter abnormalities. In hepatic encephalopathy (HE), high ammonia concentrations lead to increased synthesis of glutamine in astrocytes and osmotic swelling of the cells, mitochondrial energy failure, production of reactive nitrogen and oxygen species, increases in the inhibitory neurotransmitter GABA, and synthesis of putative “false” neurotransmitters. Over time, development of a diffuse astrocytosis is typical of chronic HE. Which, if any, of these is responsible for coma is not known.

The mechanism of the encephalopathy of renal failure is also uncertain and likely to be multifactorial; unlike ammonia, urea does not produce central nervous system (CNS) depression. Contributors to uremic encephalopathy may include accumulation of neurotoxic substances such as creatinine, guanidine, and related compounds; depletion of catecholamines; altered glutamate and GABA tone; increases in brain calcium; inflammation with disruption of the blood-brain barrier; and frequent coexisting vascular disease.

Coma and seizures are common accompaniments of large shifts in sodium and water balance in the brain. These changes in osmolarity arise from systemic medical disorders, including diabetic ketoacidosis, the nonketotic hyperosmolar state, and hyponatremia from any cause (e.g., water intoxication, excessive secretion of antidiuretic hormone, or atrial natriuretic peptides). Sodium levels  $<125$  mmol/L, especially if achieved quickly, induce confusion, and levels  $<119$  mmol/L are typically associated with coma and convulsions. In hyperosmolar coma, the serum osmolarity is generally  $>350$  mosmol/L. Hypercapnia depresses the level of consciousness in proportion to the rise in carbon dioxide ( $\text{CO}_2$ ) in the blood. In all of these metabolic encephalopathies, the degree of neurologic change depends on the rapidity with which the serum changes occur. The pathophysiology of other metabolic encephalopathies such as those due to hypercalcemia, hypothyroidism, vitamin  $B_{12}$  deficiency, and hypothermia are incompletely understood but must reflect derangements of CNS biochemistry, membrane function, or neurotransmitters.

Comas due to drugs and toxins are typically reversible and leave no residual damage provided there has not been hypoxia or severe hypotension. Many drugs and toxins are capable of depressing nervous system function. Some produce coma by affecting both the RAS and the cerebral cortex. The combination of cortical and brainstem signs, which occurs occasionally in certain drug overdoses, may lead to an incorrect diagnosis of structural brainstem disease. Overdose of medications that have atropinic actions produces signs such as dilated pupils, tachycardia, and dry skin; opiate overdose produces pinpoint pupils  $<1$  mm in diameter. Some drug intoxications, typified by barbiturates, can mimic all of the signs of brain death; thus, toxic etiologies should be excluded prior to making a diagnosis of brain death.

**Epileptic Coma** Generalized electrical seizures are associated with coma, even in the absence of motor convulsions (nonconvulsive status epilepticus). As a result, EEG monitoring is often used in the evaluation of unexplained coma to exclude this treatable etiology. The self-limited coma that follows a seizure, the postictal state, may be due to exhaustion of energy reserves or effects of locally toxic molecules that are the by-product of seizures. The postictal state produces continuous, generalized slowing of the background EEG activity similar to that of metabolic encephalopathies. It typically lasts for a few minutes but in some cases can be prolonged for hours or even rarely for days.

**Coma Due to Widespread Structural Damage to the Cerebral Hemispheres** This category, comprising several unrelated disorders, results from extensive bilateral structural cerebral damage. The clinical appearance simulates a metabolic encephalopathy. Hypoxia-ischemia is perhaps the best characterized form of this type of injury, in which it is not possible initially to distinguish the acute reversible effects of oxygen deprivation of the brain from the subsequent effects of anoxic neuronal damage. Similar cerebral damage may be produced by disorders that occlude widespread small blood vessels throughout the brain; examples include thrombotic thrombocytopenic purpura,

hyperviscosity, and cerebral malaria. Diffuse white matter damage from cranial trauma or inflammatory demyelinating diseases can cause a similar coma syndrome.

## APPROACH TO THE PATIENT

### Coma

A video examination of the comatose patient is shown in Chap. V4. Acute respiratory and cardiovascular problems should be attended to prior to neurologic assessment. In most instances, a complete medical evaluation, except for vital signs, funduscopic, and examination for nuchal rigidity, may be deferred until the neurologic evaluation has established the severity and nature of coma. **The approach to the patient with coma from cranial trauma is discussed in Chap. 443.**

### HISTORY

The cause of coma may be immediately evident as in cases of trauma, cardiac arrest, or observed drug ingestion. In the remainder, certain points are useful: (1) the circumstances and rapidity with which neurologic symptoms developed; (2) antecedent symptoms (confusion, weakness, headache, fever, seizures, dizziness, double vision, or vomiting); (3) the use of medications, drugs, or alcohol; and (4) chronic liver, kidney, lung, heart, or other medical disease. Direct interrogation of family, observers, and emergency medical technicians on the scene, in person or by telephone, is an important part of the evaluation when possible.

### GENERAL PHYSICAL EXAMINATION

Signs of head trauma raise the possibility of coexisting spinal cord injury, and in such cases, immobilization of the cervical spine is essential to prevent further injury. Fever suggests a systemic infection, bacterial meningitis, encephalitis, heat stroke, neuroleptic malignant syndrome, malignant hyperthermia due to anesthetics, or anticholinergic drug intoxication. Only rarely is fever attributable to a lesion that has disturbed hypothalamic temperature-regulating centers (“central fever”), and this diagnosis should only be considered after an exhaustive search for other causes fails to reveal an explanation for fever. A slight elevation in temperature may follow vigorous convulsions. Hypothermia is observed with alcohol, barbiturate, sedative, or phenothiazine intoxication; hypoglycemia; peripheral circulatory failure; or extreme hypothyroidism. Hypothermia itself causes coma when the temperature is  $<31^\circ\text{C}$  ( $87.8^\circ\text{F}$ ) regardless of the underlying etiology; less dramatically low body temperatures can also cause coma in some instances. Tachypnea may indicate systemic acidosis or pneumonia. Aberrant respiratory patterns that reflect brainstem disorders are discussed below. Marked hypertension suggests hypertensive encephalopathy, cerebral hemorrhage, large cerebral infarction, or head injury. Hypotension is characteristic of coma from alcohol or barbiturate intoxication, internal hemorrhage or myocardial infarction causing poor delivery of blood to the brain, sepsis, profound hypothyroidism, or Addisonian crisis. The fundoscopic examination can detect increased intracranial pressure (ICP) (papilledema), subarachnoid hemorrhage (subhyaloid hemorrhages), and hypertensive encephalopathy (exudates, hemorrhages, vessel-crossing changes, papilledema). Cutaneous petechiae suggest thrombotic thrombocytopenic purpura, meningocele, or a bleeding diathesis associated with an intracerebral hemorrhage. Cyanosis and reddish or anemic skin coloration are other indications of an underlying systemic disease or carbon monoxide as responsible for the coma.

### NEUROLOGIC EXAMINATION

The patient should first be observed without intervention by the examiner. Spontaneously moving about the bed, reaching up toward the face, crossing legs, yawning, swallowing, coughing, and moaning reflect a drowsy state that is close to normal awareness. Lack of restless movements on one side or an outturned leg suggests hemiplegia. Subtle, intermittent twitching movements of a foot, finger, or

facial muscle may be the only sign of seizures. Multifocal myoclonus usually indicates a metabolic disorder, particularly uremia, anoxia, drug intoxication, or rarely a prion disease (Chap. 438). In a drowsy and confused patient, bilateral asterixis is a sign of metabolic encephalopathy or drug intoxication.

Decorticate rigidity and decerebrate rigidity, or “posturing,” describe stereotyped arm and leg movements occurring spontaneously or elicited by sensory stimulation. Flexion of the elbows and wrists and supination of the arm (decorticate posturing) classically suggest bilateral damage rostral to the midbrain, whereas extension of the elbows and wrists with pronation (decerebrate posturing) indicates damage to motor tracts caudal to the midbrain. However, these localizations have been adapted from animal work and cannot be applied with precision to coma in humans. In fact, acute and widespread disorders of any type, regardless of location, frequently cause limb extension.

#### LEVEL OF AROUSAL

A sequence of increasingly intense stimuli is first used to determine the threshold for arousal and the motor response of each side of the body. The results of testing may vary from minute to minute, and serial examinations are useful. Tickling the nostrils with a cotton wisp is a moderate stimulus to arousal—all but deeply stuporous and comatose patients will move the head away and arouse to some degree. An even greater degree of responsiveness is present if the patient uses his hand to remove an offending stimulus. Pressure on bony prominences and pinprick stimulation, when necessary, are humane forms of noxious stimuli; pinching the skin causes ecchymoses and is generally not performed but may be useful in eliciting abduction withdrawal movements of the limbs. Posturing in response to noxious stimuli indicates severe damage to the corticospinal system, whereas abduction-avoidance movement of a limb is usually purposeful and denotes an intact corticospinal system. Posturing may also be unilateral and coexist with purposeful limb movements, reflecting incomplete damage to the motor system.

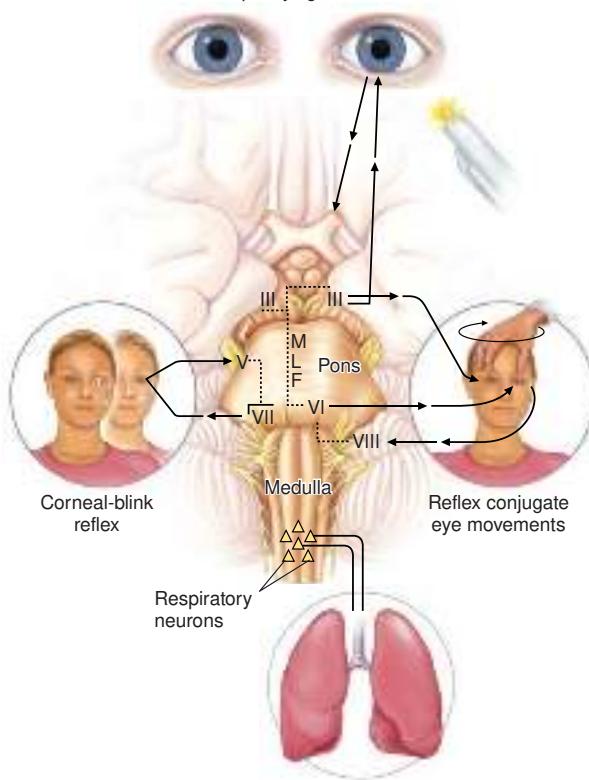
#### BRAINSTEM REFLEXES

Assessment of brainstem function is essential to localization of the lesion in coma (Fig. 28-3). Patients with preserved brainstem reflexes typically have a bihemispheric localization to coma, including toxic or drug intoxication, whereas patients with abnormal brainstem reflexes either have a lesion in the brainstem or a herniation syndrome from a cerebral mass lesion impacting the brainstem secondarily. The most important brainstem reflexes are pupillary size and reaction to light, spontaneous and elicited eye movements, corneal responses, and the respiratory pattern.

**Pupillary Signs** Pupillary reactions are examined with a bright, diffuse light. Reactive and round pupils of midsize (2.5–5 mm) essentially exclude upper midbrain damage, either primary or secondary to compression from herniation. A response to light may be difficult to appreciate in pupils <2 mm in diameter, and bright room lighting may mute pupillary reactivity. One enlarged (>6 mm) and poorly reactive pupil signifies compression of the third nerve from the effects of a cerebral mass above. Enlargement of the pupil contralateral to a hemispherical mass may occur but is infrequent. An oval and slightly eccentric pupil is a transitional sign that accompanies early midbrain–third nerve compression. The most extreme pupillary sign, bilaterally dilated and unreactive pupils, indicates severe midbrain damage, usually from compression by a supratentorial mass. Ingestion of drugs with anticholinergic activity, the use of mydriatic eye drops, nebulizer treatments, and direct ocular trauma are other causes of pupillary enlargement.

Reactive and bilaterally small (1–2.5 mm) but not pinpoint pupils are seen in metabolic encephalopathies or in deep bilateral hemispherical lesions such as hydrocephalus or thalamic hemorrhage. Even smaller reactive pupils (<1 mm) characterize opioid overdoses but also occur with extensive pontine hemorrhage. The response to naloxone and the presence of reflex eye movements (see

#### Pupillary light reflex



**FIGURE 28-3** Examination of brainstem reflexes in coma. Midbrain and third nerve function are tested by pupillary reaction to light, pontine function by spontaneous and reflex eye movements and corneal responses, and medullary function by respiratory and pharyngeal responses. Reflex conjugate, horizontal eye movements are dependent on the medial longitudinal fasciculus (MLF) interconnecting the sixth and contralateral third nerve nuclei. Head rotation (oculocephalic reflex) or caloric stimulation of the labyrinths (oculovestibular reflex) elicits contraversive eye movements (for details, see text).

below) assist in distinguishing between these. Unilateral miosis in coma has been attributed to dysfunction of sympathetic efferents originating in the posterior hypothalamus and descending in the tegmentum of the brainstem to the cervical cord. It is an occasional finding in patients with a large cerebral hemorrhage that affects the thalamus.

**Ocular Movements** The eyes are first observed by elevating the lids and observing the resting position and spontaneous movements of the globes. Horizontal divergence of the eyes at rest is normal in drowsiness. As coma deepens, the ocular axes may become parallel again.

Spontaneous eye movements in coma often take the form of conjugate horizontal roving. This finding alone exonerates extensive damage in the midbrain and pons and has the same significance as normal reflex eye movements (see below). Conjugate horizontal ocular deviation to one side indicates damage to the frontal lobe on the same side or less commonly the pons on the opposite side. This phenomenon is summarized by the following maxim: *The eyes look toward a hemispherical lesion and away from a brainstem lesion*. Seizures involving the frontal lobe drive the eyes to the opposite side, simulating a pontine destructive lesion. The eyes may occasionally turn paradoxically away from the side of a deep hemispherical lesion (“wrong-way eyes”). The eyes turn down and inward with thalamic and upper midbrain lesions, typically thalamic hemorrhage. “Ocular bobbing” describes brisk downward and slow upward movements of the eyes associated with loss of horizontal eye movements and is

diagnostic of bilateral pontine damage, usually from thrombosis of the basilar artery. ‘‘Ocular dipping’’ is a slower, arrhythmic downward movement followed by a faster upward movement in patients with normal reflex horizontal gaze; it usually indicates diffuse cortical anoxic damage.

The oculocephalic reflexes, elicited by moving the head from side to side or vertically and observing eye movements in the direction opposite to the head movement, depend on the integrity of the ocular motor nuclei and their interconnecting tracts that extend from the midbrain to the pons and medulla (Fig. 28-3). The movements, called somewhat inaccurately ‘‘doll’s eyes,’’ are normally suppressed in the awake patient with intact frontal lobes. The ability to elicit them therefore reflects both reduced cortical influence on the brainstem and intact brainstem pathways. The opposite, an absence of reflex eye movements, usually signifies damage within the brainstem but can result from overdoses of certain drugs. In this circumstance, normal pupillary size and light reaction distinguishes most drug-induced comas from structural brainstem damage. Oculocephalic maneuvers should not be attempted in patients with neck trauma, as vigorous head movements can precipitate or worsen a spinal cord injury.

Thermal, or ‘‘caloric,’’ stimulation of the vestibular apparatus (oculovestibular response) provides a more intense stimulus for the oculocephalic reflex but provides essentially the same information. The test is performed by irrigating the external auditory canal with cold water in order to induce convection currents in the labyrinths. After a brief latency, the result is tonic deviation of both eyes to the side of cold-water irrigation. In comatose patients, nystagmus in the opposite direction may not occur. The acronym ‘‘COWS’’ has been used to remind generations of medical students of the direction of nystagmus—cold water opposite, warm water same—but since nystagmus is often absent in the opposite direction due to frontal lobe dysfunction in coma, this mnemonic does not often hold true.

The corneal reflex, elicited by touching the cornea with a wisp of cotton and observing bilateral lid closure, depends on the integrity of pontine pathways between the fifth (afferent) and both seventh (efferent) cranial nerves; it is a useful test of pontine function. CNS-depressant drugs diminish or eliminate the corneal responses soon after reflex eye movements are paralyzed but before the pupils become unreactive to light. The corneal response may be lost for a time on the side of an acute hemiplegia.

**Respiratory Patterns** These are of less localizing value in comparison to other brainstem signs. Shallow, slow, but regular breathing suggests metabolic or drug-induced depression of the medullary respiratory centers. Cheyne-Stokes respiration in its typical cyclic form, ending with a brief apneic period, signifies bihemispherical damage or metabolic suppression and commonly accompanies light coma. Rapid, deep (Kussmaul) breathing usually implies metabolic acidosis but may also occur with pontomesencephalic lesions. Agonal gasps are the result of lower brainstem (medullary) damage and are recognized as the terminal respiratory pattern of severe brain damage. Other cyclic breathing patterns have been described but are of lesser significance.

## ■ LABORATORY STUDIES AND IMAGING

The studies that are most useful in the diagnosis of coma are chemical-toxicologic analysis of blood and urine, cranial CT or MRI, EEG, and cerebrospinal fluid (CSF) examination. Arterial blood gas analysis is helpful in patients with lung disease and acid-base disorders. The metabolic aberrations commonly encountered in clinical practice are usually revealed by measurement of electrolytes, glucose, calcium, magnesium, osmolarity, and renal (blood urea nitrogen) and hepatic ( $\text{NH}_3$ ) function. Toxicologic analysis may be necessary in cases of acute coma, when the diagnosis is not immediately clear. However, the presence of exogenous drugs or toxins, especially alcohol, does not exclude the possibility that other factors, particularly head trauma, are contributing to the clinical state. An ethanol level of 43 mmol/L

(0.2 g/dL) in nonhabituated patients generally causes impaired mental activity; a level of >65 mmol/L (0.3 g/dL) is associated with stupor. The development of tolerance may allow some chronic alcoholics to remain awake at levels >87 mmol/L (0.4 g/dL).

The availability of cranial CT and MRI has focused attention on causes of coma that are detectable by imaging (e.g., hemorrhage, tumor, or hydrocephalus). Resorting primarily to this approach, although at times expedient, is imprudent because most cases of coma (and confusion) are metabolic or toxic in origin. Furthermore, a normal CT scan does not exclude an anatomic lesion as the cause of coma; for example, early bilateral hemisphere infarction, acute brainstem infarction, encephalitis, meningitis, mechanical shearing of axons as a result of closed head trauma, sagittal sinus thrombosis, hypoxic injury, and subdural hematoma isodense to adjacent brain are some of the disorders that may not be detected. Sometimes imaging results can be misleading such as when small subdural hematomas or old strokes are found, but the patient’s coma is due to intoxication. Additional imaging with CT angiography or MRI can be obtained if acute posterior circulation stroke is considered.

The EEG (Chap. 425) provides clues in metabolic or drug-induced states but is rarely diagnostic in these disorders. However, it is the essential test to reveal coma due to nonconvulsive seizures and shows fairly characteristic patterns in herpesvirus encephalitis and prion disease. The EEG may be further helpful in disclosing generalized slowing of the background activity, a reflection of the severity of an encephalopathy. Predominant high-voltage slowing ( $\delta$  or triphasic waves) in the frontal regions is typical of metabolic coma, as from hepatic failure, and widespread fast ( $\beta$ ) activity implicates overdose with sedative drugs (e.g., benzodiazepines). A special pattern of ‘‘alpha coma,’’ defined by widespread, variable 8- to 12-Hz activity, superficially resembles the normal  $\alpha$  rhythm of waking but, unlike normal  $\alpha$  activity, is not altered by environmental stimuli. Alpha coma results from pontine or diffuse cortical damage and is associated with a poor prognosis. A unique EEG pattern in adults of ‘‘extreme delta brush’’ is characteristic of a specific (anti-*N*-methyl-*D*-aspartate [NMDA] receptor) form of autoimmune encephalitis. Normal  $\alpha$  activity on the EEG, which is suppressed by stimulating the patient, also alerts the clinician to the locked-in syndrome, hysteria, or catatonia.

Lumbar puncture should be performed if no cause is readily apparent, as examination of the CSF remains indispensable in the diagnosis of various forms of meningitis and encephalitis. An imaging study should be performed prior to lumbar puncture to exclude a large intracranial mass lesion, which could lead to herniation with lumbar puncture. Blood cultures and administration of antibiotics should precede the imaging study if infectious meningitis is suspected (Chap. 138).

## ■ DIFFERENTIAL DIAGNOSIS OF COMA

(Table 28-1) The causes of coma can be divided into three broad categories: those without focal neurologic signs (e.g., metabolic and toxic encephalopathies); those with prominent focal signs (e.g., stroke, cerebral hemorrhage); and meningitis syndromes, characterized by fever or stiff neck and an excess of cells in the spinal fluid (e.g., bacterial meningitis, subarachnoid hemorrhage, encephalitis). Causes of sudden coma include drug ingestion, cerebral hemorrhage, trauma, cardiac arrest, epilepsy, and basilar artery occlusion. Coma that appears subacutely is usually related to a preexisting medical or neurologic problem or, less often, to secondary brain swelling surrounding a mass such as tumor or cerebral infarction.

The diagnosis of coma due to cerebrovascular disease can be difficult (Chap. 426). The most common diseases in this category are (1) basal ganglia and thalamic hemorrhage (acute but not instantaneous onset, vomiting, headache, hemiplegia, and characteristic eye signs); (2) pontine hemorrhage (sudden onset, pinpoint pupils, loss of reflex eye movements and corneal responses, ocular bobbing, posturing, and hyperventilation); (3) cerebellar hemorrhage (occipital headache, vomiting, gaze paresis, and inability to stand and walk); (4) basilar artery thrombosis (neurologic prodrome or transient ischemic attack warning spells, diplopia, dysarthria, vomiting, eye movement and corneal response abnormalities, and asymmetric limb paresis); and

TABLE 28-1 Differential Diagnosis of Coma

1. Diseases that cause no focal brainstem or lateralizing neurologic signs (CT scan is often normal)
  - a. Intoxications: alcohol, sedative drugs, opiates, etc.
  - b. Metabolic disturbances: anoxia, hyponatremia, hypernatremia, hypercalcemia, diabetic acidosis, nonketotic hyperosmolar hyperglycemia, hypoglycemia, uremia, hepatic coma, hypercarbia, Addisonian crisis, hypo- and hyperthyroid states, profound nutritional deficiency
  - c. Severe systemic infections: pneumonia, septicemia, typhoid fever, malaria, Waterhouse-Friderichsen syndrome
  - d. Shock from any cause
  - e. Status epilepticus, nonconvulsive status epilepticus, postictal states
  - f. Hyperglycemic syndromes including hypertensive encephalopathy, eclampsia, posterior reversible encephalopathy syndrome (PRES)
  - g. Severe hyperthermia, hypothermia
  - h. Concussion
  - i. Acute hydrocephalus
2. Diseases that cause focal brainstem or lateralizing cerebral signs (CT scan is typically abnormal)
  - a. Hemispherical hemorrhage (basal ganglionic, thalamic) or infarction (large middle cerebral artery territory) with secondary brainstem compression
  - b. Brainstem infarction due to basilar artery thrombosis or embolism
  - c. Brain abscess, subdural empyema
  - d. Epidural and subdural hemorrhage, brain contusion
  - e. Brain tumor with surrounding edema
  - f. Cerebellar and pontine hemorrhage and infarction
  - g. Widespread traumatic brain injury
  - h. Metabolic coma (see above) in the setting of preexisting focal damage
3. Diseases that cause meningeal irritation with or without fever, and with an excess of white blood cells or red blood cells in the CSF
  - a. Subarachnoid hemorrhage from ruptured aneurysm, arteriovenous malformation, trauma
  - b. Infectious meningitis and meningoencephalitis
  - c. Paraneoplastic and autoimmune encephalitis
  - d. Carcinomatous and lymphomatous meningitis

(5) subarachnoid hemorrhage (precipitous coma after sudden severe headache and vomiting). The most common stroke, infarction in the territory of the middle cerebral artery, does not cause coma, but edema surrounding large infarctions may expand over several days and cause coma from mass effect.

The syndrome of acute hydrocephalus accompanies many intracranial diseases, particularly subarachnoid hemorrhage. It is characterized by headache and sometimes vomiting that may progress quickly to coma with extensor posturing of the limbs, bilateral Babinski signs, small unreactive pupils, and impaired oculocephalic movements in the vertical direction. At times, the coma may be featureless without lateralizing signs, although papilledema is often present.

## BRAIN DEATH

Brain death is a state of irreversible cessation of all cerebral and brainstem function with preservation of cardiac activity and maintenance of respiratory and somatic function by artificial means. It is the only type of brain damage recognized as morally, ethically, and legally equivalent to death. Criteria have been advanced for the diagnosis of brain death, and it is essential to adhere to consensus standards as multiple studies have shown variability in local practice. Given the implications of the diagnosis, clinicians must be thorough and precise in determining brain death. It is advisable to delay clinical testing for at least 24 h if a cardiac arrest has caused brain death or if the inciting disease is not known. Some centers advocate a brief period of observation between two examiners' tests during which the clinical signs of brain death are sustained.

Established criteria contain two essential elements, after assuring that no confounding factors (e.g., hypothermia, drug intoxication) are present: (1) widespread cortical destruction that is reflected by deep coma and unresponsiveness to all forms of stimulation; and (2) global

brainstem damage as demonstrated by absent pupillary light reaction, absent corneal reflexes, loss of oculovestibular reflexes, and destruction of the medulla, manifested by complete and irreversible apnea. Diabetes insipidus is often present but may only develop hours or days after the other clinical signs of brain death appear. The pupils are usually mid-sized but may be enlarged. Loss of deep tendon reflexes is not required because the spinal cord remains functional. Occasionally, other reflexes that originate from the spine may be present and should not preclude a diagnosis of brain death.

Demonstration that apnea is due to medullary damage requires that the  $P_{CO_2}$  be high enough to stimulate respiration during a test of spontaneous breathing. Apnea testing can be done by the use of preoxygenation with 100% oxygen prior to and following removal of the ventilator.  $CO_2$  tension increases  $\sim 0.3\text{--}0.4$  kPa/min (2–3 mmHg/min) during apnea. Apnea is confirmed if no respiratory effort has been observed in the presence of a sufficiently elevated  $P_{CO_2}$ . The apnea test is usually stopped if there is cardiovascular instability and alternative means of testing can be employed.

An isoelectric EEG may be used as an optional confirmatory test for total cerebral damage. Radionuclide brain scanning, cerebral angiography, or transcranial Doppler measurements may be used to demonstrate the absence of blood flow when a confirmatory study is desired.

It is largely accepted in Western society that the ventilator can be disconnected from a brain-dead patient and that organ donation is subsequently possible. Good communication between the physician and the family is important with appropriate preparation of the family for brain death testing and diagnosis.

## TREATMENT

### Coma

The immediate goal in a comatosed patient is prevention of further nervous system damage. Hypotension, hypoglycemia, hypercalcemia, hypoxia, hypercapnia, and hyperthermia should be corrected rapidly. Hyponatremia should be corrected slowly to avoid injury from osmotic demyelination (*Chap. 307*). An oropharyngeal airway is adequate to keep the pharynx open in a drowsy patient who is breathing normally. Tracheal intubation is indicated if there is apnea, upper airway obstruction, hypoventilation, or emesis, or if the patient is at risk for aspiration. Mechanical ventilation is required if there is hypoventilation or a need to induce hypocapnia in order to lower ICP. The management of raised ICP is discussed in *Chap. 307*. IV access is established and naloxone and dextrose are administered if opioid overdose or hypoglycemia are possibilities; thiamine is given along with glucose to avoid provoking Wernicke's encephalopathy in malnourished patients. In cases of suspected ischemic stroke including basilar thrombosis with brainstem ischemia, IV tissue plasminogen activator or mechanical embolectomy is often used after cerebral hemorrhage has been excluded and when the patient presents within established time windows for these interventions (*Chap. 427*). Physostigmine may awaken patients with anticholinergic-type drug overdose but should be used only with careful monitoring; many physicians believe that it should only be used to treat anticholinergic overdose-associated cardiac arrhythmias. The use of benzodiazepine antagonists offers some prospect of improvement after overdose; however, these drugs are not commonly used empirically in part due to their tendency to provoke seizures. Certain other toxic and drug-induced comas have specific treatments such as fomepizole for ethylene glycol ingestion.

Administration of hypotonic IV solutions should be monitored carefully in any serious acute brain illness because of the potential for exacerbating brain swelling. Cervical spine injuries must not be overlooked, particularly before attempting intubation or evaluation of oculocephalic responses. Fever and meningismus indicate an urgent need for examination of the CSF to diagnose meningitis. Whenever acute bacterial meningitis is suspected, antibiotics including at least vancomycin and a third-generation cephalosporin are typically administered rapidly along with dexamethasone (see *Chap. 138*).

## ■ PROGNOSIS

Some patients, especially children and young adults, may have ominous early clinical findings such as abnormal brainstem reflexes and yet recover; early prognostication outside of brain death therefore is unwise. Metabolic comas have a far better prognosis than traumatic ones. Systems for estimating prognosis in adults should be taken as approximations, and medical judgments must be tempered by factors such as age, underlying systemic disease, and general medical condition. In an attempt to collect prognostic information from large numbers of patients with head injury, the Glasgow Coma Scale was devised; it has predictive value in cases of brain trauma (see Chap. 443). For anoxic coma, clinical signs such as the pupillary and motor responses after 1 day, 3 days, and 1 week have predictive value; however, some prediction rules are less reliable in the setting of therapeutic hypothermia, and therefore, serial examinations and multimodal prognostication approaches are advised in this setting. For example, the absence of the cortical responses of the somatosensory evoked potentials has been shown to be a strong indicator of poor outcome following hypoxic injury.

The poor outcome of persistent vegetative and minimally conscious states has already been mentioned, but reports of a small number of patients displaying cortical activation on functional MRI in response to salient stimuli have begun to alter the perception of such individuals. In one series, about 10% of vegetative patients (mainly following traumatic brain injury) could activate their frontal or temporal lobes in response to requests by an examiner to imagine certain visuospatial tasks. Another series demonstrated that up to 15% of patients with various forms of acute brain injury and absence of behavioral responses to motor commands showed EEG activation in response to these commands. It is prudent to avoid generalizations from these findings, but the need for future studies of novel techniques to help communication and possibly recovery is needed.

## ■ FURTHER READING

- C J et al: Detection of brain activation in unresponsive patients with acute brain injury. *N Engl J Med* 380:2497, 2019.
- E JA et al: Diagnosis of reversible causes of coma. *Lancet* 384:2064, 2014.
- G DM et al: Determination of brain death/death by neurologic criteria: The World Brain Death Project. *JAMA* 324:1078, 2020.
- M MM et al: Willful modulation of brain activity in disorders of consciousness. *N Engl J Med* 362:579, 2010.
- P JB et al: *Plum and Posner's Diagnosis of Stupor and Coma*, 5th ed. New York, Oxford University Press, 2019.
- W EFM: Predicting the outcome of a comatose patient at the bedside. *Pract Neurol* 20:26, 2020.

Neuropsychiatric and social deficits also arise in many dementia syndromes, manifesting as depression, apathy, anxiety, hallucinations, delusions, agitation, insomnia, sleep disturbances, compulsions, or disinhibition. The clinical course may be slowly progressive, as in Alzheimer's disease (AD); static, as in anoxic encephalopathy; or may fluctuate from day to day or minute to minute, as in dementia with Lewy bodies (DLB). Most patients with AD, the most prevalent form of dementia, begin with episodic memory impairment, but in other dementias, such as frontotemporal dementia (FTD), memory loss is not typically a presenting feature. *Focal cerebral disorders are discussed in Chap. 30 and illustrated in a video library in Chap. V2; detailed discussions of AD can be found in Chap. 431; FTD and related disorders in Chap. 432; vascular dementia in Chap. 433; DLB in Chap. 434; Huntington's disease (HD) in Chap. 436; and prion diseases in Chap. 438.*

## FUNCTIONAL ANATOMY OF THE DEMENTIAS

Dementia syndromes result from the disruption of specific large-scale neuronal networks; the location and severity of synaptic and neuronal loss combine to produce the clinical features (Chap. 30). Behavior, mood, and attention are modulated by ascending noradrenergic, serotonergic, and dopaminergic pathways, whereas cholinergic signaling is critical for attention and memory functions. The dementias differ in the relative neurotransmitter deficit profiles; accordingly, accurate diagnosis guides effective pharmacologic therapy.

AD typically begins in the entorhinal region of the medial temporal lobe, spreads to the hippocampus and other limbic structures, and moves through the basal temporal areas and then into the lateral and posterior temporal and parietal neocortex, eventually causing a more widespread degeneration. Vascular dementia is associated with focal damage in a variable patchwork of cortical and subcortical regions or white matter tracts that disconnects nodes within distributed networks. In keeping with its anatomy, AD typically presents with episodic memory loss accompanied later by aphasia, executive dysfunction, or navigational problems. In contrast, dementias that begin in frontal or subcortical regions, such as FTD or HD, are less likely to begin with memory problems and more likely to present with difficulties with judgment, mood, executive control, movement, and behavior.

Lesions of frontal-striatal<sup>1</sup> pathways produce specific and predictable effects on behavior. The dorsolateral prefrontal cortex has connections with a central band of the caudate nucleus. Lesions of either the caudate or dorsolateral prefrontal cortex, or their connecting white matter pathways, may result in executive dysfunction, manifesting as poor organization and planning, decreased cognitive flexibility, and impaired working memory. The lateral orbital frontal cortex connects with the ventromedial caudate, and lesions of this system cause impulsiveness, distractibility, and disinhibition. The anterior cingulate cortex and adjacent medial prefrontal cortex project to the nucleus accumbens, and interruption of this system produces apathy, poverty of speech, emotional blunting, or even akinetic mutism. All corticostratial systems also include topographically organized projections through the globus pallidus and thalamus, and damage to these nodes can likewise reproduce the clinical syndrome associated with the corresponding cortical or striatal injuries. Involvement of brainstem nuclei and cerebellar structures can further contribute to cognitive, behavioral, and motor manifestations.

## ■ THE CAUSES OF DEMENTIA

The single strongest risk factor for dementia is increasing age. The prevalence of disabling memory loss increases with each decade over age 50 and is usually associated with the microscopic changes of AD at autopsy. Yet some centenarians have intact memory function and no evidence of clinically significant dementia. Whether dementia is an inevitable consequence of normal human aging remains controversial although the prevalence increases with every decade of life.

<sup>1</sup>The striatum comprises the caudate/putamen/nucleus accumbens.

# 29

## Dementia

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Dementia, a syndrome with many causes, affects nearly 6 million people in the United States and results in a total annual health care cost in excess of \$300 billion. Dementia is defined as an acquired deterioration in cognitive abilities that impairs the successful performance of activities of daily living. Episodic memory, the ability to recall events specific in time and place, is the cognitive function most commonly lost; 10% of persons age >70 years and 20–40% of individuals age >85 years have clinically identifiable memory loss. In addition to memory, dementia may erode other mental faculties, including language, visuospatial, praxis, calculation, judgment, and problem-solving abilities.

TABLE 29-1 Differential Diagnosis of Dementia

Most Common Causes of Dementia	
Alzheimer's disease	Alcoholism <sup>a</sup>
Vascular dementia	PDD/LBD spectrum
Multi-infarct	Drug/medication intoxication <sup>a</sup>
Diffuse white matter disease (Binswanger's)	Limbic-predominant age-related TDP-43 encephalopathy
Less Common Causes of Dementia	
Vitamin deficiencies	Toxic disorders
Thiamine (B <sub>1</sub> ): Wernicke's encephalopathy <sup>a</sup>	Drug, medication, and narcotic poisoning <sup>a</sup>
B <sub>12</sub> (subacute combined degeneration) <sup>a</sup>	Heavy metal intoxication <sup>a</sup>
Nicotinic acid (pellagra) <sup>a</sup>	Organic toxins
Endocrine and other organ failure	Psychiatric
Hypothyroidism <sup>a</sup>	Depression (pseudodementia) <sup>a</sup>
Adrenal insufficiency and Cushing's syndrome <sup>a</sup>	Schizophrenia <sup>a</sup>
Hypo- and hyperparathyroidism <sup>a</sup>	Conversion disorder <sup>a</sup>
Renal failure <sup>a</sup>	Degenerative disorders
Liver failure <sup>a</sup>	Huntington's disease
Pulmonary failure <sup>a</sup>	Multisystem atrophy
Chronic infections	Hereditary ataxias (some forms)
HIV	Frontotemporal lobar degeneration spectrum
Neurosyphilis <sup>a</sup>	Multiple sclerosis
Papovavirus (JC virus) (progressive multifocal leukoencephalopathy)	Adult Down's syndrome with Alzheimer's disease
Tuberculosis, fungal, and protozoal <sup>a</sup>	ALS-parkinsonism-dementia complex of Guam
Whipple's disease <sup>a</sup>	Prion (Creutzfeldt-Jakob and Gerstmann-Sträussler-Scheinker diseases)
Head trauma and diffuse brain damage	Miscellaneous
Chronic traumatic encephalopathy	Sarcoidosis <sup>a</sup>
Chronic subdural hematoma <sup>a</sup>	Vasculitis <sup>a</sup>
Postanoxia	CADASIL, etc.
Postencephalitis	Acute intermittent porphyria <sup>a</sup>
Normal-pressure hydrocephalus <sup>a</sup>	Recurrent nonconvulsive seizures <sup>a</sup>
Intracranial hypotension	Additional conditions in children or adolescents
Neoplastic	Pantothenate kinase-associated neurodegeneration
Primary brain tumor <sup>a</sup>	Subacute sclerosing panencephalitis
Metastatic brain tumor <sup>a</sup>	Metabolic disorders (e.g., Wilson's and Leigh's diseases, leukodystrophies, lipid storage diseases, mitochondrial mutations)
Autoimmune (paraneoplastic) encephalitis <sup>a</sup>	

<sup>a</sup>Potentially reversible dementia.

Abbreviations: ALS, amyotrophic lateral sclerosis; CADASIL, cerebral autosomal dominant arteriopathy with subcortical infarcts and leukoencephalopathy; LBD, Lewy body disease; PDD, Parkinson's disease dementia.

The many causes of dementia are listed in Table 29-1. The frequency of each condition depends on the age group under study, access of the group to medical care, country of origin, and perhaps racial or ethnic background. AD is the most common cause of dementia in Western countries, accounting for more than half of all patients. Vascular disease is the second most frequent cause for dementia and is particularly common in elderly patients or populations with limited access to medical care, where vascular risk factors are undertreated. Often, vascular brain injury is mixed with neurodegenerative disorders, particularly AD, making it difficult, even for the neuropathologist, to estimate the contribution of cerebrovascular disease to the cognitive disorder in an individual patient. Dementias associated with Parkinson's disease (PD) are common and may develop years after onset of a parkinsonian disorder, as seen with PD-related dementia (PDD), or they can occur concurrently with or preceding the motor syndrome, as in DLB.

Limbic-predominant aging-related TDP-43 encephalopathy (LATE) is common after age 70 and has been linked to declining episodic memory function. Chronic traumatic encephalopathy (CTE), a unique disease found in individuals with a history of repetitive head impacts (e.g., professional athletes in collision or fighting sports, military veterans exposed to multiple blasts), presents with changes in cognition, mood, behavior, or motor function. Mixed pathology is common, especially in older individuals. In patients under the age of 65, FTD rivals AD as the most common cause of dementia. Chronic intoxications, including those resulting from alcohol and prescription drugs, are an important and often treatable cause of dementia. Other disorders listed in Table 29-1 are uncommon but important because many are reversible. The classification of dementing illnesses into reversible and irreversible disorders is a useful approach to differential diagnosis. When effective treatments for the neurodegenerative conditions emerge, this dichotomy will become obsolete.

In a study of 1000 persons attending a memory disorders clinic, 19% had a potentially reversible cause of the cognitive impairment and 23% had a potentially reversible concomitant condition that may have contributed to the patient's impairment. The three most common potentially reversible diagnoses were depression, normal pressure hydrocephalus (NPH), and alcohol dependence; medication side effects are also common and should be considered in every patient (Table 29-1).

The term *rapidly progressive dementia* (RPD) is applied to illnesses that progress from initial symptom onset to dementia within a year or less; confusional states related to toxic/metabolic conditions are excluded. Although the prion proteinopathy Creutzfeldt-Jakob disease (CJD) (Chap. 438) is the classic cause of a rapidly progressive dementia, especially when associated with myoclonus, more often cases of RPD are due to AD or another neurodegenerative disorder, or to an autoimmune encephalitis.

Subtle cumulative decline in episodic memory is a common part of aging. This frustrating experience, often the source of jokes and humor, has historically been referred to as *benign forgetfulness of the elderly*. *Benign* means that it is not so progressive or serious that it impairs successful and productive daily functioning, although the distinction between benign and significant memory loss can be subtle. At age 85, the average person is able to learn and recall approximately one-half of the items (e.g., words on a list) that he or she could at age 18. The term *subjective cognitive decline* describes individuals who experience a subjective decline from their cognitive baseline but perform within normal limits for their age and educational attainment on formal neuropsychological testing. *Mild cognitive impairment (MCI)* is defined as a decline in cognition that is confirmed on objective cognitive testing but does not disrupt normal daily activities. MCI can be further subcategorized based on the presenting complaints and deficits (e.g., amnestic MCI, executive MCI). Factors that predict progression from MCI to an AD dementia include a prominent memory deficit, family history of dementia, presence of an apolipoprotein ε4 (Apo ε4) allele, small hippocampal volumes, an AD-like signature of cortical atrophy, low cerebrospinal fluid Aβ and elevated tau, or evidence of brain amyloid and tau deposition on positron emission tomography (PET) imaging.

The major degenerative dementias include AD, DLB, FTD and related disorders, HD, and prion diseases, including CJD. All are associated with the abnormal aggregation of a specific protein: Aβ<sub>42</sub> and tau in AD; α-synuclein in DLB; tau, TAR DNA-binding protein of 43 kDa (TDP-43), or the FET family of proteins (*fused in sarcoma* [FUS], Ewing sarcoma [EWS], and TBP-associated factor 15 [TAF15]) in FTD; huntingtin in HD; and misfolded prion protein (PrP<sup>sc</sup>) in CJD (Table 29-2).

The risk of developing dementia in late-life is associated with exposures and lifestyle factors that can operate across the life span. Modifiable risk factors include low education, hearing loss, traumatic brain injury, hypertension, diabetes mellitus, obesity, heavy alcohol use, smoking, depression, physical inactivity, and air pollution. Improved management of midlife vascular risk factors has been credited with a decreasing incidence of dementia observed in North America and Western Europe.

TABLE 29-2 The Molecular Basis for Degenerative Dementia

DEMENIA	MOLECULAR BASIS	CAUSAL GENES (CHROMOSOME)	SUSCEPTIBILITY GENES	PATHOLOGIC FINDINGS
AD	A $\beta$ /tau	<i>APP</i> (21), <i>PS-1</i> (14), <i>PS-2</i> (1) (>2% carry these mutations, most often in <i>PS-1</i> )	<i>Apo e4</i> (19)	Amyloid plaques, neurofibrillary tangles, and neuropil threads
FTD	Tau	<i>MAPT</i> exon and intron mutations (17) (about 10% of familial cases)	H1 <i>MAPT</i> haplotype	Tau neuronal and glial inclusions varying in morphology and distribution
	TDP-43	<i>GNN</i> (10% of familial cases), <i>C9ORF72</i> (20%–30% of familial cases), rare <i>VCP</i> , very rare <i>TARDBP</i> , <i>TBK1</i> , <i>TIA1</i>		TDP-43 neuronal and glial inclusions varying in morphology and distribution
	FET	Very rare <i>FUS</i>		FET neuronal and glial inclusions varying in morphology and distribution
DLB	$\alpha$ -Synuclein	Very rare <i>SNCA</i> (4)	Unknown	$\alpha$ -Synuclein neuronal inclusions (Lewy bodies)
CJD	PrP <sup>Sc</sup>	<i>PRNP</i> (20) (up to 15% of patients carry these dominant mutations)	Codon 129 homozygosity for methionine or valine	PrP <sup>Sc</sup> deposition, panlaminar spongiosis

Abbreviations: AD, Alzheimer's disease; CJD, Creutzfeldt-Jakob disease; DLB, dementia with Lewy bodies; FET, FUS/EWS/TAF-15; FTD, frontotemporal dementia.

## APPROACH TO THE PATIENT

### Dementias

Three major issues should be kept at the forefront: (1) What is the clinical diagnosis? (2) What component of the dementia syndrome is treatable or reversible? (3) Can the physician help to alleviate the burden on caregivers? A broad overview of the approach to dementia is shown in Table 29-3. The major degenerative dementias can usually be distinguished by the initial symptoms; neuropsychological, neuropsychiatric, and neurologic findings; and neuroimaging features (Table 29-4).

#### HISTORY

The history should concentrate on the onset, duration, and tempo of progression. An acute or subacute onset of confusion may be due to delirium (Chap. 27) and should trigger a search for intoxication, infection, or metabolic derangement. An elderly person with slowly progressive memory loss over several years is likely to suffer from AD. Nearly 75% of patients with AD begin with memory symptoms, but other early symptoms include anxiety or depression as well as difficulty managing money, driving, shopping, following instructions, finding words, or navigating. Personality change, disinhibition, and weight gain or compulsive eating suggest FTD, not AD. FTD is also suggested by prominent apathy, compulsivity, loss of empathy for others, or progressive loss of speech fluency or single-word comprehension with relative sparing of memory and visuospatial abilities. The diagnosis of DLB is suggested by early visual hallucinations; parkinsonism; proneness to delirium or sensitivity to psychoactive medications; rapid eye movement (REM) behavior disorder (RBD; dramatic, sometimes violent, limb movements during dreaming [Chap. 31]); or Capgras syndrome, the delusion that a familiar person has been replaced by an impostor.

A history of stroke with irregular stepwise progression suggests vascular dementia. Vascular dementia is also commonly seen in the setting of hypertension, atrial fibrillation, peripheral vascular disease, smoking, and diabetes. In patients suffering from cerebrovascular disease, it can be difficult to determine whether the dementia is due to AD, vascular disease, or a mixture of the two because many of the risk factors for vascular dementia, including diabetes, high cholesterol, elevated homocysteine, and low exercise, are also risk factors for AD. Moreover, many patients with a major vascular contribution to their dementia lack a history of stepwise decline. Rapid progression with motor rigidity and myoclonus suggests CJD (Chap. 438). Seizures may indicate strokes or neoplasm but also occur in AD, particularly early-age-of-onset AD. Gait disturbance is common in vascular dementia, PD/DLB, or NPH. A history of high-risk sexual behaviors or intravenous drug use should trigger a search for central nervous system (CNS) infection, especially HIV or syphilis. A history of recurrent head trauma could indicate chronic

subdural hematoma, CTE, intracranial hypotension, or NPH. Subacute onset of severe amnesia and psychosis with mesial temporal T2/fluid-attenuated inversion recovery (FLAIR) hyperintensities on MRI should raise concern for autoimmune (paraneoplastic) encephalitis, sometimes in long-term smokers or other patients at risk for cancer. The spectrum of autoimmune etiologies producing

TABLE 29-3 Evaluation of the Patient with Dementia

ROUTINE EVALUATION	OPTIONAL FOCUSED TESTS	OCCASIONALLY HELPFUL TESTS
History	Psychometric testing	EEG
Physical examination	Chest x-ray	Parathyroid function
Laboratory tests	Lumbar puncture	Adrenal function
Thyroid function (TSH)	Liver function	Urine heavy metals
Vitamin B <sub>12</sub>	Renal function	RBC sedimentation rate
Complete blood count	Urine toxin screen	Angiogram
Electrolytes	HIV	Brain biopsy
CT/MRI	Apolipoprotein E	SPECT
	RPR or VDRL	PET
		Autoantibodies
Diagnostic Categories	IRREVERSIBLE/DEGENERATIVE DEMENTIAS	PSYCHIATRIC DISORDERS
REVERSIBLE CAUSES		
Examples	Examples	Depression
Hypothyroidism	Alzheimer's	Schizophrenia
Thiamine deficiency	Frontotemporal dementia	Conversion reaction
Vitamin B <sub>12</sub> deficiency	Huntington's	
Normal pressure hydrocephalus	Dementia with Lewy bodies	
Subdural hematoma	Vascular	
Chronic infection	Leukoencephalopathies	
Brain tumor	Parkinson's	
Drug intoxication		
Autoimmune encephalopathy		
Associated Treatable Conditions		
	Depression	Agitation
	Seizures	Caregiver "burnout"
	Insomnia	Drug side effects

Abbreviations: CT, computed tomography; EEG, electroencephalogram; MRI, magnetic resonance imaging; PET, positron emission tomography; RBC, red blood cell; RPR, rapid plasma reagent (test); SPECT, single-photon emission computed tomography; TSH, thyroid-stimulating hormone; VDRL, venereal disease research laboratory (test for syphilis).

TABLE 29-4 Clinical Differentiation of the Major Dementias

DISEASE	FIRST SYMPTOM	MENTAL STATUS	NEUROPSYCHIATRY	NEUROLOGY	IMAGING
AD	Memory loss	Episodic memory loss	Irritability, anxiety, depression	Initially normal	Entorhinal cortex and hippocampal atrophy
FTD	Apathy, poor judgment/insight, speech/language, hyperorality	Frontal/executive and/or language; spares drawing	Apathy, disinhibition, overeating, compulsivity	May have vertical gaze palsy, axial rigidity, dystonia, alien hand, or MND	Frontal, insular, and/or temporal atrophy; usually spares posterior parietal lobe
DLB	Visual hallucinations, REM sleep behavior disorder, delirium, Capgras syndrome, parkinsonism	Drawing and frontal/executive, spares memory, delirium-prone	Visual hallucinations, depression, sleep disorder, delusions	Parkinsonism	Posterior parietal atrophy, hippocampi larger than in AD
CJD	Dementia, mood, anxiety, movement disorders	Variable, frontal/executive, focal cortical, memory	Depression, anxiety, psychosis in some	Myoclonus, rigidity, parkinsonism	Cortical ribboning and basal ganglia or thalamus hyperintensity on diffusion/FLAIR MRI
Vascular	Often but not always sudden, variable, apathy, falls, focal weakness	Frontal/executive, cognitive slowing, can spare memory	Apathy, delusions, anxiety	Usually motor slowing, spasticity, can be normal	Cortical and/or subcortical infarctions, confluent white matter disease

Abbreviations: AD, Alzheimer's disease; CBD, cortical basal degeneration; CJD, Creutzfeldt-Jakob disease; DLB, dementia with Lewy bodies; FLAIR, fluid-attenuated inversion recovery; FTD, frontotemporal dementia; MND, motor neuron disease; MRI, magnetic resonance imaging; REM, rapid eye movement.

RPD has rapidly expanded, and includes antibodies targeting leucine-rich glioma-inactivated 1 (LGI1; faciobrachial dystonic seizures); contactin-associated protein-like 2 (Caspr2; insomnia, ataxia, myotonia); *N*-methyl-*α*-aspartate (NMDA)-receptor (psychosis, insomnia, dyskinesias); and *α*-amino-3-hydroxy-5-methylisoxazole-4-propionic acid (AMPA)-receptor (limbic encephalitis with relapses), among others (Chap. 94). Alcohol abuse creates risk for malnutrition and thiamine deficiency. Veganism, bowel irradiation, an autoimmune diathesis, a remote history of gastric surgery, and chronic therapy with histamine H<sub>2</sub>-receptor antagonists for dyspepsia or gastroesophageal reflux predispose to B<sub>12</sub> deficiency. Certain occupations, such as working in a battery or chemical factory, might indicate heavy metal intoxication. Careful review of medication intake, especially for sedatives and analgesics, may raise the issue of chronic drug intoxication. An autosomal dominant family history is found in HD and in familial forms of AD, FTD, DLB, or prion disorders. A history of mood disorder, the recent death of a loved one, or depressive signs such as insomnia or weight loss, raise the possibility of depression-related cognitive impairment.

#### PHYSICAL AND NEUROLOGIC EXAMINATION

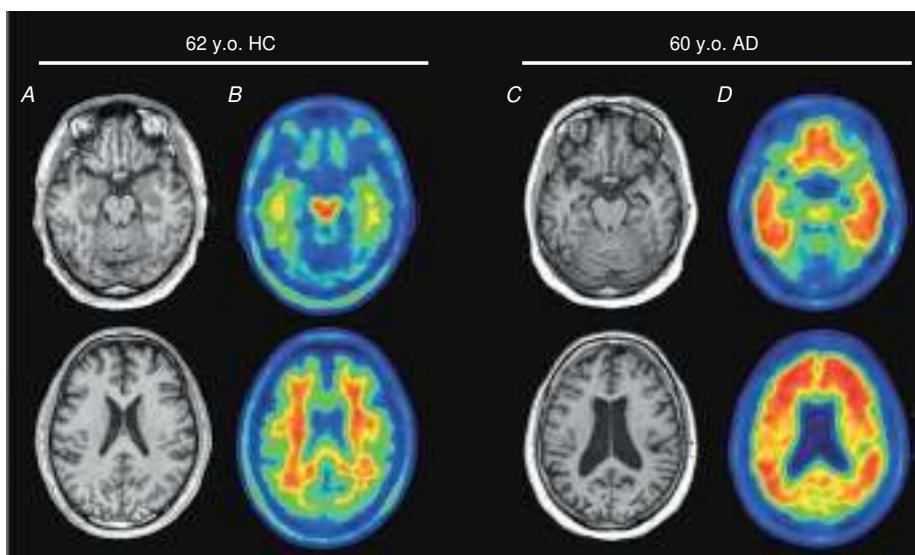
A thorough general and neurologic examination is essential to identify signs of nervous system involvement and search for clues suggesting a systemic disease that might be responsible for the cognitive disorder. Typical AD spares motor systems until late in the course. In contrast, patients with FTD often develop axial rigidity, supranuclear gaze palsy, or a motor neuron disease reminiscent of amyotrophic lateral sclerosis (ALS). In DLB, the initial symptoms may include a parkinsonian syndrome (resting tremor, cogwheel rigidity, bradykinesia, festinating gait), but DLB often starts with visual hallucinations or cognitive impairment, and symptoms referable to the lower brainstem (RBD, gastrointestinal, or autonomic problems) may arise years or even decades before parkinsonism or dementia. Corticobasal syndrome (CBS) features asymmetric akinesia and rigidity, dystonia, myoclonus, alien limb phenomena, pyramidal signs, and prefrontal deficits such as nonfluent aphasia with or without motor speech impairment, executive dysfunction, apraxia, or a behavioral disorder. Progressive supranuclear palsy (PSP) is associated with unexplained falls, axial rigidity, dysphagia, and vertical gaze deficits. CJD is suggested by the presence of diffuse rigidity, an akinetic mute state, and prominent, often startle-sensitive, myoclonus.

Hemiparesis or other focal neurologic deficits suggest vascular dementia or brain tumor. Dementia with a myelopathy and peripheral neuropathy suggests vitamin B<sub>12</sub> deficiency. Peripheral

neuropathy could also indicate another vitamin deficiency, heavy metal intoxication, thyroid dysfunction, Lyme disease, or vasculitis. Dry cool skin, hair loss, and bradycardia suggest hypothyroidism. Fluctuating confusion associated with repetitive stereotyped movements may indicate ongoing limbic, temporal, or frontal seizures. In the elderly, hearing impairment or visual loss may produce confusion and disorientation misinterpreted as dementia. Profound bilateral sensorineural hearing loss in a younger patient with short stature or myopathy, however, should raise concern for a mitochondrial disorder.

#### COGNITIVE AND NEUROPSYCHIATRIC EXAMINATION

Brief screening tools such as the Mini-Mental State Examination (MMSE), the Montreal Cognitive Assessment (MOCA), the Tablet Based Cognitive Assessment Tool, and Cognistat can be used to capture dementia and follow progression. None of these tests is highly sensitive to early-stage dementia or reliably discriminates between dementia syndromes. The MMSE is a 30-point test of cognitive function, with each correct answer being scored as 1 point. It includes tests of: orientation (e.g., identify season/date/month/year/floor/hospital/town/state/country); registration (e.g., name and restate 3 objects); recall (e.g., remember the same three objects 5 minutes later); and language (e.g., name pencil and watch; repeat “no ifs ands or buts”; follow a 3-step command; obey a written command; and write a sentence and copy a design). In most patients with MCI and some with clinically apparent AD, bedside screening tests may be normal, and a more challenging and comprehensive set of neuropsychological tests will be required. When the etiology for the dementia syndrome remains in doubt, a specially tailored evaluation should be performed that includes tasks of working and episodic memory, executive function, language, and visuospatial and perceptual abilities. In AD, the early deficits involve episodic memory, category generation (“name as many animals as you can in 1 minute”), and visuoconstructive ability. Usually deficits in verbal or visual episodic memory are the first neuropsychological abnormalities detected, and tasks that require the patient to recall a long list of words or a series of pictures after a predetermined delay will demonstrate deficits in most patients. In FTD, the earliest deficits on cognitive testing involve executive control or language (speech or naming) functions, but some patients lack either finding despite profound social-emotional deficits. PDD or DLB patients have more severe deficits in executive and visuospatial function but do better on episodic memory tasks than patients with AD. Patients with vascular dementia often demonstrate a mixture of executive and visuospatial deficits, with prominent psychomotor slowing. In delirium, the most prominent deficits involve attention, working



**FIGURE 29-1** Alzheimer's disease (AD). Axial T1-weighted magnetic resonance images of a healthy 62-year-old (*A, B*) and a 60-year-old with AD (*C, D*). Note the diffuse atrophy, plus temporal lobe volume loss, in the patient with AD. A $\beta$  positron emission tomography (PET) with  $^{11}\text{C}$ PIB (*B* and *D*) reveals extensive radiotracer retention in neocortex bilaterally in AD, consistent with the known distribution of amyloid plaques. HC, healthy control. (Source: Gil Rabinovici, University of California, San Francisco and William Jagust, University of California, Berkeley.)

memory, and executive function, making the assessment of other cognitive domains challenging and often uninformative.

A functional assessment should also be performed to help the physician determine the day-to-day impact of the disorder on the patient's memory, community affairs, hobbies, judgment, dressing, and eating. Knowledge of the patient's functional abilities will help the clinician and the family to organize a therapeutic approach.

Neuropsychiatric assessment is important for diagnosis, prognosis, and treatment. In the early stages of AD, mild depressive features, social withdrawal, and irritability or anxiety are the most prominent psychiatric changes, but patients often maintain core social graces into the middle or late stages, when delusions, agitation, and sleep disturbance may emerge. In FTD, dramatic personality change with apathy, overeating, compulsions, disinhibition, and loss of empathy are early and common. DLB is associated with visual hallucinations, delusions related to person or place identity, RBD, and excessive daytime sleepiness. Dramatic fluctuations occur not only in cognition but also in arousal. Vascular dementia can present with psychiatric symptoms such as depression, anxiety, delusions, disinhibition, or apathy.

#### LABORATORY TESTS

The choice of laboratory tests in the evaluation of dementia is complex and should be tailored to the individual patient. The physician must take measures to avoid missing a reversible or treatable cause, yet no single treatable etiology is common; thus a screen must use multiple tests, each of which has a low yield. Cost/benefit ratios are difficult to assess, and many laboratory screening algorithms for dementia discourage multiple tests. Nevertheless, even a test with only a 1–2% positive rate is worth undertaking if the alternative is missing a treatable cause of dementia. Table 29-3 lists most screening tests for dementia. The American Academy of Neurology recommends the routine measurement of a complete blood count; electrolytes; glucose; renal, liver, and thyroid functions; a vitamin B<sub>12</sub> level; and a structural neuroimaging study (MRI or CT).

Neuroimaging studies, especially MRI, help to rule out primary and metastatic neoplasms, locate areas of infarction or inflammation, detect subdural hematomas, and suggest NPH or diffuse white matter disease. They also help to establish a regional pattern of atrophy. Support for the diagnosis of AD includes hippocampal

atrophy in addition to posterior-predominant cortical atrophy (Fig. 29-1). Focal frontal, insular, and/or anterior temporal atrophy suggests FTD (Chap. 432). DLB often features less prominent atrophy, with greater involvement of the amygdala than the hippocampus. In CJD, magnetic resonance (MR) diffusion-weighted imaging reveals restricted diffusion within the cortical ribbon and/or basal ganglia in most patients. Extensive multifocal white matter abnormalities suggest a vascular etiology (Fig. 29-2). Communicating hydrocephalus with vertex effacement (crowding of dorsal convexity gyri/sulci), gaping Sylvian fissures despite minimal cortical atrophy, and additional features shown in Fig. 29-3 suggest NPH. Single-photon emission computed tomography (SPECT) and fluoro-deoxyglucose PET scanning show temporal-parietal hypoperfusion or hypometabolism in AD and frontotemporal deficits in FTD, but abnormalities in these patterns can be detected with MRI alone in many patients. Recently, amyloid- and tau-PET imaging have shown promise for the diagnosis of AD. There are currently



**FIGURE 29-2** Diffuse white matter disease. Axial fluid-attenuated inversion recovery (FLAIR) magnetic resonance image through the lateral ventricles reveals multiple areas of hyperintensity (arrows) involving the periventricular white matter as well as the corona radiata and striatum. Although seen in some individuals with normal cognition, this appearance is more pronounced in patients with dementia of a vascular etiology.



**FIGURE 29-3** Normal pressure hydrocephalus. *A.* Sagittal T1-weighted MRI demonstrates dilation of the lateral ventricle and stretching of the corpus callosum (arrows), depression of the floor of the third ventricle (single arrowhead), and enlargement of the aqueduct (double arrowheads). Note the diffuse dilation of the lateral, third, and fourth ventricles with a patent aqueduct, typical of communicating hydrocephalus. *B.* Axial T2-weighted MRIs demonstrate dilation of the lateral ventricles. This patient underwent successful ventriculoperitoneal shunting.

three amyloid PET ligands (F18-florbetapir, F18-florbetaben, F18-flutemetamol) and one tau PET ligand (F18-flortaucipir) approved by the US Food and Drug Administration for clinical use. Amyloid PET ligands bind to diffuse and neuritic amyloid plaques, as well as to vascular amyloid deposits (prominent in cerebral amyloid angiopathy), while tau PET ligands bind to the paired helical filaments of tau characteristic of neurofibrillary tangles in AD (Chap. 431). Because amyloid plaques are also commonly found in cognitively normal older persons (~25% of individuals at age 65), the main clinical value of amyloid imaging is to exclude AD as the likely cause of dementia in patients who have negative scans. The spread of tau is more tightly linked to cognitive state (Chap. 431), and thus may be more useful than amyloid imaging for “ruling in” AD, as well as for disease staging. Once disease-modifying therapies become available, CSF or molecular PET biomarkers will likely be used to identify treatment candidates. In the meantime, the prognostic value of detecting brain amyloid in an asymptomatic elder to assess preclinical disease and risk of future cognitive decline remains a topic of vigorous investigation.

Lumbar puncture need not be done routinely in the evaluation of dementia, but it is indicated when CNS infection or inflammation are credible diagnostic possibilities. Cerebrospinal fluid (CSF) levels of A $\beta_{42}$  and tau proteins show differing patterns with the various dementias, and the presence of low A $\beta_{42}$  (or a low A $\beta_{42}$ /A $\beta_{40}$  ratio), mild-moderately elevated CSF total tau, and elevated CSF phosphorylated tau (at residues 181 or 217) is highly suggestive of AD. Novel fully automated CSF A $\beta$  and tau assays perform comparably to amyloid and tau PET respectively, though, as with PET, their routine use in the diagnosis of dementia is debated. Blood-based biomarkers for AD show promise as a less invasive screening tool but remain under development (Chap. 431). Formal psychometric testing helps to document the severity of cognitive disturbance, suggests psychogenic causes, and provides a more formal method for following the disease course. Electroencephalogram (EEG) is not routinely used but can help to suggest CJD (repetitive bursts of diffuse high-amplitude sharp waves, or “periodic complexes”) or an underlying nonconvulsive seizure disorder (epileptiform discharges). Brain biopsy (including meninges) is not advised except to diagnose vasculitis, neoplasms, or unusual infections when the diagnosis is uncertain. Systemic disorders with CNS manifestations, such as sarcoidosis, can often be confirmed through biopsy of lymph node or solid organ rather than brain. MR angiography should be considered when cerebral vasculitis or cerebral venous thrombosis is a possible cause of the dementia.

## ■ GLOBAL CONSIDERATIONS

Vascular dementia (Chap. 433) is more common in Asia due to the higher prevalence of intracranial atherosclerosis. Rates of vascular dementia are also on the rise in developing countries as vascular risk factors such as hypertension, hypercholesterolemia, and diabetes mellitus become more widespread. CNS infections, HIV (and associated opportunistic infections), syphilis, cysticercosis, and tuberculosis, likewise represent major contributors to dementia in the developing world. Systemic infection with SARS-CoV-2 may, in some individuals, have lasting effects on cognition due to involvement of brain microvasculature or to immunologically mediated white matter injury (acute disseminated encephalomyelitis [ADEM]) (Chap. 444). Some individuals complain of lasting fatigue, changes in mood, and cognitive difficulties, but the long-term prognosis for SARS-CoV-2-related cognitive impairment remains unknown. Isolated populations have also contributed to our understanding of neurodegenerative dementia. Kuru, the cannibalism-associated rapidly progressive dementia seen in tribal New Guinea, played a role in the discovery of human prion disease. Amyotrophic lateral sclerosis-parkinsonism-dementia complex of Guam (or, Lytico-bodig disease) is a poly-proteinopathy, often with tau, TDP-43, and alpha-synuclein aggregation. The root cause of the disease remains uncertain, but its incidence has declined sharply over the past 60 years.

## TREATMENT

### Dementia

The major goals of dementia management are to treat reversible causes and provide comfort and support to the patient and caregivers. Treatment of underlying causes includes thyroid replacement for hypothyroidism; vitamin therapy for thiamine or B<sub>12</sub> deficiency or for elevated serum homocysteine; antimicrobials for opportunistic infections or antiretrovirals for HIV; ventricular shunting for NPH; or surgical, radiation, and/or chemotherapeutic treatment for CNS neoplasms. Removal of cognition-impairing drugs or medications is essential when appropriate. If the patient's cognitive complaints stem from a psychiatric disorder, vigorous treatment of the condition should be tried to eliminate the cognitive complaint or to confirm that it persists despite adequate resolution of the mood or anxiety symptoms. Patients with degenerative diseases may also be depressed or anxious, and those aspects of their condition often respond to therapy while not necessarily improving cognition. Antidepressants, such as selective serotonin reuptake inhibitors (SSRIs) or serotonin-norepinephrine reuptake inhibitors (SNRIs) (Chap. 452), which feature anxiolytic properties but few cognitive side effects, provide the mainstay of treatment when necessary. Anticonvulsants are used to control AD-associated seizures.

Agitation, hallucinations, delusions, and confusion are difficult to treat. These behavioral problems represent major causes for nursing home placement and institutionalization. Before treating these behaviors with medications, the clinician should aggressively seek out modifiable environmental or metabolic factors. Hunger, lack of exercise, toothache, constipation, urinary tract or respiratory infection, electrolyte imbalance, and drug toxicity all represent easily correctable causes that can be remedied without psychoactive drugs. Drugs such as phenothiazines and benzodiazepines may ameliorate the behavior problems but have untoward side effects such as sedation, rigidity, or dyskinesia; benzodiazepines can occasionally produce paradoxical disinhibition. Despite their unfavorable side effect profile, second-generation antipsychotics such as quetiapine (starting dose, 12.5–25 mg daily) can be used for patients with agitation, aggression, and psychosis, although the risk profile for these compounds is significant, including increased mortality in patients with dementia. When patients do not respond to treatment, it is usually a mistake to advance to higher doses or to use anticholinergic drugs (like diphenhydramine) or sedatives (such as barbiturates or benzodiazepines). It is important to recognize and treat depression; treatment can begin with a low dose of an

SSRI (e.g., escitalopram, starting dose 5 mg daily, target dose 5–10 mg daily) while monitoring for efficacy and toxicity. Sometimes apathy, visual hallucinations, depression, and other psychiatric symptoms respond to cholinesterase inhibitors, especially in DLB, obviating the need for other more toxic therapies.

Cholinesterase inhibitors are being used to treat AD (donepezil, rivastigmine, galantamine) and PDD (rivastigmine). Memantine is useful for some patients with moderate to severe AD; its major benefit relates to decreasing caregiver burden, most likely by decreasing resistance to dressing and grooming support. In moderate to severe AD, the combination of memantine and a cholinesterase inhibitor delayed nursing home placement in several studies, although other studies have not supported the efficacy of adding memantine to the regimen. Memantine should be used with great caution, or not at all, in patients with DLB, due to risk of worsening agitation and confusion. Therapies targeting the production, aggregation, and spread of misfolded proteins associated with dementia are under development. Recently the first drug in this class, the amyloid-beta targeting monoclonal antibody aducanumab, was approved by the United States Food & Drug Administration for treatment of Alzheimer's disease (Chap. 431). Other drugs under development target disease-associated neuroinflammation metabolic changes, synaptic loss, and neurotransmitter changes.

Proactive approaches reduce the occurrence of delirium in hospitalized patients. Frequent orientation, cognitive activities, sleep-enhancement measures, vision and hearing aids, and correction of dehydration are all valuable in decreasing the likelihood of delirium.

Nondrug behavior therapy has an important place in dementia management. The primary goals are to make the patient's life comfortable, uncomplicated, and safe. Preparing lists, schedules, calendars, and labels can be helpful in the early stages. It is also useful to stress familiar routines, walks, and simple physical exercises. For many demented patients, memory for events is worse than their ability to carry out routine activities, and they may still be able to take part in their favorite hobbies, sports, and social activities. Demented patients often object to losing control over familiar tasks such as driving, cooking, and handling finances. Attempts to help may be greeted with complaints, depression, or anger. Hostile responses on the part of the caregiver are counterproductive and sometimes even harmful. Reassurance, distraction, and calm positive statements are more productive when resistance is present. Eventually, tasks such as finances and driving must be assumed by others, and the patient will conform and adjust. Safety is an important issue that includes not only driving but controlling the kitchen, bathroom, and sleeping area environments, as well as stairways. These areas need to be monitored, supervised, and made as safe as possible. A move to a retirement complex, assisted-living center, or nursing home can initially increase confusion and agitation. Repeated reassurance, reorientation, and careful introduction to the new personnel will help to smooth the process. Providing activities that are known to be enjoyable to the patient can also help.

The clinician must pay special attention to frustration and depression among family members and caregivers. Caregiver guilt and burnout are common. Family members often feel overwhelmed and helpless and may vent their frustrations on the patient, each other, and health care providers. Caregivers should be encouraged to take advantage of day-care facilities and respite services. Education and counseling about dementia are important. Local and national support groups, such as the Alzheimer's Association ([www.alz.org](http://www.alz.org)), can provide considerable help.

## FURTHER READING

- B C et al: Non-pharmacological management of behavioral symptoms in frontotemporal and other dementias. *Curr Neurol Neurosci Rep* 16:14, 2016.
- G J et al: Psychologic/functional forms of memory disorder. *Handb Clin Neurol* 139:407, 2017.
- W SF, F D: Autoimmune encephalitides and rapidly progressive dementias. *Semin Neurol* 39:283, 2019.

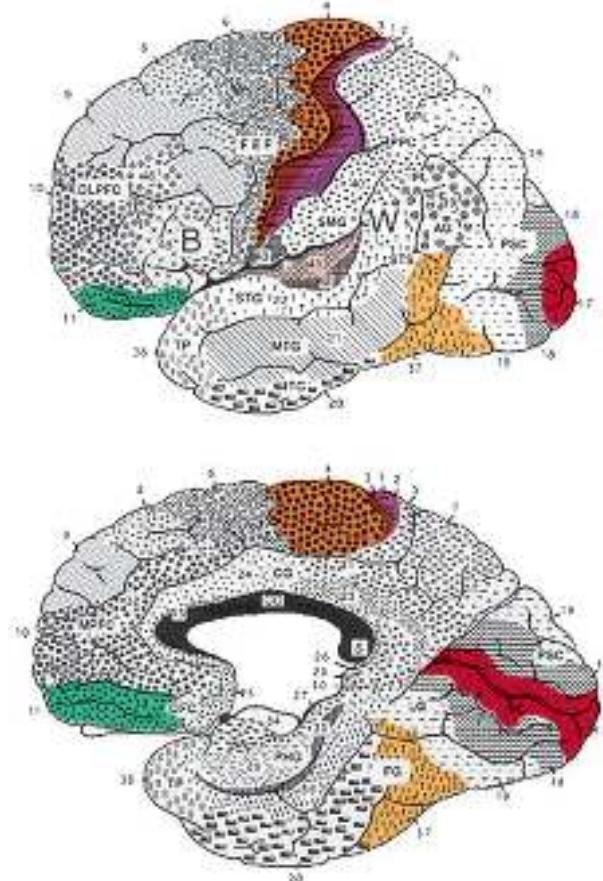
# 30

## Aphasia, Memory Loss, and Other Cognitive Disorders

M.-Marsel Mesulam



The cerebral cortex of the human brain contains ~20 billion neurons spread over an area of 2.5 m<sup>2</sup>. The primary sensory and motor areas constitute 10% of the cerebral cortex. The rest is subsumed by modality-selective, heteromodal, paralimbic, and limbic areas collectively known as the *association cortex* (Fig. 30-1). The association cortex mediates the integrative processes that subserve cognition, emotion, and comportment. A systematic testing of these mental functions is necessary for the effective clinical assessment of the association cortex and its diseases. According to current thinking, there are no centers for "hearing words," "perceiving space," or "storing memories." Cognitive



**FIGURE 30-1** Lateral (top) and medial (bottom) views of the cerebral hemispheres. The numbers refer to the Brodmann cytoarchitectonic designations. Area 17 corresponds to the primary visual cortex, 41–42 to the primary auditory cortex, 1–3 to the primary somatosensory cortex, and 4 to the primary motor cortex. The rest of the cerebral cortex contains association areas. AG, angular gyrus; B, Broca's area; CC, corpus callosum; CG, cingulate gyrus; DLPFC, dorsolateral prefrontal cortex; FEF, frontal eye fields ( premotor cortex); FG, fusiform gyrus; IPL, inferior parietal lobule; ITG, inferior temporal gyrus; LG, lingual gyrus; MFC, medial prefrontal cortex; MTG, middle temporal gyrus; OFC, orbitofrontal cortex; PHG, parahippocampal gyrus; PPC, posterior parietal cortex; PSC, peristriate cortex; SC, striate cortex; SMG, supramarginal gyrus; SPL, superior parietal lobule; STG, superior temporal gyrus; STS, superior temporal sulcus; TP, temporopolar cortex; W, Wernicke's area.

and behavioral functions (domains) are coordinated by intersecting *large-scale neural networks* that contain interconnected cortical and subcortical components. Five anatomically defined *large-scale networks* are most relevant to clinical practice: (1) a left-dominant perisylvian network for language, (2) a right-dominant parietofrontal network for spatial orientation, (3) an occipitotemporal network for face and object recognition, (4) a limbic network for episodic memory and emotional modulation, and (5) a prefrontal network for the executive control of cognition and comportment. Investigations based on functional imaging have also identified a *default mode network*, which becomes activated when the person is not engaged in a specific task requiring attention to external events. The clinical consequences of damage to this network are not yet fully defined.

## THE LEFT PERISYLVIAN NETWORK FOR LANGUAGE AND APHASIAS

The production and comprehension of words and sentences is dependent on the integrity of a distributed network located along the perisylvian region of the language-dominant (usually left) hemisphere. One hub, situated in the inferior frontal gyrus, is known as *Broca's area*. Damage to this region impairs fluency of verbal output and the grammatical structure of sentences. The location of a second hub, critical for language comprehension, is less clearly settled. Accounts of patients with focal cerebrovascular lesions identified *Wernicke's area*, located at the parietotemporal junction, as a critical hub for word and sentence comprehension. Occlusive or embolic strokes involving this area interfere with the ability to understand spoken or written language as well as the ability to express thoughts through meaningful words and statements. However, investigations of patients with the neurodegenerative syndrome of primary progressive aphasia (PPA) have shown that sentence comprehension is a widely distributed faculty jointly subserved by Broca's and Wernicke's areas, and that the areas critical for word comprehension are more closely associated with the anterior temporal lobe than with Wernicke's area. All components of the language network are interconnected with each other and with surrounding parts of the frontal, parietal, and temporal lobes. Damage to this network gives rise to language impairments known as aphasia. Aphasia should be diagnosed only when there are deficits in the formal aspects of language, such as word finding, word choice, comprehension, spelling, or grammar. Dysarthria, apraxia of speech, and mutism do not by themselves lead to a diagnosis of aphasia. In ~90% of right-handers and 60% of left-handers, aphasia occurs only after lesions of the left hemisphere.

### CLINICAL EXAMINATION

The clinical examination of language should include the assessment of naming, spontaneous speech, comprehension, repetition, reading, and writing. A deficit of naming (*anomia*) is the single most common finding in aphasic patients. When asked to name a common object, the patient may fail to come up with the appropriate word, may provide a circumlocutious description of the object ("the thing for writing"), or may come up with the wrong word (*paraphasia*). If the patient offers

an incorrect but related word ("pen" for "pencil"), the naming error is known as a *semantic paraphasia*; if the word approximates the correct answer but is phonetically inaccurate ("plentil" for "pencil"), it is known as a *phonemic paraphasia*. In most anomias, the patient cannot retrieve the appropriate name when shown an object but can point to the appropriate object when the name is provided by the examiner. This is known as a one-way (or retrieval-based) naming deficit. A two-way (comprehension-based or semantic) naming deficit exists if the patient can neither provide nor recognize the correct name. *Spontaneous speech* is described as "fluent" if it maintains appropriate output volume, phrase length, and melody or as "nonfluent" if it is sparse and halting and average utterance length is below four words. The examiner also should note the integrity of *grammar* as manifested by word order (syntax), tenses, suffixes, prefixes, plurals, and possessives. *Comprehension* can be tested by assessing the patient's ability to follow conversation, asking yes-no questions ("Can a dog fly?" "Does it snow in summer?"), asking the patient to point to appropriate objects ("Where is the source of illumination in this room?"), or asking for verbal definitions of single words. *Repetition* is assessed by asking the patient to repeat single words, short sentences, or strings of words such as "No ifs, ands, or buts." The testing of repetition with tongue twisters such as "hippopotamus" and "Irish constabulary" provides a better assessment of dysarthria and apraxia of speech than of aphasia. It is important to make sure that the number of words does not exceed the patient's attention span. Otherwise, the failure of repetition becomes a reflection of the narrowed attention span (auditory working memory) rather than an indication of an aphasic deficit caused by dysfunction of a hypothetical *phonological loop* in the language network. *Reading* should be assessed for deficits in reading aloud as well as comprehension. *Alexia* describes an inability to either read aloud or comprehend written words and sentences; *agraphia* (or *dysgraphia*) is used to describe an acquired deficit in spelling.

Aphasias can arise acutely in cerebrovascular accidents (CVAs) or gradually in neurodegenerative diseases. In CVAs, damage encompasses cerebral cortex as well as deep white matter pathways interconnecting otherwise unaffected cortical areas. The syndromes listed in Table 30-1 are most applicable to this group, where gray matter and white matter at the lesion site are abruptly and jointly destroyed. Progressive neurodegenerative diseases can have cellular, laminar, and regional specificity for the cerebral cortex, giving rise to a different set of aphasias that will be described separately.

**Wernicke's Aphasia** Comprehension is impaired for spoken and written words and sentences. Language output is fluent but is highly paraphasic and circumlocutious. Paraphasic errors may lead to strings of neologisms, which lead to "jargon aphasia." Speech contains few substantive nouns. The output is therefore voluminous but uninformative. For example, a patient attempts to describe how his wife accidentally threw away something important, perhaps his dentures: "We don't need it anymore, she says. And with it when that was downstairs was my teeth-tick ... a ... den ... dentith ... my dentist. And they happened

TABLE 30-1 Clinical Features of Aphasias and Related Conditions Commonly Seen in Cerebrovascular Accidents

	COMPREHENSION	REPETITION OF SPOKEN LANGUAGE	NAMING	FLUENCY
Wernicke's	Impaired	Impaired	Impaired	Preserved or increased
Broca's	Preserved (except grammar)	Impaired	Impaired	Decreased
Global	Impaired	Impaired	Impaired	Decreased
Conduction	Preserved	Impaired	Impaired	Preserved
Nonfluent (anterior) transcortical	Preserved	Preserved	Impaired	Impaired
Fluent (posterior) transcortical	Impaired	Preserved	Impaired	Preserved
Isolation	Impaired	Echolalia	Impaired	No purposeful speech
Anomic	Preserved	Preserved	Impaired	Preserved except for word-finding pauses
Pure word deafness	Impaired only for spoken language	Impaired	Preserved	Preserved
Pure alexia	Impaired only for reading	Preserved	Preserved	Preserved

to be in that bag ... see? ... Where my two ... two little pieces of dentist that I use ... that I ... all gone. If she throws the whole thing away ... visit some friends of hers and she can't throw them away."

Gestures and pantomime do not improve communication. The patient may not realize that his or her language is incomprehensible and may appear angry and impatient when the examiner fails to decipher the meaning of a severely paraphasic statement. In some patients, this type of aphasia can be associated with severe agitation and paranoia. The ability to follow commands aimed at axial musculature may be preserved. The dissociation between the failure to understand simple questions ("What is your name?") in a patient who rapidly closes his or her eyes, sits up, or rolls over when asked to do so is characteristic of Wernicke's aphasia and helps differentiate it from deafness, psychiatric disease, or malingering. Patients with Wernicke's aphasia cannot express their thoughts in meaning-appropriate words and cannot decode the meaning of words in any modality of input. This aphasia therefore has expressive as well as receptive components. Repetition, naming, reading, and writing also are impaired.

The lesion site most commonly associated with Wernicke's aphasia caused by CVAs is the posterior portion of the language network. An embolus to the inferior division of the middle cerebral artery (MCA), to the posterior temporal or angular branches in particular, is the most common etiology (Chap. 426). Intracerebral hemorrhage, head trauma, and neoplasm are other causes of Wernicke's aphasia. A coexisting right hemianopia or superior quadrantanopia is common, and mild right nasolabial flattening may be found, but otherwise, the examination is often unrevealing. The paraphasic, neologistic speech in an agitated patient with an otherwise unremarkable neurologic examination may lead to the suspicion of a primary psychiatric disorder such as schizophrenia or mania, but the other components characteristic of acquired aphasia and the absence of prior psychiatric disease usually settle the issue. Prognosis for recovery of language function is guarded.

**Broca's Aphasia** Speech is nonfluent, labored, interrupted by many word-finding pauses, and usually dysarthric. It is impoverished in function words but enriched in meaning-appropriate nouns. Abnormal word order and the inappropriate deployment of *bound morphemes* (word endings used to denote tenses, possessives, or plurals) lead to a characteristic agrammatism. Speech is telegraphic and pithy but quite informative. In the following passage, a patient with Broca's aphasia describes his medical history: "I see ... the dotor, dotor sent me ... Bosson. Go to hospital. Dotor ... kept me beside. Two, tee days, doctor send me home."

Output may be reduced to a grunt or single word ("yes" or "no"), which is emitted with different intonations in an attempt to express approval or disapproval. In addition to fluency, naming and repetition are impaired. Comprehension of spoken language is intact except for syntactically difficult sentences with a passive voice structure or embedded clauses, indicating that Broca's aphasia is not just an "expressive" or "motor" disorder and that it also may involve a comprehension deficit in decoding syntax. Patients with Broca's aphasia can be tearful, easily frustrated, and profoundly depressed. Insight into their condition is preserved, in contrast to Wernicke's aphasia. Even when spontaneous speech is severely dysarthric, the patient may be able to display a relatively normal articulation of words when singing. This dissociation has been used to develop specific therapeutic approaches (melodic intonation therapy) for Broca's aphasia. Additional neurologic deficits include right facial weakness, hemiparesis or hemiplegia, and a buccofacial apraxia characterized by an inability to carry out motor commands involving oropharyngeal and facial musculature (e.g., patients are unable to demonstrate how to blow out a match or suck through a straw). The cause is most often infarction of Broca's area (the inferior frontal convolution; "B" in Fig. 30-1) and surrounding anterior perisylvian and insular cortex due to occlusion of the superior division of the MCA (Chap. 426). Mass lesions, including tumor, intracerebral hemorrhage, and abscess, also may be responsible. When the cause of Broca's aphasia is stroke, recovery of language function generally peaks within 2–6 months, after which time further progress is limited. Speech therapy is more successful than in Wernicke's aphasia.

**Conduction Aphasia** Speech output is fluent but contains many phonemic paraphasias, comprehension of spoken language is intact, and repetition is severely impaired. Naming elicits phonemic paraphasias, and spelling is impaired. Reading aloud is impaired, but reading comprehension is preserved. The responsible lesion, usually a CVA in the temporoparietal or dorsal perisylvian region, interferes with the function of the phonological loop interconnecting Broca's area with Wernicke's area. Occasionally, a transient Wernicke's aphasia may rapidly resolve into a conduction aphasia. The paraphasic and circumlocutious output in conduction aphasia interferes with the ability to express meaning, but this deficit is not nearly as severe as the one displayed by patients with Wernicke's aphasia. Associated neurologic signs in conduction aphasia vary according to the primary lesion site.

**Transcortical Aphasias: Fluent and Nonfluent** Clinical features of *fluent (posterior) transcortical aphasia* are similar to those of Wernicke's aphasia, but repetition is intact. The lesion site disconnects the intact core of the language network from other temporoparietal association areas. Associated neurologic findings may include hemianopia. Cerebrovascular lesions (e.g., infarctions in the posterior watershed zone) and neoplasms that involve the temporoparietal cortex posterior to Wernicke's area are common causes. The features of *nonfluent (anterior) transcortical aphasia* are similar to those of Broca's aphasia, but repetition is intact and agrammatism is less pronounced. The neurologic examination may be otherwise intact, but a right hemiparesis also can exist. The lesion site disconnects the intact language network from prefrontal areas of the brain and usually involves the anterior watershed zone between anterior and MCA territories or the supplementary motor cortex in the territory of the anterior cerebral artery.

**Global and Isolation Aphasias** *Global aphasia* represents the combined dysfunction of Broca's and Wernicke's areas and usually results from strokes that involve the entire MCA distribution in the left hemisphere. Speech output is nonfluent, and comprehension of language is severely impaired. Related signs include right hemiplegia, hemisensory loss, and homonymous hemianopia. *Isolation aphasia* represents a combination of the two transcortical aphasias. Comprehension is severely impaired, and there is no purposeful speech output. The patient may parrot fragments of heard conversations (*echolalia*), indicating that the neural mechanisms for repetition are at least partially intact. This condition represents the pathologic function of the language network when it is isolated from other regions of the brain. Broca's and Wernicke's areas tend to be spared, but there is damage to the surrounding frontal, parietal, and temporal cortex. Lesions are patchy and can be associated with anoxia, carbon monoxide poisoning, or complete watershed zone infarctions.

**Anomic Aphasia** This form of aphasia may be considered the "minimal dysfunction" syndrome of the language network. Articulation, comprehension, and repetition are intact, but confrontation naming, word finding, and spelling are impaired. Word-finding pauses are uncommon, so language output is fluent but paraphasic, circumlocutious, and uninformative. The lesion sites can be anywhere within the left hemisphere language network, including the middle and inferior temporal gyri. *Anomic aphasia* is the single most common language disturbance seen in head trauma, metabolic encephalopathy, and Alzheimer's disease.

**Pure Word Deafness** The most common causes are either bilateral or left-sided MCA strokes affecting the superior temporal gyrus. The net effect of the underlying lesion is to interrupt the flow of information from the auditory association cortex to the language network. Patients have no difficulty understanding written language and can express themselves well in spoken or written language. They have no difficulty interpreting and reacting to environmental sounds if the primary auditory cortex and auditory association areas of the right hemisphere are spared. Because auditory information cannot be conveyed to the language network, however, it cannot be decoded into neural word representations, and the patient reacts to speech as if it were in an alien tongue that cannot be deciphered. Patients cannot

repeat spoken language but have no difficulty naming objects. In time, patients with pure word deafness teach themselves lipreading and may appear to have improved. There may be no additional neurologic findings, but agitated paranoid reactions are common in the acute stages. Cerebrovascular lesions are the most common cause.

**Pure Alexia Without Agraphia** This is the visual equivalent of pure word deafness. The lesions (usually a combination of damage to the left occipital cortex and to a posterior sector of the corpus callosum—the splenium) interrupt the flow of visual input into the language network. There is usually a right hemianopia, but the core language network remains unaffected. The patient can understand and produce spoken language, name objects in the left visual hemifield, repeat, and write. However, the patient acts as if illiterate when asked to read even the simplest sentence because the visual information from the written words (presented to the intact left visual hemifield) cannot reach the language network. Objects in the left hemifield may be named accurately because they activate nonvisual associations in the right hemisphere, which in turn can access the language network through transcallosal pathways anterior to the splenium. Patients with this syndrome also may lose the ability to name colors, although they can match colors. This is known as a *color anomia*. The most common etiology of pure alexia is a vascular lesion in the territory of the posterior cerebral artery or an infiltrating neoplasm in the left occipital cortex that involves the optic radiations as well as the crossing fibers of the splenium. Because the posterior cerebral artery also supplies medial temporal components of the limbic system, a patient with pure alexia also may experience an amnesia, but this is usually transient because the limbic lesion is unilateral.

**Apraxia and Aphemia** *Apraxia* designates a complex motor deficit that cannot be attributed to pyramidal, extrapyramidal, cerebellar, or sensory dysfunction and that does not arise from the patient's failure to understand the nature of the task. *Apraxia of speech* is used to designate articulatory abnormalities in the duration, fluidity, and stress of syllables that make up words. It can arise with CVAs in the posterior part of Broca's area or in the course of frontotemporal lobar degeneration (FTLD) with tauopathy. *Aphemia* is a severe form of acute speech apraxia that presents with severely impaired fluency (often mutism). Recovery is the rule and involves an intermediate stage of hoarse whispering. Writing, reading, and comprehension are intact, and so this is not a true aphasic syndrome. CVAs in parts of Broca's area or subcortical lesions that undercut its connections with other parts of the brain may be present. Occasionally, the lesion site is on the medial aspects of the frontal lobes and may involve the supplementary motor cortex of the left hemisphere. *Ideomotor apraxia* is diagnosed when commands to perform a specific motor act ("cough," "blow out a match") or pantomime the use of a common tool (a comb, hammer, straw, or toothbrush) in the absence of the real object cannot be followed. The patient's ability to comprehend the command is ascertained by demonstrating multiple movements and establishing that the correct one can be recognized. Some patients with this type of apraxia can imitate the appropriate movement when it is demonstrated by the examiner and show no impairment when handed the real object, indicating that the sensorimotor mechanisms necessary for the movement are intact. Some forms of ideomotor apraxia represent a disconnection of the language network from pyramidal motor systems so that commands to execute complex movements are understood but cannot be conveyed to the appropriate motor areas. *Buccofacial apraxia* involves apraxic deficits in movements of the face and mouth. Ideomotor *limb apraxia* encompasses apraxic deficits in movements of the arms and legs. Ideomotor apraxia almost always is caused by lesions in the left hemisphere and is commonly associated with aphasic syndromes, especially Broca's aphasia and conduction aphasia. Because the handling of real objects is not impaired, ideomotor apraxia by itself causes no major limitation of daily living activities. Patients with lesions of the anterior corpus callosum can display ideomotor apraxia confined to the left side of the body, a sign known as *sympathetic dyspraxia*. A severe form of sympathetic dyspraxia, known as the *alien hand* syndrome, is

characterized by additional features of motor disinhibition on the left hand. *Ideational apraxia* refers to a deficit in the sequencing of goal-directed movements in patients who have no difficulty executing the individual components of the sequence. For example, when the patient is asked to pick up a pen and write, the sequence of uncapping the pen, placing the cap at the opposite end, turning the point toward the writing surface, and writing may be disrupted, and the patient may be seen trying to write with the wrong end of the pen or even with the removed cap. These motor sequencing problems usually are seen in the context of confusional states and dementias rather than focal lesions associated with aphasic conditions. *Limb-kinetic apraxia* involves clumsiness in the use of tools or objects that cannot be attributed to sensory, pyramidal, extrapyramidal, or cerebellar dysfunction. This condition can emerge in the context of focal premotor cortex lesions or *corticobasal degeneration* and can interfere with the use of tools and utensils.

**Gerstmann's Syndrome** The combination of *acalculia* (impairment of simple arithmetic), *dysgraphia* (impaired writing), *finger anomia* (an inability to name individual fingers such as the index and thumb), and *right-left confusion* (an inability to tell whether a hand, foot, or arm of the patient or examiner is on the right or left side of the body) is known as Gerstmann's syndrome. In making this diagnosis, it is important to establish that the finger and left-right naming deficits are not part of a more generalized anomia and that the patient is not otherwise aphasic. When Gerstmann's syndrome arises acutely and in isolation, it is commonly associated with damage to the inferior parietal lobule (especially the angular gyrus) in the left hemisphere.

**Pragmatics and Prosody** *Pragmatics* refers to aspects of language that communicate attitude, affect, and the figurative rather than literal aspects of a message (e.g., "green thumb" does not refer to the actual color of the finger). One component of pragmatics, *prosody*, refers to variations of melodic stress and intonation that influence attitude and the inferential aspect of verbal messages. For example, the two statements "He is clever." and "He is clever?" contain an identical word choice and syntax but convey vastly different messages because of differences in the intonation with which the statements are uttered. Damage to right hemisphere regions corresponding to Broca's area impairs the ability to introduce meaning-appropriate prosody into spoken language. The patient produces grammatically correct language with accurate word choice, but the statements are uttered in a monotone that interferes with the ability to convey the intended stress and effect. Patients with this type of *aprosodia* give the mistaken impression of being depressed or indifferent. Other aspects of pragmatics, especially the ability to infer the figurative aspect of a message, become impaired by damage to the right hemisphere or frontal lobes.

**Subcortical Aphasia** Damage to subcortical components of the language network (e.g., the striatum and thalamus of the left hemisphere) also can lead to aphasia. The resulting syndromes contain combinations of deficits in the various aspects of language but rarely fit the specific patterns described in Table 30-1. In a patient with a CVA, an anomic aphasia accompanied by dysarthria or a fluent aphasia with hemiparesis should raise the suspicion of a subcortical lesion site.

**CLINICAL PRESENTATION AND DIAGNOSIS OF PPA** Aphasias caused by CVAs start suddenly and display maximal deficits at the onset. These are the "classic" aphasias described above. Aphasias caused by neurodegenerative diseases have an insidious onset and relentless progression. The neuropathology can be selective not only for gray matter but also for specific layers and cell types. The clinico-anatomic patterns are therefore different from those described in Table 30-1.

Several neurodegenerative syndromes, such as typical Alzheimer-type (amnestic; [Chap. 431](#)) and frontotemporal (behavioral; [Chap. 432](#)) dementias, can also include language impairments as the disease progresses. In these cases, the aphasia is an ancillary component of the overall syndrome. A diagnosis of primary progressive aphasia (PPA) is justified only if the language disorder (i.e., aphasia) arises in relative isolation, becomes the primary concern that brings the patient to medical attention, and remains the most salient deficit for 1–2 years. PPA

can be caused by either FTLD or Alzheimer's disease (AD) pathology. Rarely, an identical syndrome can be caused by Creutzfeldt-Jacob disease (CJD) but with a more rapid progression (Chap. 438).

**LANGUAGE IN PPA** The impairments of language in PPA have slightly different patterns from those seen in CVA-caused aphasias. For example, the full syndrome of Wernicke's aphasia is almost never seen in PPA, confirming the view that sentence comprehension and word comprehension are controlled by different regions of the language network. Three major subtypes of PPA can be recognized.

**Agrammatic PPA** The *agrammatic variant* is characterized by consistently low fluency and impaired grammar but intact word comprehension. It most closely resembles Broca's aphasia or anterior transcortical aphasia but usually lacks the right hemiparesis or dysarthria and may have more profound impairments of grammar. Peak sites of neuronal loss (gray matter atrophy) include the left inferior frontal gyrus where Broca's area is located. The neuropathology is usually a FTLD with tauopathy but can also be an atypical form of AD pathology.

**Semantic PPA** The *semantic variant* is characterized by preserved fluency and syntax but poor single-word comprehension and profound two-way naming impairments. This kind of aphasia is not seen with CVAs. It differs from Wernicke's aphasia or posterior transcortical aphasia because speech is usually informative and repetition is intact. Comprehension of sentences is relatively preserved if the meaning is not too dependent on words that fail to be understood allowing the patient to surmise the gist of the conversation through contextual cues. Such patients may appear unimpaired in the course of casual small talk but become puzzled upon encountering an undecipherable word such as "pumpkin" or "umbrella." Peak atrophy sites are located in the left anterior temporal lobe, indicating that this part of the brain plays a critical role in the comprehension of words, especially words that denote concrete objects. This is a part of the brain that was not included within the classic language network, probably because it is not a common site for focal CVAs. The neuropathology is frequently an FTLD with abnormal precipitates of the 43-kDa transactivating response DNA-binding protein TDP-43 of type C.

**Logopenic PPA** The *logopenic variant* is characterized by preserved syntax and comprehension but frequent and severe word-finding pauses, anomia, circumlocutions, and simplifications during spontaneous speech. Repetition is usually impaired. Peak atrophy sites are located in the temporoparietal junction and posterior temporal lobe, partially overlapping with traditional location of Wernicke's area. However, the comprehension impairment of *Wernicke's aphasia* is absent probably because the underlying deep white matter, frequently damaged by CVAs, remains relatively intact in PPA. The repetition impairment suggests that parts of Wernicke's area are critical for phonological loop functionality. In contrast to Broca's aphasia or agrammatic PPA, the interruption of fluency is variable so that speech may appear entirely normal if the patient is allowed to engage in small talk. Logopenic PPA resembles the anomic aphasia of Table 30-1 but usually has longer and more frequent word-finding pauses. When repetition is impaired, the aphasia resembles the *conduction aphasia* in Table 30-1. Of all PPA subtypes, this is the one most commonly associated with the pathology of AD, but FTLD can also be the cause. In addition to these three major subtypes, there is also a *mixed* type of PPA where grammar, fluency, and word comprehension are jointly impaired. This is most like the global aphasia of Table 30-1. Rarely, PPA can present with patterns reminiscent of *pure word deafness* or *Gerstmann's syndrome*.

## THE PARIETOFRONTAL NETWORK FOR SPATIAL ORIENTATION

Adaptive spatial orientation is subserved by a large-scale network containing three major cortical components. The *cingulate cortex* provides access to a motivational mapping of the extrapersonal space, the *posterior parietal cortex* to a sensorimotor representation of salient extrapersonal events, and the *frontal eye fields* to motor strategies for attentional

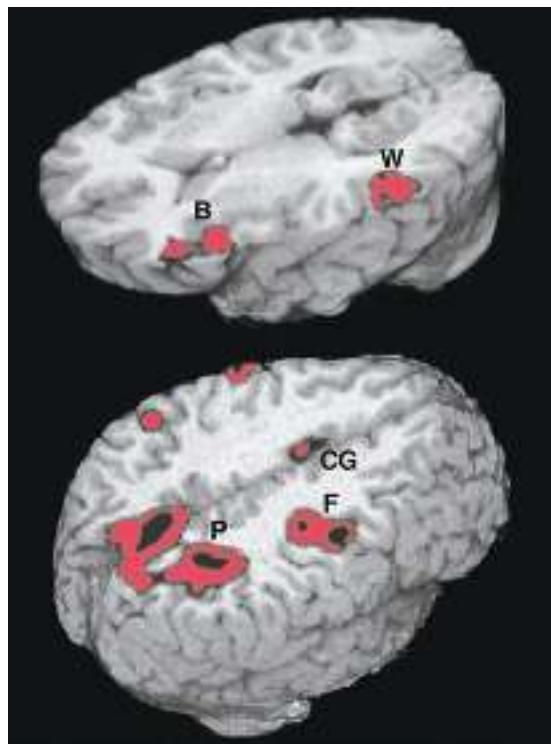


FIGURE 30-2 Functional magnetic resonance imaging of language and spatial attention in neurologically intact subjects. The red and black areas show regions of task-related significant activation. (Top) The subjects were asked to determine if two words were synonymous. This language task led to the simultaneous activation of the two components of the language network, Broca's area (B) and Wernicke's area (W). The activations are exclusively in the left hemisphere. (Bottom) The subjects were asked to shift spatial attention to a peripheral target. This task led to the simultaneous activation of the three epicenters of the attentional network: the posterior parietal cortex (P), the frontal eye fields (F), and the cingulate gyrus (CG). The activations are predominantly in the right hemisphere. (Courtesy of Darren Gitelman, MD.)

behaviors (Fig. 30-2). Subcortical components of this network include the striatum and the thalamus. Damage to this network can undermine the distribution of attention within the extrapersonal space, giving rise to hemispatial neglect, simultanagnosia, and object finding failures. The integration of egocentric (self-centered) with allocentric (object-centered) coordinates can also be disrupted, giving rise to impairments in route finding, the ability to avoid obstacles, and the ability to dress.

### ■ HEMISPATIAL NEGLECT

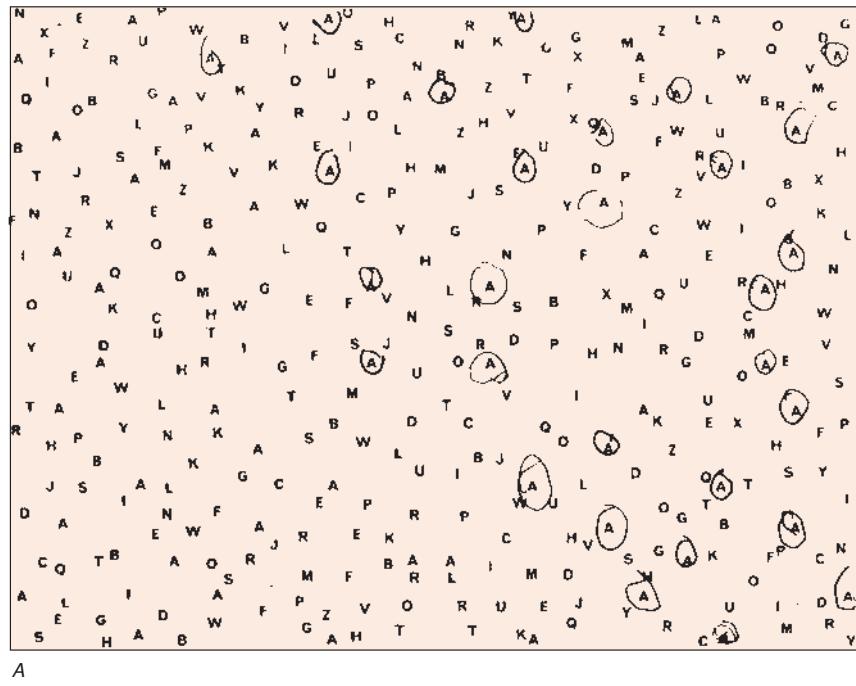
Contralesional hemispatial neglect represents one outcome of damage to the cortical or subcortical components of this network. *The traditional view that hemispatial neglect always denotes a parietal lobe lesion is inaccurate.* According to one model of spatial cognition, the right hemisphere directs attention within the *entire* extrapersonal space, whereas the left hemisphere directs attention mostly within the contralateral right hemisphere. Consequently, left hemisphere lesions do not give rise to much contralesional neglect because the global attentional mechanisms of the right hemisphere can compensate for the loss of the *contralaterally* directed attentional functions of the left hemisphere. Right hemisphere lesions, however, give rise to severe contralesional left hemispatial neglect because the unaffected left hemisphere does not contain ipsilateral attentional mechanisms. This model is consistent with clinical experience, which shows that contralesional neglect is more common, more severe, and longer lasting after damage to the right hemisphere than after damage to the left hemisphere. Severe neglect for the right hemisphere is rare, even in left-handers with left hemisphere lesions.

**Clinical Examination** Patients with severe neglect may fail to dress, shave, or groom the left side of the body; fail to eat food placed on the left side of the tray; and fail to read the left half of sentences. When asked to copy a simple line drawing, the patient fails to copy detail on the left, and when the patient is asked to write, there is a tendency to leave an unusually wide margin on the left. Two bedside tests that are useful in assessing neglect are *simultaneous bilateral stimulation* and *visual target cancellation*. In the former, the examiner provides either unilateral or simultaneous bilateral stimulation in the visual, auditory, and tactile modalities. After right hemisphere injury, patients who have no difficulty detecting unilateral stimuli on either side experience the bilaterally presented stimulus as coming only from the right. This phenomenon is known as *extinction* and is a manifestation of the sensory-representational aspect of hemispatial neglect. In the target detection task, targets (e.g., A's) are interspersed with foils (e.g., other letters of the alphabet) on a 21.5- to 28.0-cm (8.5–11 in.) sheet

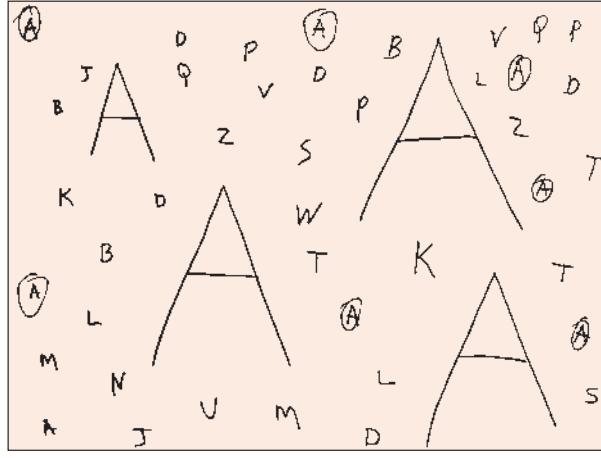
of paper, and the patient is asked to circle all the targets. A failure to detect targets on the left is a manifestation of the exploratory (motor) deficit in hemispatial neglect (Fig. 30-3A). Hemianopia is not by itself sufficient to cause the target detection failure because the patient is free to turn the head and eyes to the left. Target detection failures therefore reflect a distortion of spatial attention, not just of sensory input. Some patients with neglect also may deny the existence of hemiparesis and may even deny ownership of the paralyzed limb, a condition known as *anosognosia*.

### BÁLINT'S SYNDROME, SIMULTANAGNOSIA, DRESSING APRAXIA, CONSTRUCTION APRAXIA, AND ROUTE FINDING IMPAIRMENTS

Bilateral involvement of the network for spatial attention, especially its parietal components, leads to a state of severe spatial disorientation known as *Bálint's syndrome*. Bálint's syndrome involves deficits in the



A



B

**FIGURE 30-3** A. A 47-year-old man with a large frontoparietal lesion in the right hemisphere was asked to circle all the A's. Only targets on the right are circled. This is a manifestation of left hemispatial neglect. B. A 70-year-old woman with a 2-year history of degenerative dementia was able to circle most of the small targets but ignored the larger ones. This is a manifestation of simultanagnosia.

orderly visuomotor scanning of the environment (*oculomotor apraxia*), accurate manual reaching toward visual targets (*optic ataxia*), and the ability to integrate visual information in the center of gaze with more peripheral information (*simultanagnosia*). A patient with simultanagnosia “misses the forest for the trees.” For example, a patient who is shown a table lamp and asked to name the object may look at its circular base and call it an ashtray. Some patients with simultanagnosia report that objects they look at may vanish suddenly, probably indicating an inability to compute the oculomotor return to the original point of gaze after brief saccadic displacements. Movement and distracting stimuli greatly exacerbate the difficulties of visual perception. Simultanagnosia can occur without the other two components of Bálint’s syndrome, especially in association with AD.

A modification of the letter cancellation task described above can be used for the bedside diagnosis of simultanagnosia. In this modification, some of the targets (e.g., As) are made to be much larger than the others (7.5–10 cm vs 2.5 cm [3–4 in. vs 1 in.] in height), and all targets are embedded among foils. Patients with simultanagnosia display a counterintuitive but characteristic tendency to miss the larger targets (Fig. 30-3B). This occurs because the information needed for the identification of the larger targets cannot be confined to the immediate line of gaze and requires the integration of visual information across multiple fixation points. The greater difficulty in the detection of the larger targets also indicates that poor acuity is not responsible for the impairment of visual function and that the problem is central rather than peripheral. The test shown in Fig. 30-3B is not by itself sufficient to diagnose simultanagnosia as some patients with a frontal network syndrome may omit the letters that appear incongruous for the size of the paper. This may happen because they lack the mental flexibility to realize that the two types of targets are symbolically identical despite being superficially different.

Bilateral parietal lesions can impair the integration of egocentric with allocentric spatial coordinates. One manifestation is *dressing apraxia*. A patient with this condition is unable to align the body axis with the axis of the garment and can be seen struggling as he or she holds a coat from its bottom or extends his or her arm into a fold of the garment rather than into its sleeve. Lesions that involve the posterior parietal cortex also lead to severe difficulties in copying simple line drawings. This is known as a *construction apraxia* and is much more severe if the lesion is in the right hemisphere. In some patients with right hemisphere lesions, the drawing difficulties are confined to the left side of the figure and represent a manifestation of hemispatial neglect; in others, there is a more universal deficit in reproducing contours and three-dimensional perspective. Impairments of route finding can be included in this group of disorders, which reflect an inability to orient the self with respect to external objects and landmarks.

**Causes of Spatial Disorientation and the Posterior Cortical Atrophy Syndrome** Cerebrovascular lesions and neoplasms in the right hemisphere are common causes of hemispatial neglect. Depending on the site of the lesion, a patient with neglect also may have hemiparesis, hemihypesthesia, and hemianopia on the left, but these are not invariant findings. The majority of these patients display considerable improvement of hemispatial neglect, usually within the first several weeks. Bálint’s syndrome, dressing apraxia, and route-finding impairments are more likely to result from bilateral dorsal parietal lesions; common settings for acute onset include watershed infarction between the middle and posterior cerebral artery territories, hypoglycemia, and sagittal sinus thrombosis.

A progressive form of spatial disorientation, known as the *posterior cortical atrophy* (PCA) syndrome, most commonly represents a variant of AD with unusual concentrations of neurofibrillary degeneration in the parieto-occipital cortex and the superior colliculus (Fig. 30-4). Lewy body disease (LBD), CJD, and FTLD (corticobasal degeneration type) are other possible causes. The patient displays progressive hemispatial neglect, Bálint’s syndrome, and route-finding impairments, usually accompanied by dressing and construction apraxia.

## THE OCCIPITOTEMPORAL NETWORK FOR FACE AND OBJECT RECOGNITION

A patient with *prosopagnosia* cannot recognize familiar faces, including, sometimes, the reflection of their own face in the mirror. This is not a perceptual deficit because prosopagnosic patients easily can tell whether two faces are identical. Furthermore, a prosopagnosic patient who cannot recognize a familiar face by visual inspection alone can use auditory cues to reach appropriate recognition if allowed to listen to the person’s voice. The deficit in prosopagnosia is therefore modality-specific and reflects the existence of a lesion that prevents the activation of otherwise intact multimodal associative templates by relevant visual input. Prosopagnosic patients characteristically have no difficulty with the generic identification of a face as a face or a car as a car, but may not recognize the identity of an individual face or the make of an individual car. This reflects a visual recognition deficit for proprietary features that characterize individual members of an object class. When recognition problems become more generalized and extend to the generic identification of common objects, the condition is known as *visual object agnosia*. A patient with anomia cannot name the object but can describe its use. In contrast, a patient with visual agnosia is unable either to name a visually presented object or to describe its use. Face and object recognition disorders also can result from the simultanagnosia of Bálint’s syndrome, in which case they are known as *apperceptive agnosias* as opposed to the *associative agnosias* that result from inferior temporal lobe lesions.

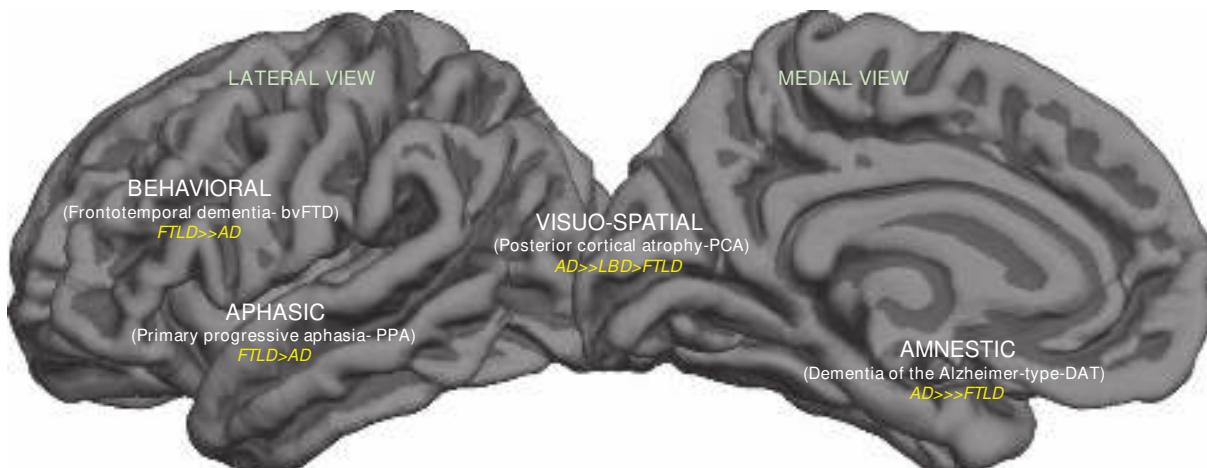


FIGURE 30-4 Four focal dementia syndromes and their most likely neuropathologic correlates. AD, Alzheimer’s disease; bvFTD, behavioral variant frontotemporal dementia; DAT, amnestic dementia of the Alzheimer type; FTLD, frontotemporal lobar degeneration (tau or TDP-43 type); LBD, Lewy body disease; PCA, posterior cortical atrophy syndrome; PPA, primary progressive aphasia.

## ■ CAUSES AND RELATION TO SEMANTIC DEMENTIA

The characteristic lesions in prosopagnosia and visual object agnosia of acute onset consist of bilateral infarctions in the territory of the posterior cerebral arteries that involve the fusiform gyrus. Associated deficits can include visual field defects (especially superior quadrantanopias) and a centrally based color blindness known as achromatopsia. Rarely, the responsible lesion is unilateral. In such cases, prosopagnosia is associated with lesions in the right hemisphere, and object agnosia with lesions in the left. Degenerative diseases of anterior and inferior temporal cortex can cause progressive associative prosopagnosia and object agnosia. The combination of progressive associative agnosia and a fluent aphasia with word comprehension impairment is known as *semantic dementia*. Patients with semantic dementia fail to recognize faces and objects and cannot understand the meaning of words denoting objects. This needs to be differentiated from the semantic type of PPA where there is severe impairment in understanding words that denote objects and in naming faces and objects but a relative preservation of face and object recognition. The anterior temporal lobe atrophy is usually bilateral in semantic dementia whereas it tends to affect mostly the left hemisphere in semantic PPA. Acute onset of the semantic dementia syndrome can be associated with herpes simplex encephalitis.

## LIMBIC NETWORK FOR EXPLICIT MEMORY AND AMNESIA

Limbic areas (e.g., the hippocampus, amygdala, and entorhinal cortex), paralimbic areas (e.g., the cingulate gyrus, insula, temporopolar cortex, and parts of orbitofrontal regions), the anterior and medial nuclei of the thalamus, the medial and basal parts of the striatum, and the hypothalamus collectively constitute a distributed network known as the *limbic system*. The behavioral affiliations of this network can be classified into two groups. One includes the coordination of emotion, motivation, affiliative behaviors, autonomic tone, and endocrine function. These functions are under the influence of the amygdala and anterior paralimbic areas. They make up the salience network. The two neurologic conditions that most frequently interfere with this group of limbic functions are temporal lobe epilepsy and behavioral variant frontotemporal dementia (bvFTD). An additional area of specialization for the limbic network and the one that is of most relevance to clinical practice is that of declarative (explicit) memory for recent episodes and experiences. This function is under the influence of the hippocampus, entorhinal cortex, posterior paralimbic areas, and limbic nuclei of the thalamus. This part of the limbic system is also known as the Papez circuit. A disturbance of explicit memory is known as an *amnestic state*. In the absence of deficits in motivation, attention, language, or visuospatial function, the clinical diagnosis of a persistent global amnestic state is always associated with bilateral damage to the limbic network, usually within the hippocampo-entorhinal complex or the thalamus. Damage to the limbic network does not necessarily destroy memories but interferes with their conscious recall in coherent form. The individual fragments of information remain preserved despite the limbic lesions and can sustain what is known as *implicit memory*. For example, patients with amnestic states can acquire new motor or perceptual skills even though they may have no conscious knowledge of the experiences that led to the acquisition of these skills.

The memory disturbance in the amnestic state is multimodal and includes retrograde and anterograde components. The *retrograde amnesia* involves an inability to recall experiences that occurred before the onset of the amnestic state. Relatively recent events are more vulnerable to retrograde amnesia than are more remote and more extensively consolidated events. A patient who comes to the emergency room complaining that he cannot remember his or her identity but can remember the events of the previous day almost certainly does not have a neurologic cause of memory disturbance. The second and most important component of the amnestic state is the *anterograde amnesia*, which indicates an inability to store, retain, and recall new knowledge. Patients with amnestic states cannot remember what they

ate a few hours ago or the details of an important event they may have experienced in the recent past. In the acute stages, there also may be a tendency to fill in memory gaps with inaccurate, fabricated, and often implausible information. This is known as *confabulation*. Patients with the amnestic syndrome forget that they forget and tend to deny the existence of a memory problem when questioned. Confabulation is more common in cases where the underlying lesion also interferes with parts of the frontal network, as in the case of the Wernicke-Korsakoff syndrome or traumatic head injury.

## ■ CLINICAL EXAMINATION

A patient with an amnestic state is almost always disoriented, especially to time, and has little knowledge of current news. The anterograde component of an amnestic state can be tested with a list of four to five words read aloud by the examiner up to five times or until the patient can immediately repeat the entire list without an intervening delay. The next phase of the recall occurs after a period of 5–10 min during which the patient is engaged in other tasks. Amnestic patients fail this phase of the task and may even forget that they were given a list of words to remember. Accurate recognition of the words by multiple choice in a patient who cannot recall them indicates a less severe memory disturbance that affects mostly the retrieval stage of memory. The retrograde component of an amnesia can be assessed with questions related to autobiographical or historic events. The anterograde component of amnestic states is usually much more prominent than the retrograde component. In rare instances, occasionally associated with temporal lobe epilepsy or herpes simplex encephalitis, the retrograde component may dominate. Confusional states caused by toxic-metabolic encephalopathies and some types of frontal lobe damage lead to secondary memory impairments, especially at the stages of encoding and retrieval, even in the absence of limbic lesions. This sort of memory impairment can be differentiated from the amnestic state by the presence of additional impairments in the attention-related tasks described below in the section on the frontal lobes.

## ■ CAUSES, INCLUDING ALZHEIMER'S DISEASE

Neurologic diseases that give rise to an amnestic state include tumors (of the sphenoid wing, posterior corpus callosum, thalamus, or medial temporal lobe), infarctions (in the territories of the anterior or posterior cerebral arteries), head trauma, herpes simplex encephalitis, Wernicke-Korsakoff encephalopathy, autoimmune limbic encephalitis, and degenerative dementias such as AD and Pick's disease. The one common denominator of all these diseases is the presence of bilateral lesions within one or more components in the limbic network. Occasionally, unilateral left-sided hippocampal lesions can give rise to an amnestic state, but the memory disorder tends to be transient. Depending on the nature and distribution of the underlying neurologic disease, the patient also may have visual field deficits, eye movement limitations, or cerebellar findings.

The most common cause of progressive memory impairments in the elderly is AD. This is why a predominantly amnestic dementia is also known as a dementia of the Alzheimer type (DAT). A prodromal stage of DAT, when daily living activities are generally preserved, is known as amnestic mild cognitive impairment (MCI). The predilection of the entorhinal cortex and hippocampus for early neurofibrillary degeneration by typical AD pathology is responsible for the initially selective impairment of episodic memory. In time, additional impairments in language, attention, and visuospatial skills emerge as the neurofibrillary degeneration spreads to additional neocortical areas. Less frequently, amnestic dementias can also be caused by FTLD.

*Transient global amnesia* is a distinctive syndrome usually seen in late middle age. Patients become acutely disoriented and repeatedly ask who they are, where they are, and what they are doing. The spell is characterized by anterograde amnesia (inability to retain new information) and a retrograde amnesia for relatively recent events that occurred before the onset. The syndrome usually resolves within 24–48 h and is followed by the filling in of the period affected by the retrograde amnesia, although there is persistent loss of memory for the events that occurred during the ictus. Recurrences are noted in

~20% of patients. Migraine, temporal lobe seizures, and perfusion abnormalities in the posterior cerebral territory have been postulated as causes of transient global amnesia. The absence of associated neurologic findings occasionally may lead to the incorrect diagnosis of a psychiatric disorder.

## THE PREFRONTAL NETWORK FOR EXECUTIVE FUNCTION AND BEHAVIOR

The frontal lobes can be subdivided into motor-premotor, dorsolateral prefrontal, medial prefrontal, and orbitofrontal components. The terms *frontal lobe syndrome* and *prefrontal cortex* refer only to the last three of these four components. These are the parts of the cerebral cortex that show the greatest phylogenetic expansion in primates, especially in humans. The dorsolateral prefrontal, medial prefrontal, and orbitofrontal areas, along with the subcortical structures with which they are interconnected (i.e., the head of the caudate and the dorsomedial nucleus of the thalamus), collectively make up a large-scale network that coordinates exceedingly complex aspects of human cognition and behavior. The prefrontal network overlaps with the salience network through the anterior cingulate gyrus and parts of the orbitofrontal region. Impairments of social conduct and empathy seen in neurodegenerative frontal dementias (such as bvFTD) are attributed to pathology of the prefrontal and salience networks.

The prefrontal network plays an important role in behaviors that require multitasking and the integration of thought with emotion. Cognitive operations impaired by prefrontal cortex lesions often are referred to as “executive functions.” The most common clinical manifestations of damage to the prefrontal network take the form of two relatively distinct syndromes. In the *frontal abulic syndrome*, the patient shows a loss of initiative, creativity, and curiosity and displays a pervasive emotional blandness, apathy, and lack of empathy. In the *frontal disinhibition syndrome*, the patient becomes socially disinhibited and shows severe impairments of judgment, insight, foresight, and the ability to mind rules of conduct. The dissociation between intact intellectual function and a total lack of even rudimentary common sense is striking. Despite the preservation of all essential memory functions, the patient cannot learn from experience and continues to display inappropriate behaviors without appearing to feel emotional pain, guilt, or regret when those behaviors repeatedly lead to disastrous consequences. The impairments may emerge only in real-life situations when behavior is under minimal external control and may not be apparent within the structured environment of the medical office. Testing judgment by asking patients what they would do if they detected a fire in a theater or found a stamped and addressed envelope on the road is not very informative because patients who answer these questions wisely in the office may still act very foolishly in real-life settings. The physician must therefore be prepared to make a diagnosis of frontal lobe disease based on historic information alone even when the mental state is quite intact in the office examination.

### ■ CLINICAL EXAMINATION

The emergence of developmentally primitive reflexes, also known as frontal release signs, such as grasping (elicited by stroking the palm) and sucking (elicited by stroking the lips) are seen primarily in patients with large structural lesions that extend into the premotor components of the frontal lobes or in the context of metabolic encephalopathies. The vast majority of patients with prefrontal lesions and frontal lobe behavioral syndromes do not display these reflexes. Damage to the frontal lobe disrupts a variety of attention-related functions, including working memory (the transient online holding and manipulation of information), concentration span, the effortful scanning and retrieval of stored information, the inhibition of immediate but inappropriate responses, and mental flexibility. Digit span (which should be seven forward and five reverse) is decreased, reflecting poor working memory; the recitation of the months of the year in reverse order (which should take <15 s) is slowed as another indication of poor working memory; and the fluency in producing words starting with the letter a, f, or s that can be generated in 1 min (normally  $\geq 12$  per letter) is diminished even in nonaphasic patients, indicating an impairment in

the ability to search and retrieve information from long-term stores. In “go–no go” tasks (where the instruction is to raise the finger upon hearing one tap but keep it still upon hearing two taps), the patient shows a characteristic inability to inhibit the response to the “no go” stimulus. Mental flexibility (tested by the ability to shift from one criterion to another in sorting or matching tasks) is impoverished; distractibility by irrelevant stimuli is increased; and there is a pronounced tendency for impersistence and perseveration. The ability for abstracting similarities and interpreting proverbs is also undermined.

The attentional deficits disrupt the orderly registration and retrieval of new information and lead to *secondary* deficits of explicit memory. The distinction of the underlying neural mechanisms is illustrated by the observation that severely amnestic patients who cannot remember events that occurred a few minutes ago may have intact if not superior working memory capacity as shown in tests of digit span. The use of the term *memory* to designate two completely different mental faculties is confusing. Working memory depends on the on-line holding of information for brief periods of time, whereas explicit memory depends on the off-line storage and subsequent retrieval of the information.

### ■ CAUSES: TRAUMA, NEOPLASM, AND FRONTOTEMPORAL DEMENTIA

The abulic syndrome tends to be associated with damage in dorsolateral or dorsomedial prefrontal cortex, and the disinhibition syndrome with damage in orbitofrontal or ventromedial cortex. These syndromes tend to arise almost exclusively after bilateral lesions. Unilateral lesions confined to the prefrontal cortex may remain silent until the pathology spreads to the other side; this explains why thromboembolic CVA is an unusual cause of the frontal lobe syndrome. When behavioral syndromes of the frontal network arise in conjunction with asymmetric disease, the lesion tends to be predominantly on the right side of the brain. Common settings for frontal lobe syndromes include head trauma, ruptured aneurysms, hydrocephalus, tumors (including metastases, glioblastoma, and falx or olfactory groove meningiomas), and focal degenerative diseases, especially FTLD. The most prominent neurodegenerative frontal syndrome is bvFTD. In many patients with bvFTD, the atrophy includes orbitofrontal cortex and also extends into the anterior temporal lobes, insula, and anterior cingulate cortex. Occasionally, atrophy predominantly in the right anterior temporal lobe presents with the bvFTD syndrome. The behavioral changes in these patients can range from apathy to shoplifting, compulsive gambling, sexual indiscretions, remarkable lack of common sense, new ritualistic behaviors, and alterations in dietary preferences, usually leading to increased taste for sweets or rigid attachment to specific food items. In many patients with AD, neurofibrillary degeneration eventually spreads to prefrontal cortex and gives rise to components of the frontal lobe syndrome, but almost always on a background of severe memory impairment. Rarely, the bvFTD syndrome can arise in isolation in the context of an atypical form of AD pathology.

Lesions in the caudate nucleus or in the dorsomedial nucleus of the thalamus (subcortical components of the prefrontal network) also can produce a frontal lobe syndrome affecting mostly executive functions. This is one reason why the changes in mental state associated with degenerative basal ganglia diseases such as Parkinson’s disease and Huntington’s disease display components of the frontal lobe syndrome. Bilateral multifocal lesions of the cerebral hemispheres, none of which are individually large enough to cause specific cognitive deficits such as aphasia and neglect, can collectively interfere with the connectivity and therefore integrating (executive) function of the prefrontal cortex. A frontal lobe syndrome, usually of the abulic form, is therefore the single most common behavioral profile associated with a variety of bilateral multifocal brain diseases, including metabolic encephalopathy, multiple sclerosis, and vitamin B<sub>12</sub> deficiency, among others. Many patients with the clinical diagnosis of a frontal lobe syndrome tend to have lesions that do not involve prefrontal cortex but involve either the subcortical components of the prefrontal network or its connections with other parts of the brain. To avoid making a diagnosis of “frontal lobe syndrome” in a patient with no evidence of frontal cortex disease, it is advisable to use the diagnostic term *frontal network syndrome*, with the

understanding that the responsible lesions can lie anywhere within this distributed network. A patient with frontal lobe disease raises potential dilemmas in differential diagnosis: the apathy and blandness may be misinterpreted as depression, and the disinhibition as idiopathic mania or acting out. Appropriate intervention may be delayed while a treatable tumor keeps expanding.

## CARING FOR PATIENTS WITH DEFICITS OF HIGHER CEREBRAL FUNCTION

Spontaneous improvement of cognitive deficits following stroke or trauma is common. It is most rapid in the first few weeks but may continue for up to 2 years, especially in young individuals with single brain lesions. Some of the initial deficits in such cases appear to arise from remote dysfunction (diaschisis) in brain regions that are interconnected with the site of initial injury. Improvement in these patients may reflect, at least in part, a normalization of the remote dysfunction. Other mechanisms may involve functional reorganization in surviving neurons adjacent to the injury or the compensatory use of homologous structures, e.g., the right superior temporal gyrus with recovery from Wernicke's aphasia. In contrast, neurodegenerative diseases show a progression of impairment but at rates that vary greatly from patient to patient.

**Pharmacologic and Nonpharmacologic Interventions** Some of the deficits described in this chapter are so complex that they may bewilder not only the patient and family but also the physician. The care of patients with such deficits requires a careful evaluation of the history, cognitive test results, and diagnostic procedures. Each piece of information needs to be interpreted cautiously and placed in context. A complaint of "poor memory," for example, may reflect an anomia; poor scores on a learning task may reflect a weakness of attention rather than explicit memory; a report of depression or indifference may reflect impaired prosody rather than a change in mood or empathy; jocularity may arise from poor insight rather than good mood. Although there are few well-controlled studies, several nonpharmacologic interventions have been used to treat higher cortical deficits. These include speech therapy for aphasias, behavioral modification for compartmental disorders, and cognitive training for visuospatial disorientation and amnestic syndromes. More practical interventions, usually delivered through occupational therapy, aim to improve daily living activities through assistive devices and modifications of the home environment. Determining driving competence is challenging, especially in the early stages of dementing diseases. An on-the-road driving test and reports from family members may help time decisions related to this very important activity. In neurodegenerative conditions such as PPA, transcranial magnetic (or direct current) stimulation has had mixed success in eliciting symptomatic improvement. The goal is to activate remaining neurons at sites of atrophy or in unaffected regions of the contralateral hemisphere. Depression and sleep disorders can intensify the cognitive disorders and should be treated with appropriate modalities. If neuroleptics become absolutely necessary for the control of agitation, atypical neuroleptics are preferable because of their lower extrapyramidal side effects. Treatment with neuroleptics in elderly patients with dementia requires weighing the potential benefits against the potentially serious side effects. This is especially relevant to the case of patients with Lewy body dementia, who can be unusually sensitive to side effects.

As in all other branches of medicine, a crucial step in patient care is to identify the underlying cause of the impairment. This is easily done in cases of CVA, head trauma, or encephalitis but becomes particularly challenging in the dementias because the same progressive clinical syndrome can be caused by one of several neuropathologic entities. The advent of imaging, blood, and cerebrospinal fluid biomarkers now makes it possible to address this question with reasonable success and to make specific diagnoses of AD, LBD, CJD, and FTLD. A specific etiologic diagnosis allows the physician to recommend medications or clinical trials that are the most appropriate for the underlying disease process. A clinical assessment that identifies the principal domain of behavioral and cognitive impairment followed by the judicious use of

biomarker information to surmise the nature of the underlying disease allows a personalized approach to patients with higher cognitive impairment.

## FURTHER READING

- G B et al: *Frontotemporal Dementias: Emerging Milestones of the 21st Century*. New York, Springer, 2021.
- H ML et al: Retraining speech production and fluency in non-fluent/agrammatic primary progressive aphasia. *Brain* 141:1799, 2018.
- M M-M: Behavioral neuroanatomy: Large-scale networks, association cortex, frontal syndromes, the limbic system and hemispheric specialization, in *Principles of Behavioral and Cognitive Neurology*, M-M Mesulam (ed). New York, Oxford University Press, 2000, pp 1–120.
- M M-M et al: Word comprehension in temporal cortex and Wernicke area: A PPA perspective. *Neurology* 92:e224, 2019.
- M BL, B BF (eds): *The Behavioral Neurology of Dementia*, 2nd ed. Cambridge, Cambridge University Press, 2017.

## 31

## Sleep Disorders

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Charles A. Czeisler



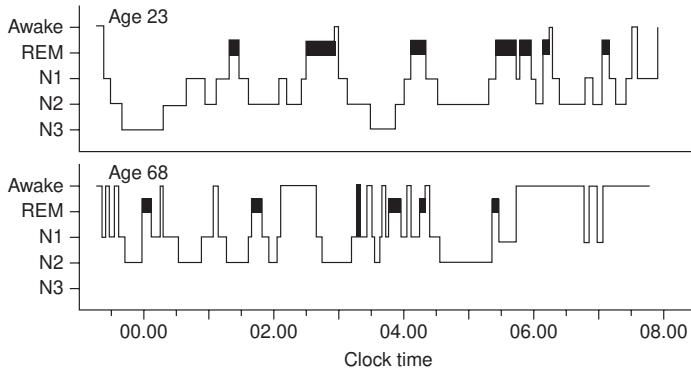
Disturbed sleep is one of the most common health complaints that physicians encounter. More than one-half of adults in the United States experience at least intermittent sleep disturbance, and only 30% of adult Americans report consistently obtaining a sufficient amount of sleep. The National Academy of Medicine has estimated that 50–70 million Americans suffer from a chronic disorder of sleep and wakefulness, which can adversely affect daytime functioning as well as physical and mental health. A high prevalence of sleep disorders across all cultures is also now increasingly recognized, and these problems are expected to further increase in the years ahead as the global population ages. Over the last 30 years, the field of sleep medicine has emerged as a distinct specialty in response to the impact of sleep disorders and sleep deficiency on overall health. Nonetheless, over 80% of patients with sleep disorders remain undiagnosed and untreated—costing the U.S. economy over \$400 billion annually in increased health care costs, lost productivity, accidents and injuries, and leading to the development of workplace-based sleep health education and sleep disorders screening programs designed to address this unmet medical need.

## PHYSIOLOGY OF SLEEP AND WAKEFULNESS

Most adults need 7–9 h of sleep per night to promote optimal health, although the timing, duration, and internal structure of sleep vary among individuals. In the United States, adults tend to have one consolidated sleep episode each night, although in some cultures sleep may be divided into a mid-afternoon nap and a shortened night sleep. This pattern changes considerably over the life span, as infants and young children sleep considerably more than older people, while individuals >70 years of age sleep on average about an hour less than young adults.

The stages of human sleep are defined on the basis of characteristic patterns in the electroencephalogram (EEG), the electrooculogram (EOG—a measure of eye-movement activity), and the surface electromyogram (EMG) measured on the chin, neck, and legs. The continuous recording of these electrophysiologic parameters to define sleep and wakefulness is termed *polysomnography*.

Polysomnographic profiles define two basic states of sleep: (1) rapid eye movement (REM) sleep and (2) non-rapid eye movement (NREM)



**FIGURE 31-1** Wake-sleep architecture. Alternating stages of wakefulness, the three stages of non-rapid eye movement sleep (N1–N3), and rapid eye movement (REM) sleep (solid bars) occur over the course of the night for representative young and older adult men. Characteristic features of sleep in older people include reduction of N3 slow-wave sleep, frequent spontaneous awakenings, early sleep onset, and early morning awakening.

sleep. NREM sleep is further subdivided into three stages: N1, N2, and N3, characterized by an increasing threshold for arousal and slowing of the cortical EEG. REM sleep is characterized by a low-amplitude, mixed-frequency EEG, similar to NREM stage N1 sleep, and an EOG pattern of REMs that tend to occur in flurries or bursts. EMG activity is absent in nearly all skeletal muscles except those involved in respiration, reflecting the brainstem-mediated muscle paralysis that is characteristic of REM sleep.

### ■ ORGANIZATION OF HUMAN SLEEP

Normal nocturnal sleep in adults displays a consistent organization from night to night (Fig. 31-1). After sleep onset, sleep usually progresses through NREM stages N1–N3 sleep within 45–60 min. NREM stage N3 sleep (also known as slow-wave sleep) predominates in the first third of the night and comprises 15–25% of total nocturnal sleep time in young adults. Sleep deprivation increases the rapidity of sleep onset and both the intensity and amount of slow-wave sleep.

The first REM sleep episode usually occurs in the second hour of sleep. NREM and REM sleep alternate through the night with an average period of 90–110 min (the “ultradian” sleep cycle). Overall, in a healthy young adult, REM sleep constitutes 20–25% of total sleep, and NREM stages N1 and N2 constitute 50–60%.

Age has a profound impact on sleep state organization (Fig. 31-1). N3 sleep is most intense and prominent during childhood, decreasing with puberty and across the second and third decades of life. In older adults, N3 sleep may be completely absent, and the remaining NREM sleep typically becomes more fragmented, with frequent awakenings from NREM sleep. It is the increased frequency of awakenings, rather than a decreased ability to fall back asleep, that accounts for the increased wakefulness during the sleep episode in older people. While REM sleep may account for 50% of total sleep time in infancy, the percentage falls off sharply over the first postnatal year as a mature REM-NREM cycle develops; thereafter, REM sleep occupies about 25% of total sleep time.

Sleep deprivation degrades cognitive performance, particularly on tests that require continual vigilance. Paradoxically, older people are less vulnerable than young adults to the neurobehavioral performance impairment induced by acute sleep deprivation, maintaining their reaction time and sustaining vigilance with fewer lapses of attention. However, it is more difficult for older adults to obtain recovery sleep after staying awake all night, as the ability to sleep during the daytime declines with age.

After sleep deprivation, NREM sleep generally recovers first, followed by REM sleep. However, because REM sleep tends to be most prominent in the second half of the night, sleep truncation (e.g., by an alarm clock) results in selective REM sleep deprivation. This may increase REM sleep pressure to the point where the first REM sleep may occur much earlier in the nightly sleep episode. Because several

disorders (see below) also cause sleep fragmentation, it is important that the patient have sufficient sleep opportunity (at least 8 h per night) for several nights prior to a diagnostic polysomnogram.

There is growing evidence that inadequate sleep in humans is associated with glucose intolerance that may contribute to the development of diabetes, obesity, and the metabolic syndrome, as well as impaired immune responses, accelerated atherosclerosis, and increased risk of cardiac disease, cognitive impairment, Alzheimer’s disease, and stroke. For these reasons, the National Academy of Medicine declared sleep deficiency and sleep disorders “an unmet public health problem.”

### ■ WAKE AND SLEEP ARE REGULATED BY BRAIN CIRCUITS

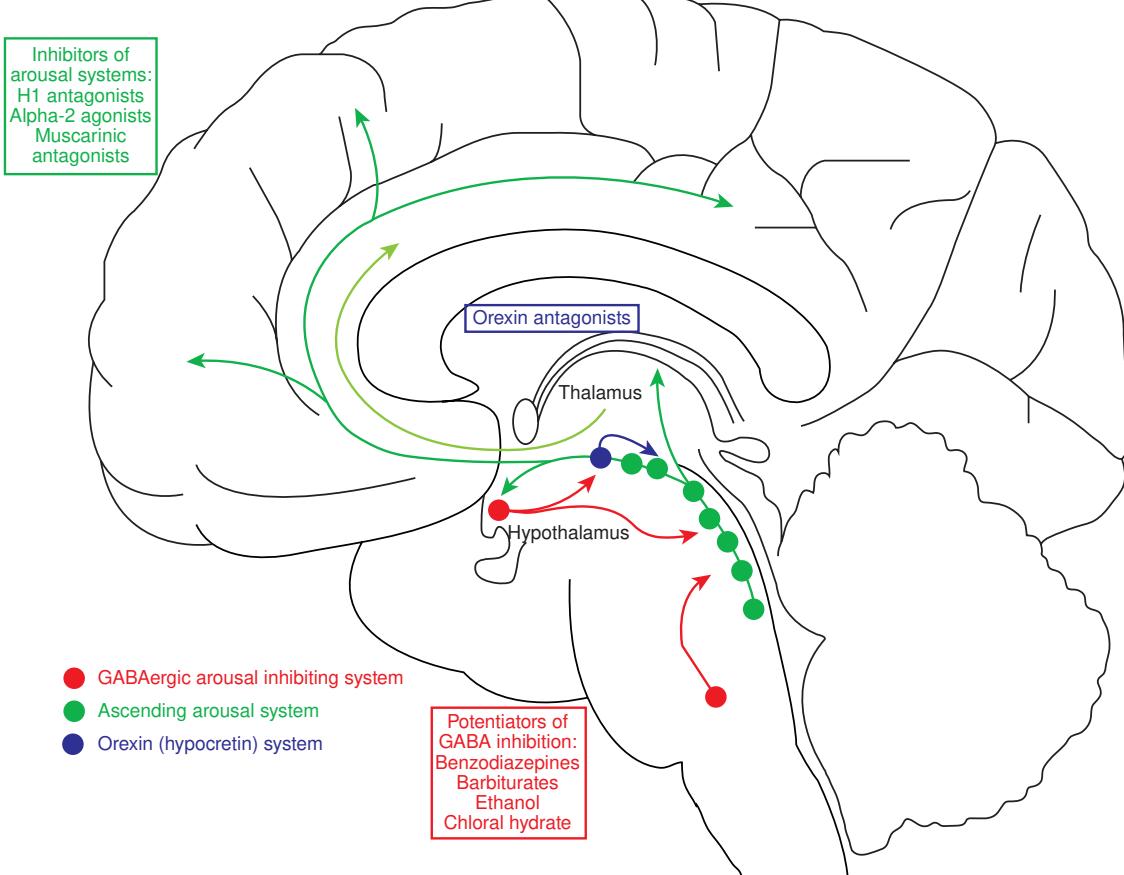
Two principal neural systems govern the expression of sleep and wakefulness. The ascending arousal system, illustrated in green in Fig. 31-2, consists of clusters of nerve cells extending from the upper pons to the hypothalamus and basal forebrain that activate the cerebral cortex, thalamus (which is necessary to relay sensory information to the cortex), and other forebrain regions. The ascending arousal neurons use monoamines (norepinephrine, dopamine, serotonin, and histamine), glutamate, or acetylcholine as neurotransmitters to activate their target neurons. Some basal forebrain neurons use  $\gamma$ -aminobutyric acid (GABA) to inhibit cortical inhibitory interneurons, thus promoting arousal. Additional wake-promoting neurons in the hypothalamus use the peptide neurotransmitter orexin (also known as hypocretin, shown in Fig. 31-2 in blue) to reinforce activity in the other arousal cell groups.

Damage to the arousal system at the level of the rostral pons and lower midbrain causes coma, indicating that the ascending arousal influence from this level is critical in maintaining wakefulness. Injury to the hypothalamic branch of the arousal system causes profound sleepiness but usually not coma. Specific loss of the orexin neurons produces the sleep disorder narcolepsy (see below). Isolated damage to the thalamus causes loss of the content of wakefulness, known as a persistent vegetative state, but wake-sleep cycles are largely preserved.

The arousal system is turned off during sleep by inhibitory inputs from cell groups in the sleep-promoting system, shown in Fig. 31-2 in red. These neurons in the preoptic area and pons use GABA to inhibit the arousal system. Additional neurons in the lateral hypothalamus containing the peptide melanin-concentrating hormone promote REM sleep. Many sleep-promoting neurons are themselves inhibited by inputs from the arousal system. This mutual inhibition between the arousal- and sleep-promoting systems forms a neural circuit akin to what electrical engineers call a “flip-flop switch.” A switch of this type tends to promote rapid transitions between the on (wake) and off (sleep) states, while avoiding intermediate states. The relatively rapid transitions between waking and sleeping states, as seen in the EEG of humans and animals, is consistent with this model.

Neurons in the ventrolateral preoptic nucleus, one of the key sleep-promoting sites, are lost during normal human aging, correlating with reduced ability to maintain sleep (sleep fragmentation). The ventrolateral preoptic neurons are also injured in Alzheimer’s disease, which may in part account for the poor sleep quality in those patients.

Transitions between NREM and REM sleep appear to be governed by a similar switch in the brainstem. GABAergic REM-Off neurons have been identified in the lower midbrain that inhibit REM-On neurons in the upper pons. The REM-On group contains both GABAergic neurons that inhibit the REM-Off group (thus satisfying the conditions for a REM sleep flip-flop switch) as well as glutamatergic neurons that project widely in the central nervous system (CNS) to cause the key phenomena associated with REM sleep. REM-On neurons that project to the medulla and spinal cord activate inhibitory (GABA and glycine-containing) interneurons, which in turn hyperpolarize the motor neurons, producing the paralysis of REM sleep. REM-On neurons that project to the forebrain may be important in producing dreams.



**FIGURE 31-2** Relationship of drugs for insomnia with wake-sleep systems. The arousal system in the brain (green) includes monoaminergic, glutamatergic, and cholinergic neurons in the brainstem that activate neurons in the hypothalamus, thalamus, basal forebrain, and cerebral cortex. Orexin neurons (blue) in the hypothalamus, which are lost in narcolepsy, reinforce and stabilize arousal by activating other components of the arousal system. The sleep-promoting system (red) consists of GABAergic neurons in the preoptic area and brainstem that inhibit the components of the arousal system, thus allowing sleep to occur. Drugs used to treat insomnia include those that block the effects of arousal system neurotransmitters (green and blue) and those that enhance the effects of  $\gamma$ -aminobutyric acid (GABA) produced by the sleep system (red).

The REM sleep switch receives cholinergic input, which favors transitions to REM sleep, and monoaminergic (norepinephrine and serotonin) input that prevents REM sleep. As a result, drugs that increase monoamine tone (e.g., serotonin or norepinephrine reuptake inhibitors) tend to reduce the amount of REM sleep. Damage to the neurons that promote REM sleep paralysis can produce REM sleep behavior disorder, a condition in which patients act out their dreams (see below).

### SLEEP WAKE CYCLES ARE DRIVEN BY HOMEOSTATIC, ALLOSTATIC, AND CIRCADIAN INPUTS

The gradual increase in sleep drive with prolonged wakefulness, followed by deeper slow-wave sleep and prolonged sleep episodes, demonstrates that there is a *homeostatic* mechanism that regulates sleep. The neurochemistry of sleep homeostasis is only partially understood, but with prolonged wakefulness, adenosine levels rise in parts of the brain. Adenosine may act through A1 receptors to directly inhibit many arousal-promoting brain regions. In addition, adenosine promotes sleep through A2a receptors; blockade of these receptors by caffeine is one of the chief ways in which people fight sleepiness. Other humoral factors, such as prostaglandin D<sub>2</sub>, have also been implicated in this process. Both adenosine and prostaglandin D<sub>2</sub> activate the sleep-promoting neurons in the ventrolateral preoptic nucleus.

*Allostasis* is the physiologic response to a challenge such as physical danger or psychological threat that cannot be managed by homeostatic mechanisms. These stress responses can severely impact the need for

and ability to sleep. For example, insomnia is very common in patients with anxiety and other psychiatric disorders. Stress-induced insomnia is even more common, affecting most people at some time in their lives. Positron emission tomography (PET) studies in patients with chronic insomnia show hyperactivation of components of the ascending arousal system, as well as their limbic system targets in the forebrain (e.g., cingulate cortex and amygdala). The limbic areas are not only targets for the arousal system, but they also send excitatory outputs back to the arousal system, which contributes to a vicious cycle of anxiety about insomnia that makes it more difficult to sleep. Approaches to treating insomnia may employ drugs that either inhibit the output of the ascending arousal system (green and blue in Fig. 31-2) or potentiate the output of the sleep-promoting system (red in Fig. 31-2). However, behavioral approaches (cognitive behavioral therapy [CBT] and sleep hygiene) that may reduce forebrain limbic activity at bedtime are often the best long-term treatment.

Sleep is also regulated by a strong *circadian* timing signal, driven by the suprachiasmatic nuclei (SCN) of the hypothalamus, as described below. The SCN sends outputs to key sites in the hypothalamus, which impose 24-h rhythms on a wide range of behaviors and body systems, including the wake-sleep cycle.

### PHYSIOLOGY OF CIRCADIAN RHYTHMICITY

The wake-sleep cycle is the most evident of many 24-h rhythms in humans. Prominent daily variations also occur in endocrine, thermoregulatory, cardiac, pulmonary, renal, immune, gastrointestinal, and neurobehavioral functions. In evaluating daily rhythms in humans,

it is important to distinguish between diurnal components passively evoked by periodic environmental or behavioral changes (e.g., the increase in blood pressure and heart rate that occurs upon assumption of the upright posture) and circadian rhythms actively driven by an endogenous oscillatory process (e.g., the circadian variations in adrenal cortisol and pineal melatonin secretion that persist across a variety of environmental and behavioral conditions).

At the cellular level, endogenous circadian rhythmicity is driven by self-sustaining feedback loops. While it is now recognized that most cells in the body have circadian clocks that regulate diverse physiologic processes, these clocks in different tissues, or even in different cells in the same tissue, when placed in isolation in a tissue explant are unable to maintain the long-term synchronization with each other that is required to produce useful 24-h rhythms aligned with the external light-dark cycle. The only tissue that maintains this rhythm *in vitro* is the SCN, whose neurons are interconnected with one another in such a way as to produce a near-24-h synchronous rhythm of neural activity even in prolonged slice culture. SCN neurons are located just above the optic chiasm in the hypothalamus, from which they receive visual input to synchronize them with the external world, and they have outputs to transmit that signal to the rest of the body. Bilateral destruction of the SCN results in a loss of most endogenous circadian rhythms including wake-sleep behavior and rhythms in endocrine and metabolic systems. The genetically determined period of this endogenous neural oscillator, which averages ~24.15 h in humans, is normally synchronized to the 24-h period of the environmental light-dark cycle through direct input from intrinsically photosensitive ganglion cells in the retina to the SCN. Humans are exquisitely sensitive to the resetting effects of light, particularly the shorter wavelengths (~460–500 nm) in the blue part of the visible spectrum. Small differences in circadian period contribute to variations in diurnal preference. Changes in homeostatic sleep regulation may underlie age-related changes in sleep-wake timing.

The timing and internal architecture of sleep are directly coupled to the output of the endogenous circadian pacemaker. Paradoxically, the endogenous circadian rhythm for wake propensity peaks just before the habitual bedtime, whereas that of sleep propensity peaks near the habitual wake time. These rhythms are thus timed to oppose the rise of sleep tendency throughout the usual waking day and the decline of sleep propensity during the habitual sleep episode, respectively, thus promoting consolidated sleep and wakefulness. Misalignment of the endogenous circadian pacemaker with the desired wake-sleep cycle can, therefore, induce insomnia, decrease alertness, and impair performance, posing health problems for night-shift workers and airline travelers.

## ■ BEHAVIORAL AND PHYSIOLOGIC CORRELATES OF SLEEP STATES AND STAGES

Polysomnographic staging of sleep correlates with behavioral changes during specific states and stages. During the transitional state (stage N1) between wakefulness and deeper sleep, individuals may respond to faint auditory or visual signals. Formation of short-term memories is inhibited at the onset of NREM stage N1 sleep, which may explain why individuals aroused from that transitional sleep stage frequently lack situational awareness. After sleep deprivation, such transitions may intrude upon behavioral wakefulness notwithstanding attempts to remain continuously awake (for example, see “Shift-Work Disorder,” below).

Subjects awakened from REM sleep recall vivid dream imagery >80% of the time, especially later in the night. Less vivid imagery may also be reported after NREM sleep interruptions. Certain disorders may occur during specific sleep stages and are described below under “Parasomnias.” These include sleepwalking, night terrors, and enuresis (bed wetting), which occur most commonly in children during deep (N3) NREM sleep, and REM sleep behavior disorder, which occurs mainly among older men who fail to maintain full paralysis during REM sleep, and often call out, thrash around, or even act out fragments of dreams.

All major physiologic systems are influenced by sleep. Blood pressure and heart rate decrease during NREM sleep, particularly during N3 sleep. During REM sleep, bursts of eye movements are associated

with large variations in both blood pressure and heart rate mediated by the autonomic nervous system. Cardiac dysrhythmias may occur selectively during REM sleep. Respiratory function also changes. In comparison to relaxed wakefulness, respiratory rate becomes slower but more regular during NREM sleep (especially N3 sleep) and becomes irregular during bursts of eye movements in REM sleep. Decreases in minute ventilation during NREM sleep are out of proportion to the decrease in metabolic rate, resulting in a slightly higher  $P_{CO_2}$ .

Within the brain itself, neurotransmission is supported by ion gradients across the cell membranes of neurons and astrocytes. These ion flows are accompanied by increases in intracellular volume, so that during wake, there is very little extracellular space in the brain. During sleep, intracellular volume is reduced, resulting in increased extracellular space, which has higher calcium and lower potassium concentrations, supporting hyperpolarization and reduced firing of neurons. This expansion of the extracellular space during sleep increases diffusion of substances that accumulate extracellularly, like  $\beta$ -amyloid peptide, enhancing their clearance from the brain via cerebrospinal fluid (CSF) flow. Recent evidence suggests that lack of adequate sleep may contribute to extracellular accumulation of  $\beta$ -amyloid peptide, a key step in the pathogenesis of Alzheimer’s disease.

Endocrine function also varies with sleep. N3 sleep is associated with secretion of growth hormone in men, while sleep in general is associated with augmented secretion of prolactin in both men and women. Sleep has a complex effect on the secretion of luteinizing hormone (LH): during puberty, sleep is associated with increased LH secretion, whereas sleep in postpubertal women inhibits LH secretion in the early follicular phase of the menstrual cycle. Sleep onset (and probably N3 sleep) is associated with inhibition of thyroid-stimulating hormone and of the adrenocorticotrophic hormone–cortisol axis, an effect that is superimposed on the prominent circadian rhythms in the two systems.

The pineal hormone melatonin is secreted predominantly at night in both day- and night-active species, reflecting the direct modulation of pineal activity by the SCN via the sympathetic nervous system, which innervates the pineal gland. Melatonin secretion does not require sleep, but melatonin secretion is inhibited by ambient light, an effect mediated by the neural connection from the retina to the pineal gland via the SCN. In humans, sleep efficiency is highest when sleep coincides with endogenous melatonin secretion. When endogenous melatonin levels are low, such as during the biological day or at the desired bedtime in people with delayed sleep-wake phase disorder (DSWPD), administration of exogenous melatonin can hasten sleep onset and increase sleep efficiency, but it does not increase sleep efficiency if administered when endogenous melatonin levels are elevated. This may explain why melatonin is often ineffective in the treatment of patients with primary insomnia. On the other hand, patients with sympathetic denervation of the pineal gland, such as occurs in cervical spinal cord injury or in patients with Parkinson’s disease, often have low melatonin levels, and administration of melatonin (3 mg 30 min before bedtime) may help them sleep.

Sleep is accompanied by alterations of thermoregulatory function. NREM sleep is associated with an increase in the firing of warm-responsive neurons in the preoptic area and a fall in body temperature; conversely, skin warming without increasing core body temperature has been found to increase NREM sleep. REM sleep is associated with reduced thermoregulatory responsiveness.

## DISORDERS OF SLEEP AND WAKEFULNESS

### APPROACH TO THE PATIENT

#### Sleep Disorders

Patients may seek help from a physician because of: (1) sleepiness or tiredness during the day; (2) difficulty initiating or maintaining sleep at night (insomnia); or (3) unusual behaviors during sleep itself (parasomnias).

Obtaining a careful history is essential. In particular, the duration, severity, and consistency of the symptoms are important, along with the patient's estimate of the consequences of the sleep disorder on waking function. Information from a bed partner or family member is often helpful because some patients may be unaware of symptoms such as heavy snoring or may underreport symptoms such as falling asleep at work or while driving. Physicians should inquire about when the patient typically goes to bed, when they fall asleep and wake up, whether they awaken during sleep, whether they feel rested in the morning, and whether they nap during the day. Depending on the primary complaint, it may be useful to ask about snoring, witnessed apneas, restless sensations in the legs, movements during sleep, depression, anxiety, and behaviors around the sleep episode. The physical examination may provide evidence of a small airway, large tonsils, or a neurologic or medical disorder that contributes to the main complaint.

It is important to remember that, rarely, seizures may occur exclusively during sleep, mimicking a primary sleep disorder; such sleep-related seizures typically occur during episodes of NREM sleep and may take the form of generalized tonic-clonic movements (sometimes with urinary incontinence or tongue biting) or stereotyped movements in partial complex epilepsy ([Chap. 418](#)).

It is often helpful for the patient to complete a daily sleep log for 1–2 weeks to define the timing and amounts of sleep. When relevant, the log can also include information on levels of alertness, work times, and drug and alcohol use, including caffeine and hypnotics.

Polysomnography is necessary for the diagnosis of several disorders such as sleep apnea, narcolepsy, and periodic limb movement disorder (PLMD). A conventional polysomnogram performed in a clinical sleep laboratory allows measurement of sleep stages, respiratory effort and airflow, oxygen saturation, limb movements, heart rhythm, and additional parameters. A home sleep test usually focuses on just respiratory measures and is helpful in patients with a moderate to high likelihood of having obstructive sleep apnea. The multiple sleep latency test (MSLT) is used to measure a patient's propensity to sleep during the day and can provide crucial evidence for diagnosing narcolepsy and some other causes of sleepiness. The maintenance of wakefulness test is used to measure a patient's ability to sustain wakefulness during the daytime and can provide important evidence for evaluating the efficacy of therapies for improving sleepiness in conditions such as narcolepsy and obstructive sleep apnea.

## EVALUATION OF DAYTIME SLEEPINESS

Up to 25% of the adult population has persistent daytime sleepiness that impairs an individual's ability to perform optimally in school, at work, while driving, and in other conditions that require alertness. Sleepy students often have trouble staying alert and performing well in school, and sleepy adults struggle to stay awake and focused on their work. More than half of Americans have fallen asleep while driving. An estimated 1.2 million motor vehicle crashes per year are due to drowsy drivers, causing about 20% of all serious crash injuries and deaths. One need not fall asleep to have a motor vehicle crash, as the inattention and slowed responses of drowsy drivers are major contributors. Twenty-four hours of continuous wakefulness impairs reaction time as much as a blood alcohol concentration of 0.10 g/dL (which is legally drunk in all 50 states).

Identifying and quantifying sleepiness can be challenging. First, patients may describe themselves as "sleepy," "fatigued," or "tired," and the meanings of these words may differ between patients. For clinical purposes, it is best to use the term "sleepiness" to describe a propensity to fall asleep, whereas "fatigue" is best used to describe a feeling of low physical or mental energy but without a tendency to actually sleep. Sleepiness is usually most evident when the patient is sedentary, whereas fatigue may interfere with more active pursuits. Sleepiness generally occurs with disorders that reduce the quality or quantity of sleep or that interfere with the neural mechanisms of arousal, whereas fatigue is more common in inflammatory disorders such as cancer, multiple sclerosis ([Chap. 444](#)), fibromyalgia ([Chap. 373](#)), chronic fatigue syndrome ([Chap. 450](#)), or endocrine deficiencies such as hypothyroidism ([Chap. 383](#)) or Addison's disease ([Chap. 386](#)). Second, sleepiness can affect judgment in a manner analogous to ethanol, such that patients may have limited insight into the condition and the extent of their functional impairment. Finally, patients may be reluctant to admit that sleepiness is a problem because they may have become unfamiliar with feeling fully alert, and because sleepiness is sometimes viewed pejoratively as reflecting poor motivation or bad sleep habits.

**Table 31-1** outlines the diagnostic and therapeutic approach to the patient with a complaint of excessive daytime sleepiness.

To determine the extent and impact of sleepiness on daytime function, it is helpful to ask patients about the occurrence of sleep episodes during normal waking hours, both intentional and unintentional. Specific areas to be addressed include the occurrence of inadvertent sleep episodes while driving or in other safety-related settings, sleepiness while at work or school (and its impact on performance), and the effect of sleepiness on social and family life. Standardized questionnaires such as the Epworth Sleepiness Scale are often used clinically to measure sleepiness.

TABLE 31-1 Evaluation of the Patient with Excessive Daytime Sleepiness

FINDINGS ON HISTORY AND PHYSICAL EXAMINATION	DIAGNOSTIC EVALUATION	DIAGNOSIS	THERAPY
Difficulty waking in the morning, rebound sleep on weekends and vacations with improvement in sleepiness	Sleep log	Insufficient sleep	Sleep education and behavioral modification to increase amount of sleep
Obesity, snoring, hypertension	Polysomnogram or home sleep test	Obstructive sleep apnea ( <a href="#">Chap. 297</a> )	Continuous positive airway pressure; upper airway surgery (e.g., uvulopalatopharyngoplasty); dental appliance; weight loss
Cataplexy, hypnagogic hallucinations, sleep paralysis	Polysomnogram and multiple sleep latency test	Narcolepsy	Stimulants (e.g., modafinil, methylphenidate); REM sleep-suppressing antidepressants (e.g., venlafaxine); pitolisant; solriamfetol; sodium oxybate
Restless legs, kicking movements during sleep	Assessment for predisposing medical conditions (e.g., iron deficiency or renal failure)	Restless legs syndrome with or without periodic limb movements	Treatment of predisposing condition; dopamine agonists (e.g., pramipexole, ropinirole); gabapentin; pregabalin; opiates
Sedating medications, stimulant withdrawal, head trauma, systemic inflammation, Parkinson's disease and other neurodegenerative disorders, hypothyroidism, encephalopathy	Thorough medical history and examination including detailed neurologic examination	Sleepiness due to a drug or medical condition	Change medications, treat underlying condition, consider stimulants

Eliciting a history of daytime sleepiness is usually adequate, but objective quantification is sometimes necessary. The MSLT measures a patient's propensity to sleep under quiet conditions. An overnight polysomnogram should precede the MSLT to establish that the patient has had an adequate amount of good-quality nighttime sleep. The MSLT consists of five 20-min nap opportunities every 2 h across the day. The patient is instructed to try to fall asleep, and the major endpoints are the average latency to sleep and the occurrence of REM sleep during the naps. An average sleep latency across the naps of <8 min is considered objective evidence of excessive daytime sleepiness. REM sleep normally occurs only during nighttime sleep, and the occurrence of REM sleep in two or more of the MSLT daytime naps provides support for the diagnosis of narcolepsy.

For the safety of the individual and the general public, physicians have a responsibility to help manage issues around driving in patients with sleepiness. Legal reporting requirements vary between states and countries, but at a minimum, physicians should inform sleepy patients about their increased risk of having an accident and advise such patients not to drive a motor vehicle until the sleepiness has been treated effectively. This discussion is especially important for commercial drivers, and it should be documented in the patient's medical record.

### ■ INSUFFICIENT SLEEP

Insufficient sleep is probably the most common cause of excessive daytime sleepiness. The average adult needs 7.5–8 h of sleep, but on weeknights the average U.S. adult gets only 6.75 h of sleep. Only 30% of the U.S. adult population reports consistently obtaining sufficient sleep. Insufficient sleep is especially common among shift workers, individuals working multiple jobs, and people in lower socioeconomic groups. Most teenagers need ≥9 h of sleep, but many fail to get enough sleep because of circadian phase delay, plus social pressures to stay up late coupled with early school start times. Late evening light exposure, television viewing, video-gaming, social media, texting, and smartphone use often delay bedtimes, despite the fixed early wake times required for work or school. As is typical with any disorder that causes sleepiness, individuals with chronically insufficient sleep may feel inattentive, irritable, unmotivated, and depressed, and have difficulty with school, work, and driving. Individuals differ in their optimal amount of sleep, and it can be helpful to ask how much sleep the patient obtains on a quiet vacation when he or she can sleep without restrictions. Some patients may think that a short amount of sleep is normal or advantageous, and they may not appreciate their biological need for more sleep, especially if coffee and other stimulants mask the sleepiness. A 2-week sleep log documenting the timing of sleep and daily level of alertness is diagnostically useful and provides helpful feedback for the patient. Extending sleep to the optimal amount on a regular basis can resolve the sleepiness and other symptoms. As with any lifestyle change, extending sleep requires commitment and adjustments, but the improvements in daytime alertness make this change worthwhile.

### ■ SLEEP APNEA SYNDROMES

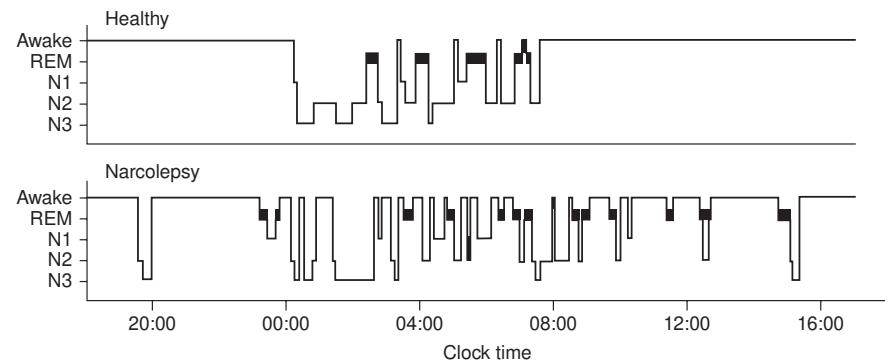
Respiratory dysfunction during sleep is a common, serious cause of excessive daytime sleepiness as well as of disturbed nocturnal sleep. At least 24% of middle-aged men and 9% of middle-aged women in the United States have a reduction or cessation of breathing dozens or more times each night during sleep, with 9% of men and 4% of women doing so more than a hundred times per night. These episodes may be due to an occlusion of the airway (*obstructive sleep apnea*), absence of respiratory effort (*central sleep apnea*), or a combination of these factors. Failure to recognize and treat these

conditions appropriately may reduce daytime alertness and increase the risk of sleep-related motor vehicle crashes, depression, hypertension, myocardial infarction, diabetes, stroke, and mortality. Sleep apnea is particularly prevalent in overweight men and in the elderly, yet it is estimated to go undiagnosed in most affected individuals. This is unfortunate because several effective treatments are available. Readers are referred to Chap. 297 for a comprehensive review of the diagnosis and treatment of patients with sleep apnea.

### ■ NARCOLEPSY

Narcolepsy is characterized by difficulty sustaining wakefulness, poor regulation of REM sleep, and disturbed nocturnal sleep. All patients with narcolepsy have excessive daytime sleepiness. This sleepiness is usually moderate to severe, and in contrast to patients with disrupted sleep (e.g., sleep apnea), people with narcolepsy usually feel well rested upon awakening and then feel tired throughout much of the day. They may fall asleep at inappropriate times, but then feel refreshed again after a nap. In addition, they often experience symptoms related to an intrusion of REM sleep characteristics into wakefulness. REM sleep is characterized by dreaming and muscle paralysis, and people with narcolepsy can have: (1) sudden muscle weakness without a loss of consciousness, which is usually triggered by strong emotions (cataplexy; Video 31-1); (2) dream-like hallucinations at sleep onset (hypnagogic hallucinations) or upon awakening (hypnopompic hallucinations); and (3) muscle paralysis upon awakening (sleep paralysis). With severe cataplexy, an individual may be laughing at a joke and then suddenly collapse to the ground, immobile but awake for 1–2 min. With milder episodes, patients may have partial weakness of the face or neck. Narcolepsy is one of the more common causes of chronic sleepiness and affects about 1 in 2000 people in the United States. Narcolepsy typically begins between age 10 and 20; once established, the disease persists for life.

Narcolepsy is caused by loss of the hypothalamic neurons that produce the orexin neuropeptides (also known as hypocretins). Research in mice and dogs first demonstrated that a loss of orexin signaling due to null mutations of either the orexin neuropeptides or one of the orexin receptors causes sleepiness and cataplexy nearly identical to that seen in people with narcolepsy. Although genetic mutations rarely cause human narcolepsy, researchers soon discovered that patients with narcolepsy with cataplexy (now called type 1 narcolepsy) have very low or undetectable levels of orexins in their CSF, and autopsy studies showed a nearly complete loss of the orexin-producing neurons in the hypothalamus. The orexins normally promote long episodes of wakefulness and suppress REM sleep, and thus loss of orexin signaling results in frequent intrusions of sleep during the usual waking episode, with REM sleep and fragments of REM sleep at any time of day (Fig. 31-3). Patients with narcolepsy but no cataplexy (type 2 narcolepsy) usually have normal orexin levels and may have other yet uncharacterized causes of their excessive daytime sleepiness.



**FIGURE 31-3** Polysomnographic recordings of a healthy individual and a patient with narcolepsy. The healthy individual has a long period of NREM sleep before entering REM sleep, but the individual with narcolepsy enters rapid eye movement (REM) sleep quickly at night and has moderately fragmented sleep. During the day, the healthy subject stays awake from 8:00 A.M. until midnight, but the patient with narcolepsy dozes off frequently, with many daytime naps that include REM sleep.

Extensive evidence suggests that an autoimmune process likely causes this selective loss of the orexin-producing neurons. Certain human leukocyte antigens (HLAs) can increase the risk of autoimmune disorders (Chap. 350), and narcolepsy has the strongest known HLA association. HLA DQB1\*06:02 is found in >90% of people with type 1 narcolepsy, whereas it occurs in only 12–25% of the general population. Researchers now hypothesize that in people with DQB1\*06:02, an immune response against influenza, *Streptococcus*, or other infections may also damage the orexin-producing neurons through a process of molecular mimicry. This mechanism may account for the eight- to twelvefold increase in new cases of narcolepsy among children in Europe who received a particular brand of H1N1 influenza A vaccine (Pandemrix). In support of this hypothesis, people with type 1 narcolepsy have heightened T cell responses against orexin peptides.

On rare occasions, narcolepsy can occur with neurologic disorders such as tumors or strokes that directly damage the orexin-producing neurons in the hypothalamus or their projections.

**Diagnosis** Narcolepsy is most commonly diagnosed by the history of chronic sleepiness plus cataplexy or other symptoms. Many disorders can cause feelings of weakness, but with true cataplexy patients will describe definite functional weakness (e.g., slurred speech, dropping a cup, slumping into a chair) that has consistent emotional triggers such as laughing at a joke, happy surprise at unexpectedly seeing a friend, or intense anger. Cataplexy occurs in about half of all narcolepsy patients and is diagnostically very helpful because it occurs in almost no other disorder. In contrast, occasional hypnagogic hallucinations and sleep paralysis occur in about 20% of the general population, and these symptoms are not as diagnostically specific.

When narcolepsy is suspected, the diagnosis should be firmly established with a polysomnogram followed the next day by an MSLT. The polysomnogram helps rule out other possible causes of sleepiness such as sleep apnea and establishes that the patient had adequate sleep the night before, and the MSLT provides essential, objective evidence of sleepiness plus REM sleep dysregulation. Across the five naps of the MSLT, most patients with narcolepsy will fall asleep in <8 min on average, and they will have episodes of REM sleep in at least two of the naps. Abnormal regulation of REM sleep is also manifested by the appearance of REM sleep within 15 min of sleep onset at night, which is rare in healthy individuals sleeping at their habitual bedtime. Stimulants should be stopped 1 week before the MSLT and antidepressants should be stopped 3 weeks prior, because these medications can affect the MSLT. In addition, patients should be encouraged to obtain a fully adequate amount of sleep each night for the week prior to the test to eliminate any effects of insufficient sleep.

## TREATMENT

### Narcolepsy

The treatment of narcolepsy is symptomatic. Most patients with narcolepsy feel more alert after sleep, and they should be encouraged to get adequate sleep each night and to take a 15- to 20-min nap in the afternoon. This nap may be sufficient for some patients with mild narcolepsy, but most also require treatment with wake-promoting medications. Modafinil is often used because it has fewer side effects than amphetamines and a relatively long half-life; for most patients, 200–400 mg each morning is very effective. Methylphenidate (10–20 mg bid) or dextroamphetamine (10 mg bid) are also effective, but sympathomimetic side effects, anxiety, and the potential for abuse can be concerns. These medications are available in slow-release formulations, extending their duration of action and allowing easier dosing. Solriamfetol, a norepinephrine-dopamine reuptake inhibitor (75–150 mg daily), and pitolisant, a selective histamine 3 ( $H_3$ ) receptor antagonist (8.9–35.6 mg daily), also improve sleepiness and have relatively few side effects. Sodium oxybate (gamma hydroxybutyrate), given at bedtime and 3–4 h later, is often very valuable in improving alertness, but it can produce excessive sedation, nausea, and confusion.

Cataplexy is usually much improved with antidepressants that increase noradrenergic or serotonergic tone because these neurotransmitters strongly suppress REM sleep and cataplexy. Venlafaxine (37.5–150 mg each morning) and fluoxetine (10–40 mg each morning) are often quite effective. The tricyclic antidepressants, such as protriptyline (10–40 mg/d) or clomipramine (25–50 mg/d) are potent suppressors of cataplexy, but their anticholinergic effects, including sedation and dry mouth, make them less attractive.<sup>1</sup> Sodium oxybate, twice each night, is also very helpful in reducing cataplexy.

<sup>1</sup>No antidepressant has been approved by the US Food and Drug Administration (FDA) for treating narcolepsy.

## EVALUATION OF INSOMNIA

Insomnia is the complaint of poor sleep and usually presents as difficulty initiating or maintaining sleep. People with insomnia are dissatisfied with their sleep and feel that it impairs their ability to function well in work, school, and social situations. Affected individuals often experience fatigue, decreased mood, irritability, malaise, and cognitive impairment.

Chronic insomnia, lasting >3 months, occurs in about 10% of adults and is more common in women, older adults, people of lower socioeconomic status, and individuals with medical, psychiatric, and substance abuse disorders. Acute or short-term insomnia affects over 30% of adults and is often precipitated by stressful life events such as a major illness or loss, change of occupation, medications, and substance abuse. If the acute insomnia triggers maladaptive behaviors such as increased nocturnal light exposure, frequently checking the clock, or attempting to sleep more by napping, it can lead to chronic insomnia.

Most insomnia begins in adulthood, but many patients may be predisposed and report easily disturbed sleep predating the insomnia, suggesting that their sleep is lighter than usual. Clinical studies and animal models indicate that insomnia is associated with activation during sleep of brain areas normally active only during wakefulness. The polysomnogram is rarely used in the evaluation of insomnia, as it typically confirms the patient's subjective report of long latency to sleep and numerous awakenings but usually adds little new information. Many patients with insomnia have increased fast (beta) activity in the EEG during sleep; this fast activity is normally present only during wakefulness, which may explain why some patients report feeling awake for much of the night. The MSLT is rarely used in the evaluation of insomnia because, despite their feelings of low energy, most people with insomnia do not easily fall asleep during the day, and on the MSLT, their average sleep latencies are usually longer than normal.

Many factors can contribute to insomnia, and obtaining a careful history is essential so one can select therapies targeting the underlying factors. The assessment should focus on identifying predisposing, precipitating, and perpetuating factors.

**Psychophysiological Factors** Many patients with insomnia have negative expectations and conditioned arousal that interfere with sleep. These individuals may worry about their insomnia during the day and have increasing anxiety as bedtime approaches if they anticipate a poor night of sleep. While attempting to sleep, they may frequently check the clock, which only heightens anxiety and frustration. They may find it easier to sleep in a new environment rather than their bedroom, as it lacks the negative associations.

**Inadequate Sleep Hygiene** Patients with insomnia sometimes develop counterproductive behaviors that contribute to their insomnia. These can include daytime napping that reduces sleep drive at night; an irregular sleep-wake schedule that disrupts their circadian rhythms; use of wake-promoting substances (e.g., caffeine, tobacco) too close to bedtime; engaging in alerting or stressful activities close to bedtime (e.g., arguing with a partner, work-related emailing and texting while in bed, sleeping with a smartphone or tablet at the bedside); and routinely using the bedroom for activities other than sleep or sex (e.g., email,

television, work), so the bedroom becomes associated with arousing or stressful feelings.

**Psychiatric Conditions** About 80% of patients with psychiatric disorders have sleep complaints, and about half of all chronic insomnia occurs in association with a psychiatric disorder. Depression is classically associated with early morning awakening, but it can also interfere with the onset and maintenance of sleep. Mania and hypomania can disrupt sleep and often are associated with substantial reductions in the total amount of sleep. Anxiety disorders can lead to racing thoughts and rumination that interfere with sleep and can be very problematic if the patient's mind becomes active midway through the night. Panic attacks can arise from sleep and need to be distinguished from other parasomnias. Insomnia is common in schizophrenia and other psychoses, often resulting in fragmented sleep, less deep NREM sleep, and sometimes reversal of the day-night sleep pattern.

**Medications and Drugs of Abuse** A wide variety of psychoactive drugs can interfere with sleep. Caffeine, which has a half-life of 6–9 h, can disrupt sleep for up to 8–14 h, depending on the dose, variations in metabolism, and an individual's caffeine sensitivity. Insomnia can also result from use of prescription medications too close to bedtime (e.g., antidepressants, stimulants, glucocorticoids, theophylline). Conversely, withdrawal of sedating medications such as alcohol, narcotics, or benzodiazepines can cause insomnia. Alcohol taken just before bed can shorten sleep latency, but it often produces rebound insomnia 2–3 h later as it wears off. This same problem with sleep maintenance can occur with short-acting medications such as alprazolam or zolpidem.

**Medical Conditions** A large number of medical conditions disrupt sleep. Pain from rheumatologic disorders or a painful neuropathy commonly disrupts sleep. Some patients may sleep poorly because of respiratory conditions such as asthma, chronic obstructive pulmonary disease, cystic fibrosis, congestive heart failure, or restrictive lung disease, and some of these disorders are worse at night due to circadian variations in airway resistance and postural changes in bed that can result in nocturnal dyspnea. Many women experience poor sleep with the hormonal changes of menopause. Gastroesophageal reflux is also a common cause of difficulty sleeping.

**Neurologic Disorders** Dementia (Chap. 29) is often associated with poor sleep, probably due to a variety of factors, including napping during the day, altered circadian rhythms, and perhaps a weakened output of the brain's sleep-promoting mechanisms. In fact, insomnia and nighttime wandering are some of the most common causes for institutionalization of patients with dementia, because they place a larger burden on caregivers. Conversely, in cognitively intact elderly men, fragmented sleep and poor sleep quality are associated with subsequent cognitive decline. Patients with Parkinson's disease may sleep poorly due to rigidity, dementia, and other factors. Fatal familial insomnia is a very rare neurodegenerative condition caused by mutations in the prion protein gene (Chap. 438), and although insomnia is a common early symptom, most patients present with other obvious neurologic signs such as dementia, myoclonus, dysarthria, or autonomic dysfunction.

## TREATMENT

### Insomnia

Treatment of insomnia improves quality of life and can promote long-term health. With improved sleep, patients often report less daytime fatigue, improved cognition, and more energy. Treating the insomnia can also improve comorbid disease. For example, management of insomnia at the time of diagnosis of major depression often improves the response to antidepressants and reduces the risk of relapse. Sleep loss can heighten the perception of pain, so a similar approach is warranted in acute and chronic pain management.

The treatment plan should target all putative contributing factors: establish good sleep hygiene, treat medical disorders, use behavioral therapies for anxiety and negative conditioning, and use

pharmacotherapy and/or psychotherapy for psychiatric disorders. Behavioral therapies should be the first-line treatment, followed by judicious use of sleep-promoting medications if needed.

### TREATMENT OF MEDICAL AND PSYCHIATRIC DISEASE

If the history suggests that a medical or psychiatric disease contributes to the insomnia, then it should be addressed by, for example, treating the pain or depression, improving breathing, and switching or adjusting the timing of medications.

### IMPROVE SLEEP HYGIENE

Attention should be paid to improving sleep hygiene and avoiding counterproductive, arousing behaviors before bedtime. Patients should establish a regular bedtime and wake time, even on weekends, to help synchronize their circadian rhythms and sleep patterns. The amount of time allocated for sleep should not be more than their actual total amount of sleep. In the 30 min before bedtime, patients should establish a relaxing "wind-down" routine that can include a warm bath, listening to music, meditation, or other relaxation techniques. The bedroom should be off-limits to computers, televisions, radios, smartphones, videogames, and tablets. If an e-reader is used, the light should be adjusted for evening use (dimmer and reduced blue light) if possible, because light itself, especially in the blue spectrum, suppresses melatonin secretion and is arousing. Once in bed, patients should try to avoid thinking about anything stressful or arousing such as problems with relationships or work. If they cannot fall asleep within 20 min, it often helps to get out of bed and read or listen to relaxing music in dim light as a form of distraction from any anxiety, but artificial light, including light from a television, cell phone, or computer, should be avoided.

Table 31-2 outlines some of the key aspects of good sleep hygiene to improve insomnia.

### COGNITIVE BEHAVIORAL THERAPY

Cognitive behavioral therapy (CBT) uses a combination of the techniques above plus additional methods to improve insomnia. A trained therapist may use cognitive psychology techniques to reduce excessive worrying about sleep and to reframe faulty beliefs about the insomnia and its daytime consequences. The therapist may also teach the patient relaxation techniques, such as progressive muscle relaxation or meditation, to reduce autonomic arousal, intrusive thoughts, and anxiety.

### MEDICATIONS FOR INSOMNIA

If insomnia persists after treatment of these contributing factors, pharmacotherapy is often used on a nightly or intermittent basis. A variety of sedatives can improve sleep.

*Antihistamines*, such as diphenhydramine, are the primary active ingredient in most over-the-counter sleep aids. These may be of

TABLE 31-2 Methods to Improve Sleep Hygiene in Insomnia Patients

HELPFUL BEHAVIORS	BEHAVIORS TO AVOID
Use the bed only for sleep and sex	Avoid behaviors that interfere with sleep physiology, including: <ul style="list-style-type: none"> <li>• Napping, especially after 3:00 PM</li> <li>• Attempting to sleep too early</li> <li>• Caffeine after lunchtime</li> </ul>
Make quality sleep a priority	In the 2–3 h before bedtime, avoid: <ul style="list-style-type: none"> <li>• Heavy eating</li> <li>• Smoking or alcohol</li> <li>• Vigorous exercise</li> </ul>
Develop a consistent bedtime routine. For example:	When trying to fall asleep, avoid: <ul style="list-style-type: none"> <li>• Solving problems</li> <li>• Thinking about life issues</li> <li>• Reviewing events of the day</li> </ul>
• Prepare for sleep with 20–30 min of relaxation (e.g., soft music, meditation, yoga, pleasant reading)	
• Take a warm bath	

benefit when used intermittently but can produce tolerance and anticholinergic side effects such as dry mouth and constipation, which limit their use, particularly in the elderly.

**Benzodiazepine receptor agonists (BzRAs)** are an effective and well-tolerated class of medications for insomnia. BzRAs bind to the GABA<sub>A</sub> receptor and potentiate the postsynaptic response to GABA. GABA<sub>A</sub> receptors are found throughout the brain, and BzRAs may globally reduce neural activity and enhance the activity of specific sleep-promoting GABAergic pathways. Classic BzRAs include lorazepam, triazolam, and clonazepam, whereas newer agents such as zolpidem and zaleplon have more selective affinity for the α<sub>1</sub> subunit of the GABA<sub>A</sub> receptor.

Specific BzRAs are often chosen based on the desired duration of action. The most commonly prescribed agents in this family are zaleplon (5–20 mg), with a half-life of 1–2 h; zolpidem (5–10 mg) and triazolam (0.125–0.25 mg), with half-lives of 2–4 h; eszopiclone (1–3 mg), with a half-life of 5–8 h; and temazepam (15–30 mg), with a half-life of 8–20 h. Generally, side effects are minimal when the dose is kept low and the serum concentration is minimized during the waking hours (by using the shortest-acting effective agent). For chronic insomnia, intermittent use is recommended, unless the consequences of untreated insomnia outweigh concerns regarding chronic use.

The heterocyclic antidepressants (trazodone, amitriptyline,<sup>2</sup> and doxepin) are the most commonly prescribed alternatives to BzRAs due to their lack of abuse potential and low cost. Trazodone (25–100 mg) is used more commonly than the tricyclic antidepressants, because it has a much shorter half-life (5–9 h) and less anticholinergic activity.

The orexin receptor antagonists suvorexant (10–20 mg) and lemborexant (5–10 mg) can also improve insomnia by blocking the wake-promoting effects of the orexin neuropeptides. These have long half-lives and can produce morning sedation, and as they reduce orexin signaling, they can rarely produce hypnagogic hallucinations and sleep paralysis (see narcolepsy section above).

Medications for insomnia are now among the most commonly prescribed medications, but they should be used cautiously. All sedatives increase the risk of injurious falls and confusion in the elderly, and therefore if needed these medications should be used at the lowest effective dose. Morning sedation can interfere with driving and judgment, and when selecting a medication, one should consider the duration of action. Benzodiazepines carry a risk of addiction and abuse, especially in patients with a history of alcohol or sedative abuse. In patients with depression, all sedatives can worsen the depression. Like alcohol, some sleep-promoting medications can worsen sleep apnea. Sedatives can also produce complex behaviors during sleep, such as sleepwalking and sleep eating, especially at higher doses.

<sup>2</sup>Trazodone and amitriptyline have not been approved by the FDA for treating insomnia.

## ■ RESTLESS LEGS SYNDROME

Patients with restless legs syndrome (RLS) report an irresistible urge to move the legs. Many patients report a creepy-crawly or unpleasant deep ache within the thighs or calves, and those with more severe RLS may have discomfort in the arms as well. For most patients with RLS, these dysesthesias and restlessness are much worse in the evening and first half of the night. The symptoms appear with inactivity and can make sitting still in an airplane or when watching a movie a miserable experience. The sensations are temporarily relieved by movement, stretching, or massage. This nocturnal discomfort usually interferes with sleep, and patients may report daytime sleepiness as a consequence. RLS is very common, affecting 5–10% of adults, and is more common in women and older adults.

A variety of factors can cause RLS. Iron deficiency is the most common treatable cause, and iron replacement should be considered if the ferritin level is <75 ng/mL. RLS can also occur with peripheral

neuropathies and uremia and can be worsened by pregnancy, caffeine, alcohol, antidepressants, lithium, neuroleptics, and antihistamines. Genetic factors contribute to RLS, and polymorphisms in a variety of genes (*BTBD9*, *MEIS1*, *MAP2K5/LBXCOR*, and *PTPRD*) have been linked to RLS, although as yet, the mechanism through which they cause RLS remains unknown. Roughly one-third of patients (particularly those with an early age of onset) have multiple affected family members.

RLS is treated by addressing the underlying cause such as iron deficiency if present. Otherwise, treatment is symptomatic, and dopamine agonists or alpha-2-delta calcium channel ligands are used most frequently. Agonists of dopamine D<sub>2/3</sub> receptors such as pramipexole (0.25–0.5 mg q7PM) or ropinirole (0.5–4 mg q7PM) are usually quite effective, but about 25% of patients taking dopamine agonists develop augmentation, a worsening of RLS such that symptoms begin earlier in the day and can spread to other body regions. Other possible side effects of dopamine agonists include nausea, morning sedation, and increases in rewarding behaviors such as sex and gambling. Alpha-2-delta calcium channel ligands such as gabapentin (300–600 mg q7PM) and pregabalin (150–450 mg q7PM) can also be quite effective; these are less likely to cause augmentation, and they can be especially helpful in patients with concomitant pain, neuropathy, or anxiety. Opioids and benzodiazepines may also be of therapeutic value. Most patients with restless legs also experience PLMD, although the reverse is not the case.

## ■ PERIODIC LIMB MOVEMENT DISORDER

PLMD involves rhythmic twitches of the legs that disrupt sleep. The movements resemble a triple flexion reflex with extensions of the great toe and dorsiflexion of the foot for 0.5–5.0 s, which recur every 20–40 s during NREM sleep, in episodes lasting from minutes to hours. PLMD is diagnosed by a polysomnogram that includes recordings of the anterior tibialis and sometimes other muscles. The EEG shows that the movements of PLMD frequently cause brief arousals that disrupt sleep and can cause insomnia and daytime sleepiness. PLMD can be caused by the same factors that cause RLS (see above), and the frequency of leg movements improves with the same medications used for RLS, including dopamine agonists. Genetic studies identified polymorphisms associated with both RLS and PLMD, suggesting that they may have a common pathophysiology.

## ■ PARASOMNIAS

Parasomnias are abnormal behaviors or experiences that arise from or occur during sleep. A variety of parasomnias can occur during NREM sleep, from brief confusional arousals to sleepwalking and night terrors. The presenting complaint is usually related to the behavior itself, but the parasomnias can disturb sleep continuity or lead to mild impairments in daytime alertness. Two main parasomnias occur in REM sleep: REM sleep behavior disorder (RBD) and nightmares.

**Sleepwalking (Somnambulism)** Patients affected by this disorder carry out automatic motor activities that range from simple to complex. Individuals may walk, urinate inappropriately, eat, exit the house, or drive a car with minimal awareness. It may be difficult to arouse the patient to wakefulness, and some individuals may respond to attempted awakening with agitation or violence. In general, it is safest to lead the patient back to bed, at which point he or she will often fall back asleep. Sleepwalking arises from NREM stage N3 sleep, usually in the first few hours of the night, and the EEG initially shows the slow cortical activity of deep NREM sleep even when the patient is moving about. Sleepwalking is most common in children and adolescents, when deep NREM sleep is most abundant. About 15% of children have occasional sleepwalking, and it persists in about 1% of adults. Episodes are usually isolated but may be recurrent in 1–6% of patients. The cause is unknown, although it has a familial basis in roughly one-third of cases. Sleepwalking can be worsened by stress, alcohol, and insufficient sleep, which subsequently causes an increase in deep NREM sleep. These should be addressed if present. Small studies have shown some efficacy of antidepressants and benzodiazepines;

relaxation techniques and hypnosis can also be helpful. Patients and their families should improve home safety (e.g., replace glass doors, remove low tables to avoid tripping) to minimize the chance of injury if sleepwalking occurs.

**Sleep Terrors** This disorder occurs primarily in young children during the first few hours of sleep during NREM stage N3 sleep. The child often sits up during sleep and screams, exhibiting autonomic arousal with sweating, tachycardia, large pupils, and hyperventilation. The individual may be difficult to arouse and rarely recalls the episode on awakening in the morning. Treatment usually consists of reassuring parents that the condition is self-limited and benign, and like sleepwalking, it may improve by avoiding insufficient sleep.

**Sleep Enuresis** Bedwetting, like sleepwalking and night terrors, is another parasomnia that occurs during sleep in the young. Before age 5 or 6 years, nocturnal enuresis should be considered a normal feature of development. The condition usually improves spontaneously by puberty, persists in 1–3% of adolescents, and is rare in adulthood. Treatment consists of bladder training exercises and behavioral therapy. Symptomatic pharmacotherapy is usually accomplished in adults with desmopressin (0.2 mg qhs), oxybutynin chloride (5 mg qhs), or imipramine (10–25 mg qhs). Important causes of nocturnal enuresis in patients who were previously continent for 6–12 months include urinary tract infections or malformations, cauda equina lesions, emotional disturbances, epilepsy, sleep apnea, and certain medications.

**Sleep Bruxism** Bruxism is an involuntary, forceful grinding of teeth during sleep that affects 10–20% of the population. The patient is usually unaware of the problem. The typical age of onset is 17–20 years, and spontaneous remission usually occurs by age 40. In many cases, the diagnosis is made during dental examination, damage is minor, and no treatment is indicated. In more severe cases, treatment with a mouth guard is necessary to prevent tooth injury. Stress management, benzodiazepines, and biofeedback can be useful when bruxism is a manifestation of psychological stress.

**REM Sleep Behavior Disorder (RBD)** RBD ([Video 31-2](#)) is distinct from other parasomnias in that it occurs during REM sleep. The patient or the bed partner usually reports agitated or violent behavior during sleep, and upon awakening, the patient can often report a dream that matches the accompanying movements. During normal REM sleep, nearly all nonrespiratory skeletal muscles are paralyzed, but in patients with RBD, dramatic limb movements such as punching or kicking lasting seconds to minutes occur during REM sleep, and it is not uncommon for the patient or the bed partner to be injured.

The prevalence of RBD increases with age, afflicting about 2% of adults aged >70, and is about twice as common in men. Within 12 years of disease onset, half of RBD patients develop a synucleinopathy such as Parkinson's disease ([Chap. 435](#)) or dementia with Lewy bodies ([Chap. 434](#)), or occasionally multiple system atrophy ([Chap. 440](#)), and over 90% develop a synucleinopathy by 25 years. RBD can occur in patients taking antidepressants, and in some, these medications may unmask this early indicator of neurodegeneration. Synucleinopathies probably cause neuronal loss in brainstem regions that regulate muscle paralysis during REM sleep, and loss of these neurons permits movements to break through during REM sleep. RBD also occurs in about 30% of patients with narcolepsy, but the underlying cause is probably different, as they seem to be at no increased risk of a neurodegenerative disorder.

Many patients with RBD have sustained improvement with clonazepam (0.5–2.0 mg qhs).<sup>3</sup> Melatonin at doses up to 9 mg nightly may also prevent attacks.

## CIRCADIAN RHYTHM SLEEP DISORDERS

A subset of patients presenting with either insomnia or hypersomnia may have a disorder of sleep timing rather than sleep generation.

Disorders of sleep timing can be either organic (i.e., due to an abnormality of circadian pacemaker[s]) or environmental/behavioral (i.e., due to a disruption of environmental synchronizers). Effective therapies aim to entrain the circadian rhythm of sleep propensity to the appropriate behavioral phase.

**Delayed Sleep-Wake Phase Disorder** DSWPD is characterized by: (1) sleep onset and wake times persistently later than desired; (2) actual sleep times at nearly the same clock hours daily; and (3) if conducted at the habitual delayed sleep time, essentially normal sleep on polysomnography (except for delayed sleep onset). About half of patients with DSWPD exhibit an abnormally delayed endogenous circadian phase, which can be assessed by measuring the onset of secretion of melatonin in either the blood or saliva; this is best done in a dimly lit environment as light suppresses melatonin secretion. Dim-light melatonin onset (DLMO) in DSWPD patients occurs later in the evening than normal, which is about 8:00–9:00 . . (i.e., about 1–2 h before habitual bedtime). Patients tend to be young adults. The delayed circadian phase could be due to: (1) an abnormally long, genetically determined intrinsic period of the endogenous circadian pacemaker; (2) reduced phase-advancing capacity of the pacemaker; (3) slower buildup of homeostatic sleep drive during wakefulness; or (4) an irregular prior sleep-wake schedule, characterized by frequent nights when the patient chooses to remain awake while exposed to artificial light well past midnight (for personal, social, school, or work reasons). In most cases, it is difficult to distinguish among these factors, as patients with either a behaviorally induced or biologically driven circadian phase delay may both exhibit a similar circadian phase delay in DLMO, and both factors make it difficult to fall asleep at the desired hour. Late onset of dim-light melatonin secretion can help distinguish DSWPD from other forms of sleep-onset insomnia. DSWPD is a chronic condition that can persist for years and may not respond to attempts to reestablish normal bedtime hours. Treatment methods involving phototherapy with blue-enriched light during the morning hours and/or melatonin administration in the evening hours show promise in these patients, although the relapse rate is high.

**Advanced Sleep-Wake Phase Disorder** Advanced sleep-wake phase disorder (ASWPD) is the converse of DSWPD. Most commonly, this syndrome occurs in older people, 15% of whom report that they cannot sleep past 5:00 . ., with twice that number complaining that they wake up too early at least several times per week. Patients with ASWPD are sleepy during the evening hours, even in social settings. Sleep-wake timing in ASWPD patients can interfere with a normal social life. Patients with this circadian rhythm sleep disorder can be distinguished from those who have early wakening due to insomnia because ASWPD patients show early onset of dim-light melatonin secretion.

In addition to age-related ASWPD, an early-onset familial variant of this condition has also been reported. In two families in which ASWPD was inherited in an autosomal dominant pattern, the syndrome was due to missense mutations in a circadian clock component (in the casein kinase binding domain of *PER2* in one family, and in casein kinase I delta in the other) that shortens the circadian period. Patients with ASWPD may benefit from bright light and/or blue enriched phototherapy during the evening hours to reset the circadian pacemaker to a later hour.

**Non-24-h Sleep-Wake Rhythm Disorder** Non-24-h sleep-wake rhythm disorder (N24SWD) most commonly occurs when the primary synchronizing input (i.e., the light-dark cycle) from the environment to the circadian pacemaker is lost (as occurs in many blind people with no light perception), and the maximal phase-advancing capacity of the circadian pacemaker in response to nonphotic cues cannot accommodate the difference between the 24-h geophysical day and the intrinsic period of the patient's circadian pacemaker, resulting in loss of entrainment to the 24-h day. The sleep of most blind patients with N24SWD is restricted to the nighttime hours due to social or occupational demands. Despite this regular sleep-wake schedule, affected patients with N24SWD are nonetheless unable to maintain

<sup>3</sup>No medications have been approved by the FDA for the treatment of RBD.

a stable phase relationship between the output of the non-entrained circadian pacemaker and the 24-h day. Therefore, most blind patients present with intermittent bouts of insomnia. When the blind patient's endogenous circadian rhythms are out of phase with the local environment, nighttime insomnia coexists with excessive daytime sleepiness. Conversely, when the endogenous circadian rhythms of those same patients are in phase with the local environment, symptoms remit. The interval between symptomatic phases may last several weeks to several months in blind patients with N24SWD, depending on the period of the underlying nonentrained rhythm and the 24-h day. Nightly low-dose (0.5 mg) melatonin administration may improve sleep and, in some cases, induce synchronization of the circadian pacemaker. In sighted patients, N24SWD can be caused by self-selected exposure to artificial light that inadvertently entrains the circadian pacemaker to a >24-h schedule, and these individuals present with an incremental pattern of successive delays in sleep timing, progressing in and out of phase with local time—a clinical presentation that is seldom seen in blind patients with N24SWD.

**Shift-Work Disorder** More than 7 million workers in the United States regularly work at night, either on a permanent or rotating schedule. Many more begin the commute to work or school between 4:00 . . . and 7:00 . . . , requiring them to commute and then work during a time of day that they would otherwise be asleep. In addition, each week, millions of “day” workers and students elect to remain awake at night or awaken very early in the morning to work or study to meet work or school deadlines, drive long distances, compete in sporting events, or participate in recreational activities. Such schedules can result in both sleep loss and misalignment of circadian rhythms with respect to the sleep-wake cycle.

The circadian timing system usually fails to adapt successfully to the inverted schedules required by overnight work or the phase advance required by early morning (4:00 . . . to 7:00 . . . ) start times. This leads to a misalignment between the desired work-rest schedule and the output of the pacemaker, resulting in disturbed daytime sleep in most such individuals. Excessive work hours (per day or per week), insufficient time off between consecutive days of work or school, and frequent travel across time zones may be contributing factors. Sleep deficiency, increased length of time awake prior to work, and misalignment of circadian phase impair alertness and performance, increase reaction time, and increase risk of performance lapses, thereby resulting in greater safety hazards among night workers and other sleep-deprived individuals. Sleep disturbance nearly doubles the risk of a fatal work accident. In addition, long-term night-shift workers have higher rates of breast, colorectal, and prostate cancer and of cardiac, gastrointestinal, metabolic, and reproductive disorders. The World Health Organization has added night-shift work to its list of probable carcinogens.

Sleep onset begins in local brain regions before gradually sweeping over the entire brain as sensory thresholds rise and consciousness is lost. A sleepy individual struggling to remain awake may attempt to continue performing routine and familiar motor tasks during the transition state between wakefulness and stage N1 sleep, while unable to adequately process sensory input from the environment. Such sleep-related attentional failures typically last only seconds but are known on occasion to persist for longer durations. Motor vehicle operators who fail to heed the warning signs of sleepiness are especially vulnerable to sleep-related accidents, as sleep processes can slow reaction times, induce automatic behavior, and intrude involuntarily upon the waking brain, causing catastrophic consequences—including 6400 fatalities and 50,000 debilitating injuries in the United States annually. For this reason, an expert consensus panel has concluded that individuals who have slept <2 h in the prior 24 h are unfit to drive a motor vehicle. There is a significant increase in the risk of sleep-related, fatal-to-the-driver highway crashes in the early morning and late afternoon hours, coincident with bimodal peaks in the daily rhythm of sleep tendency.

Physicians who work prolonged shifts, especially intermittent overnight shifts, constitute another group of workers at greater risk for accidents and other adverse consequences of lack of sleep and

misalignment of the circadian rhythm. Recurrent scheduling of resident physicians to work shifts of ≥24 consecutive hours impairs psychomotor performance to a degree that is comparable to alcohol intoxication, doubles the risk of attentional failures among intensive care unit resident physicians working at night, and significantly increases the risk of serious medical errors in intensive care units, including a fivefold increase in the risk of serious diagnostic mistakes. Some 20% of hospital resident physicians report making a fatigue-related mistake that injured a patient, and 5% admit making a fatigue-related mistake that resulted in the death of a patient. Moreover, working for >24 consecutive hours increases the risk of percutaneous injuries and more than doubles the risk of motor vehicle crashes during the commute home. For these reasons, in 2008, the National Academy of Medicine concluded that the practice of scheduling resident physicians to work for >16 consecutive hours without sleep is hazardous for both resident physicians and their patients.

Of individuals scheduled to work at night or in the early morning hours, 5–15% have much greater-than-average difficulties remaining awake during night work and sleeping during the day; these individuals are diagnosed with chronic and severe shift-work disorder (SWD). Patients with this disorder have a level of excessive sleepiness during work at night or in the early morning and insomnia during day sleep that the physician judges to be clinically significant; the condition is associated with an increased risk of sleep-related accidents and with some of the illnesses associated with night-shift work. Patients with chronic and severe SWD are profoundly sleepy at work. In fact, their sleep latencies during night work average just 2 min, comparable to mean daytime sleep latency durations of patients with narcolepsy or severe sleep apnea.

## TREATMENT

### Shift-Work Disorder

Caffeine is frequently used by night workers to promote wakefulness. However, it cannot forestall sleep indefinitely, and it does not shield users from sleep-related performance lapses. Postural changes, exercise, and strategic placement of nap opportunities can sometimes temporarily reduce the risk of fatigue-related performance lapses. Properly timed exposure to blue-enriched light or bright white light can directly enhance alertness and facilitate more rapid adaptation to night-shift work.

Modafinil (200 mg) or armodafinil (150 mg) 30–60 min before the start of an 8-h overnight shift is an effective treatment for the excessive sleepiness during night work in patients with SWD. Although treatment with modafinil or armodafinil significantly improves performance and reduces sleep propensity and the risk of lapses of attention during night work, affected patients remain excessively sleepy.

Fatigue risk management programs for night-shift workers should promote education about sleep, increase awareness of the hazards associated with sleep deficiency and night work, and screen for common sleep disorders. Work schedules should be designed to minimize: (1) exposure to night work; (2) the frequency of shift rotations; (3) the number of consecutive night shifts; and (4) the duration of night shifts.

**Jet Lag Disorder** Each year, >60 million people fly from one time zone to another, often resulting in excessive daytime sleepiness, sleep-onset insomnia, and frequent arousals from sleep, particularly in the latter half of the night. The syndrome is transient, typically lasting 2–14 d depending on the number of time zones crossed, the direction of travel, and the traveler's age and phase-shifting capacity. Travelers who spend more time outdoors at their destination reportedly adapt more quickly than those who remain in hotel or seminar rooms, presumably due to brighter (outdoor) light exposure. Avoidance of antecedent sleep loss or napping on the afternoon prior to overnight travel can reduce the difficulties associated with extended wakefulness. Laboratory studies suggest that low doses of melatonin can enhance

sleep efficiency, but only if taken when endogenous melatonin concentrations are low (i.e., during the biologic daytime).

In addition to jet lag associated with travel across time zones, many patients report a behavioral pattern that has been termed *social jet lag*, in which bedtimes and wake times on weekends or days off occur 4–8 h later than during the week. Such recurrent displacement of the timing of the sleep-wake cycle is common in adolescents and young adults and is associated with delayed circadian phase, sleep-onset insomnia, excessive daytime sleepiness, poorer academic performance, and increased risk of both obesity and depressive symptoms.

## MEDICAL IMPLICATIONS OF CIRCADIAN RHYTHMICITY

Prominent circadian variations have been reported in the incidence of acute myocardial infarction, sudden cardiac death, and stroke, the leading causes of death in the United States. Platelet aggregability is increased in the early morning hours, coincident with the peak incidence of these cardiovascular events. Recurrent circadian disruption combined with chronic sleep deficiency, such as occurs during night-shift work, is associated with increased plasma glucose concentrations after a meal due to inadequate pancreatic insulin secretion. Night-shift workers with elevated fasting glucose have an increased risk of progressing to diabetes. Blood pressure of night workers with sleep apnea is higher than that of day workers. A better understanding of the possible role of circadian rhythmicity in the acute destabilization of a chronic condition such as atherosclerotic disease could improve the understanding of its pathophysiology.

Diagnostic and therapeutic procedures may also be affected by the time of day at which data are collected. Examples include blood pressure, body temperature, the dexamethasone suppression test, and plasma cortisol levels. The timing of chemotherapy administration has been reported to have an effect on the outcome of treatment. In addition, both the toxicity and effectiveness of drugs can vary with time of day. For example, more than a fivefold difference has been observed in mortality rates after administration of toxic agents to experimental animals at different times of day. Anesthetic agents are particularly sensitive to time-of-day effects. Finally, the physician must be aware of the public health risks associated with the ever-increasing demands made by the 24/7 schedules in our round-the-clock society.

A

*John W. Winkelman, MD, PhD, and Gary S. Richardson, MD, contributed to this chapter in prior editions, and some material from their work has been retained here.*

## FURTHER READING

- C RE et al: Association between sleep duration and ideal cardiovascular health among US adults, National Health and Nutrition Examination Survey. *Prev Chronic Dis* 17:E43, 2020.
- C ED et al: Unrestricted evening use of light-emitting tablet computers delays self-selected bedtime and disrupts circadian timing and alertness. *Physiol Rep* 6:e13692, 2018.
- F NE et al: Coupled electrophysiological, hemodynamic, and cerebrospinal fluid oscillations in human sleep. *Science* 366:628, 2019.
- H JK et al: The sleep-wake cycle regulates brain interstitial fluid tau in mice and CSF tau in humans. *Science* 363:880, 2019.
- L CP et al: Effect on patient safety of a resident physician schedule without 24-hour shifts. *N Engl J Med* 382:2514, 2020.
- L ML et al: High risk of near-crash driving events following night-shift work. *Proc Natl Acad Sci USA* 113:176, 2016.
- L AS et al: Sleep is related to neuron numbers in the ventrolateral preoptic/intermediate nucleus in older adults with and without Alzheimer's disease. *Brain* 137:2847, 2014.
- M A CS et al: Sleep modulates haematopoiesis and protects against atherosclerosis. *Nature* 566:383, 2019.
- R D et al: The neurobiology, investigation, and treatment of chronic insomnia. *Lancet Neurol* 14:547, 2015.
- S TE: Narcolepsy. *N Engl J Med* 373:2654, 2015.
- S TE et al: Neural circuitry of wakefulness and sleep. *Neuron* 93:747, 2017.

S TL et al: Efficacy of melatonin with behavioural sleep-wake scheduling for delayed sleep-wake phase disorder: a double-blind, randomised clinical trial. *PLoS Med* 15:e1002587, 2018.

**VIDEO 31-1** A typical episode of severe cataplexy. The patient is joking and then falls to the ground with an abrupt loss of muscle tone. The electromyogram recordings (*four lower traces on the right*) show reductions in muscle activity during the period of paralysis. The electroencephalogram (*top two traces*) shows wakefulness throughout the episode. (*Video courtesy of Giuseppe Plazzi, University of Bologna.*)

**VIDEO 31-2** Typical aggressive movements in rapid eye movement (REM) sleep behavior disorder. (*Video courtesy of Dr. Carlos Schenck, University of Minnesota Medical School.*)

## Section 4 Disorders of Eyes, Ears, Nose, and Throat

### 32

### Disorders of the Eye

Jonathan C. Horton



## THE HUMAN VISUAL SYSTEM

The visual system provides a supremely efficient means for the rapid assimilation of information from the environment to aid in the guidance of behavior. The act of seeing begins with the capture of images focused by the cornea and lens on a light-sensitive membrane in the back of the eye called the *retina*. The retina is actually part of the brain, banished to the periphery to serve as a transducer for the conversion of patterns of light energy into neuronal signals. Light is absorbed by pigment in two types of photoreceptors: rods and cones. In the human retina, there are 100 million rods and 5 million cones. The rods operate in dim (scotopic) illumination. The cones function under daylight (photopic) conditions. The cone system is specialized for color perception and high spatial resolution. The majority of cones are within the macula, the portion of the retina that serves the central 10° of vision. In the middle of the macula, a small pit termed the *fovea*, packed exclusively with cones, provides the best visual acuity.

Photoreceptors hyperpolarize in response to light, activating bipolar, amacrine, and horizontal cells in the inner nuclear layer. After processing of photoreceptor responses by this complex retinal circuit, the flow of sensory information ultimately converges on a final common pathway: the ganglion cells. These cells translate the visual image impinging on the retina into a continuously varying barrage of action potentials that propagates along the primary optic pathway to visual centers within the brain. There are a million ganglion cells in each retina and hence a million fibers in each optic nerve.

Ganglion cell axons sweep along the inner surface of the retina in the nerve fiber layer, exit the eye at the optic disc, and travel through the optic nerve, optic chiasm, and optic tract to reach targets in the brain. The majority of fibers synapse on cells in the lateral geniculate body, a thalamic relay station. Cells in the lateral geniculate body project in turn to the primary visual cortex. This afferent retinogeniculocortical sensory pathway provides the neural substrate for visual perception. Although the lateral geniculate body is the main target of the retina, separate classes of ganglion cells project to other subcortical visual nuclei involved in different functions. Ganglion cells that mediate pupillary constriction and circadian rhythms are light sensitive owing to a novel visual pigment, melanopsin. Pupil responses are mediated by input to the pretectal olivary nuclei in the midbrain. The pretectal nuclei send their output to the Edinger-Westphal nuclei, which in turn provide parasympathetic innervation to the iris sphincter via an interneuron in the ciliary ganglion. Circadian rhythms are

timed by a retinal projection to the suprachiasmatic nucleus. Visual orientation and eye movements are served by retinal input to the superior colliculus. Gaze stabilization and optokinetic reflexes are governed by a group of small retinal targets known collectively as the *brainstem accessory optic system*.

The eyes must be rotated constantly within their orbits to place and maintain targets of visual interest on the fovea. This activity, called *foveation*, or looking, is governed by an elaborate efferent motor system. Each eye is moved by six extraocular muscles that are supplied by cranial nerves from the oculomotor (III), trochlear (IV), and abducens (VI) nuclei. Activity in these ocular motor nuclei is coordinated by pontine and midbrain mechanisms for smooth pursuit, saccades, and gaze stabilization during head and body movements. Large regions of the frontal and parietooccipital cortex control these brainstem eye movement centers by providing descending supranuclear input.

## CLINICAL ASSESSMENT OF VISUAL FUNCTION

### REFRACTIVE STATE

In approaching a patient with reduced vision, the first step is to decide whether refractive error is responsible. In *emmetropia*, parallel rays from infinity are focused perfectly on the retina. Sadly, this condition is enjoyed by only a minority of the population. In *myopia*, the globe is too long, and light rays come to a focal point in front of the retina. Near objects can be seen clearly, but distant objects require a diverging lens in front of the eye. In *hyperopia*, the globe is too short, and hence, a converging lens is used to supplement the refractive power of the eye. In *astigmatism*, the corneal surface is not perfectly spherical, necessitating a cylindrical corrective lens. Most patients elect to wear eyeglasses or contact lenses to neutralize refractive error. An alternative is to permanently alter the refractive properties of the cornea by performing laser *in situ* keratomileusis (LASIK) or photorefractive keratectomy (PRK).

With the onset of middle age, *presbyopia* develops as the lens within the eye becomes unable to increase its refractive power to accommodate on near objects. To compensate for presbyopia, an emmetropic patient must use reading glasses. A patient already wearing glasses for distance correction usually switches to bifocals. The only exception is a myopic patient, who may achieve clear vision at near simply by removing glasses containing the distance prescription.

Refractive errors usually develop slowly and remain stable after adolescence, except in unusual circumstances. For example, the acute onset of diabetes mellitus can produce sudden myopia because of lens edema induced by hyperglycemia. Testing vision through a pinhole aperture is a useful way to screen quickly for refractive error. If visual acuity is better through a pinhole than it is with the unaided eye, the patient needs refraction to obtain best corrected visual acuity.

### VISUAL ACUITY

The Snellen chart is used to test acuity at a distance of 6 m (20 ft). For convenience, a scale version of the Snellen chart called the Rosenbaum card is held at 36 cm (14 in.) from the patient (Fig. 32-1). All subjects should be able to read the 6/6 m (20/20 ft) line with each eye using their refractive correction, if any. Patients who need reading glasses because of presbyopia must wear them for accurate testing with the Rosenbaum card. If 6/6 (20/20) acuity is not present in each eye, the deficiency in vision must be explained. If it is worse than 6/240 (20/800), acuity should be recorded in terms of counting fingers, hand motions, light perception, or no light perception. Legal blindness is defined by the Internal Revenue Service as a best corrected acuity of 6/60 (20/200) or less in the better eye or a binocular visual field subtending 20° or less. Loss of vision in one eye only does not constitute legal blindness. For driving, the laws vary by state, but most require a corrected acuity of 6/12 (20/40) in at least one eye for unrestricted privileges. Patients who develop a homonymous hemianopia should not drive.

### PUPILS

The pupils should be tested individually in dim light with the patient fixating on a distant target. There is no need to check the near response

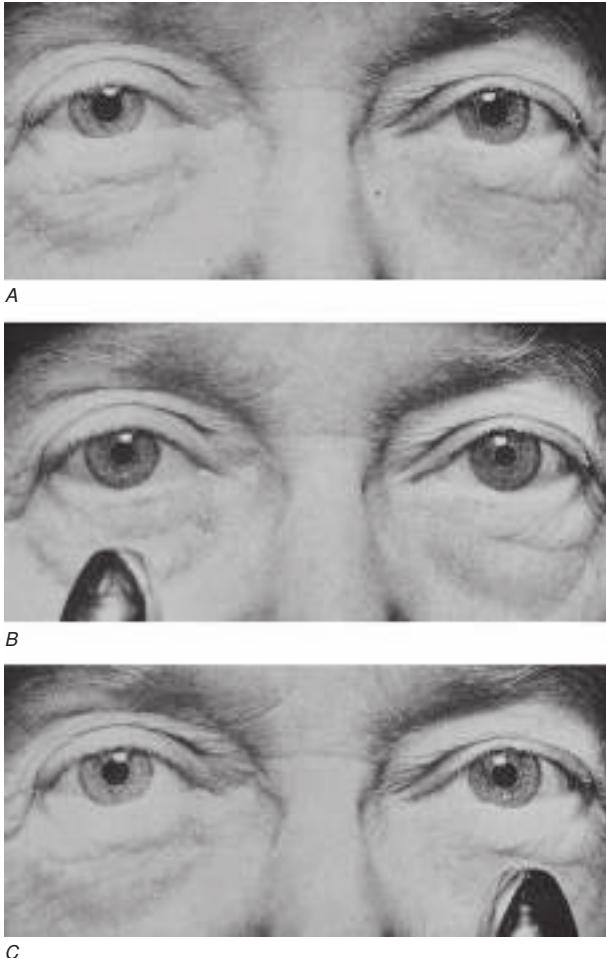


FIGURE 32-1 The Rosenbaum card is a miniature, scale version of the Snellen chart for testing visual acuity at near. When the visual acuity is recorded, the Snellen distance equivalent should bear a notation indicating that vision was tested at near, not at 6 m (20 ft), or else the Jaeger number system should be used to report the acuity. (Design Courtesy J.G. Rosenbaum MD.)

if the pupils respond briskly to light, because isolated loss of constriction (miosis) to accommodation does not occur. For this reason, the ubiquitous abbreviation PERRLA (pupils equal, round, and reactive to light and accommodation) implies a wasted effort with the last step. However, it is important to test the near response if the light response is poor or absent. Light-near dissociation occurs with neurosyphilis (Argyll Robertson pupil), with lesions of the dorsal midbrain (*Parinaud's syndrome*), and after aberrant regeneration (oculomotor nerve palsy, Adie's tonic pupil).

An eye with no light perception has no pupillary response to direct light stimulation. If the retina or optic nerve is only partially injured, the direct pupillary response will be weaker than the consensual pupillary response evoked by shining a light into the healthy fellow eye. A *relative afferent pupillary defect* (Marcus Gunn pupil) is elicited with the swinging flashlight test (Fig. 32-2). It is an extremely useful sign in retrobulbar optic neuritis and other optic nerve diseases, in which it may be the sole objective evidence for disease. In bilateral optic neuropathy, no afferent pupil defect is present if the optic nerves are affected equally.

Subtle inequality in pupil size, up to 0.5 mm, is a fairly common finding in normal persons. The diagnosis of essential or physiologic anisocoria is secure as long as the relative pupil asymmetry remains constant as ambient lighting varies. Anisocoria that increases in dim light indicates a sympathetic paresis of the iris dilator muscle. The triad of miosis with ipsilateral ptosis and anhidrosis constitutes *Horner's*



**FIGURE 32-2** Demonstration of a relative afferent pupil defect (Marcus Gunn pupil) in the left eye, done with the patient fixating on a distant target. *A*, With dim background lighting, the pupils are equal and relatively large. *B*, Shining a flashlight into the right eye evokes equal, strong constriction of both pupils. *C*, Swinging the flashlight over to the damaged left eye causes dilation of both pupils, although they remain smaller than in *A*. Swinging the flashlight back over to the healthy right eye would result in symmetric constriction back to the appearance shown in *B*. Note that the pupils always remain equal; the damage to the left retina/optic nerve is revealed by weaker bilateral pupil constriction to a flashlight in the left eye compared with the right eye. (*From P Levatin: Arch Ophthalmol 62:768, 1959. Copyright © 1959 American Medical Association. All rights reserved.*)

**syndrome**, although anhidrosis is an inconstant feature. A drop of 1% apraclonidine produces no effect on the normal pupil, but the miotic pupil dilates because of denervation hypersensitivity. Brainstem stroke, carotid dissection, and neoplasm impinging on the sympathetic chain occasionally are identified as the cause of Horner's syndrome, but most cases are idiopathic.

Anisocoria that increases in bright light suggests a parasympathetic palsy. The first concern is an oculomotor nerve paresis. This possibility is excluded if the eye movements are full and the patient has no ptosis or diplopia. Acute pupillary dilation (mydriasis) can result from damage to the ciliary ganglion in the orbit. Common mechanisms are infection (herpes zoster, influenza), trauma (blunt, penetrating, surgical), and ischemia (diabetes, temporal arteritis). After denervation of the iris sphincter, the pupil does not respond well to light, but the response to near is often relatively intact. When the near stimulus is removed, the pupil redilates very slowly compared with the normal pupil, hence the term *tonic pupil*. In *Adie's syndrome*, a tonic pupil is present, sometimes in conjunction with weak or absent tendon reflexes in the lower

extremities. This benign disorder, which occurs predominantly in healthy young women, is assumed to represent a mild dysautonomia. Tonic pupils are also associated with multiple system atrophy, segmental hypohidrosis, diabetes, and amyloidosis. Occasionally, a tonic pupil is discovered incidentally in an otherwise completely normal, asymptomatic individual. The diagnosis is confirmed by placing a drop of dilute (0.125%) pilocarpine into each eye. Denervation hypersensitivity produces pupillary constriction in a tonic pupil, whereas the normal pupil shows no response. Pharmacologic dilatation from accidental or deliberate instillation of anticholinergic (atropine, scopolamine) drops can produce pupillary mydriasis. Gardner's pupil refers to mydriasis induced by exposure to tropane alkaloids, contained in plants such as deadly nightshade, jimsonweed, or angel's trumpet. When an anticholinergic agent is responsible for pupil dilation, 1% pilocarpine causes no constriction.

Both pupils are affected equally by systemic medications. They are small with narcotic use (morphine, oxycodone) and large with anticholinergics (scopolamine). Parasympathetic agents (pilocarpine) used to treat glaucoma produce miosis. In any patient with an unexplained pupillary abnormality, a slit-lamp examination is helpful to exclude surgical trauma to the iris, an occult foreign body, perforating injury, intraocular inflammation, adhesions (synechia), angle-closure glaucoma, and iris sphincter rupture from blunt trauma.

### EYE MOVEMENTS AND ALIGNMENT

Eye movements are tested by asking the patient, with both eyes open, to pursue a small target such as a pen tip into the cardinal fields of gaze. Normal ocular versions are smooth, symmetric, full, and maintained in all directions without nystagmus. Saccades, or quick refixation eye movements, are assessed by having the patient look back and forth between two stationary targets. The eyes should move rapidly and accurately in a single jump to their target. Ocular alignment can be judged by holding a penlight directly in front of the patient at about 1 m. If the eyes are straight, the corneal light reflex will be centered in the middle of each pupil. To test eye alignment more precisely, the cover test is useful. The patient is instructed to look at a small fixation target in the distance. One eye is occluded with a paddle or hand, while the other eye is observed. If the viewing eye shifts position to take up fixation on the target, it was misaligned. If it remains motionless, the first eye is uncovered and the test is repeated on the second eye. If neither eye moves, the eyes are aligned orthotropically. If the eyes are orthotropic in primary gaze but the patient complains of diplopia, the cover test should be performed with the head tilted or turned in whatever direction elicits diplopia. With practice, the examiner can detect an ocular deviation (heterotropia) as small as 1–2° with the cover test. In a patient with vertical diplopia, a small deviation can be difficult to detect and easy to dismiss. The magnitude of the deviation can be measured by placing a prism in front of the misaligned eye to determine the power required to neutralize the fixation shift evoked by covering the other eye. Temporary press-on plastic Fresnel prisms, prism eyeglasses, or eye muscle surgery can be used to restore binocular alignment.

### STEREOPSIS

Stereoaucuity is determined by presenting targets with retinal disparity separately to each eye by using polarized images. The most popular office tests measure a range of thresholds from 800 to 40 s of arc. Normal stereoaucuity is 40 s of arc. If a patient achieves this level of stereoaucuity, one is assured that the eyes are aligned orthotropically and that vision is intact in each eye. Random dot stereograms have no monocular depth cues and provide an excellent screening test for strabismus.

### COLOR VISION

The retina contains three classes of cones, with visual pigments of differing peak spectral sensitivity: red (560 nm), green (530 nm), and blue (430 nm). The red and green cone pigments are encoded on the X chromosome, and the blue cone pigment on chromosome 7. Mutations of the blue cone pigment are exceedingly rare. Mutations of the red and green pigments cause congenital X-linked color blindness in 8% of males. Affected individuals are not truly color blind; rather, they differ

from normal subjects in the way they perceive color and how they combine primary monochromatic lights to match a particular color. Anomalous trichromats have three cone types, but a mutation in one cone pigment (usually red or green) causes a shift in peak spectral sensitivity, altering the proportion of primary colors required to achieve a color match. Dichromats have only two cone types and therefore will accept a color match based on only two primary colors. Anomalous trichromats and dichromats have 6/6 (20/20) visual acuity, but their hue discrimination is impaired. Ishihara color plates can be used to detect red-green color blindness. The test plates contain a hidden number that is visible only to subjects with color confusion from red-green color blindness. Because color blindness is almost exclusively X-linked, it is worthwhile screening only male children.

The Ishihara plates often are used to detect acquired defects in color vision, although they are intended as a screening test for congenital color blindness. Acquired defects in color vision frequently result from disease of the macula or optic nerve. For example, patients with a history of optic neuritis often complain of color desaturation long after their visual acuity has returned to normal. Color blindness also can result from bilateral strokes involving the ventral portion of the occipital lobe (cerebral achromatopsia). Such patients can perceive only shades of gray and also may have difficulty recognizing faces (prosopagnosia) (Chap. 30). Infarcts of the dominant occipital lobe sometimes give rise to color anomia. Affected patients can discriminate colors but cannot name them.

## ■ VISUAL FIELDS

Vision can be impaired by damage to the visual system anywhere from the eyes to the occipital lobes. One can localize the site of the lesion with considerable accuracy by mapping the visual field deficit by finger confrontation and then correlating it with the topographic anatomy of the visual pathway (Fig. 32-3). Quantitative visual field mapping is performed by computer-driven perimeters that present a target of variable intensity at fixed positions in the visual field (Fig. 32-3A). By generating an automated printout of light thresholds, these static perimeters provide a sensitive means of detecting scotomas in the visual field. They are exceedingly useful for serial assessment of visual function in chronic diseases such as glaucoma and pseudotumor cerebri.

The crux of visual field analysis is to decide whether a lesion is before, at, or behind the optic chiasm. If a scotoma is confined to one eye, it must be due to a lesion anterior to the chiasm, involving either the optic nerve or the retina. Retinal lesions produce scotomas that correspond optically to their location in the fundus. For example, a superior-nasal retinal detachment results in an inferior-temporal field cut. Damage to the macula causes a central scotoma (Fig. 32-3B).

Optic nerve disease produces characteristic patterns of visual field loss. Glaucoma selectively destroys axons that enter the superotemporal or inferotemporal poles of the optic disc, resulting in arcuate scotomas shaped like a Turkish scimitar, which emanate from the blind spot and curve around fixation to end flat against the horizontal meridian (Fig. 32-3C). This type of field defect mirrors the arrangement of the nerve fiber layer in the temporal retina. Arcuate or nerve fiber layer scotomas also result from optic neuritis, ischemic optic neuropathy, optic disc drusen, and branch retinal artery or vein occlusion.

Damage to the entire upper or lower pole of the optic disc causes an altitudinal field cut that follows the horizontal meridian (Fig. 32-3D). This pattern of visual field loss is typical of ischemic optic neuropathy but also results from retinal vascular occlusion, advanced glaucoma, and optic neuritis.

About half the fibers in the optic nerve originate from ganglion cells serving the macula. Damage to papillomacular fibers causes a cecocentral scotoma that encompasses the blind spot and macula (Fig. 32-3E). If the damage is irreversible, pallor eventually appears in the temporal portion of the optic disc. Temporal pallor from a cecocentral scotoma may develop in optic neuritis, nutritional optic neuropathy, toxic optic neuropathy, Leber's hereditary optic neuropathy, Kjer's dominant optic atrophy, and compressive optic neuropathy. It is worth mentioning that the temporal side of the optic disc is slightly paler than the nasal side in most normal individuals. Therefore, it sometimes can be difficult

to decide whether the temporal pallor visible on fundus examination represents a pathologic change. Pallor of the nasal rim of the optic disc is a less equivocal sign of optic atrophy.

At the optic chiasm, fibers from nasal ganglion cells decussate into the contralateral optic tract. Crossed fibers are damaged more by compression than are uncrossed fibers. As a result, mass lesions of the sellar region cause a temporal hemianopia in each eye. Tumors anterior to the optic chiasm, such as meningiomas of the tuberculum sella, produce a junctional scotoma characterized by an optic neuropathy in one eye and a superior-temporal field cut in the other eye (Fig. 32-3G). More symmetric compression of the optic chiasm by a pituitary adenoma (see Fig. 380-1), meningioma, craniopharyngioma, glioma, or aneurysm results in a bitemporal hemianopia (Fig. 32-3H). The insidious development of a bitemporal hemianopia often goes unnoticed by the patient and will escape detection by the physician unless each eye is tested separately.

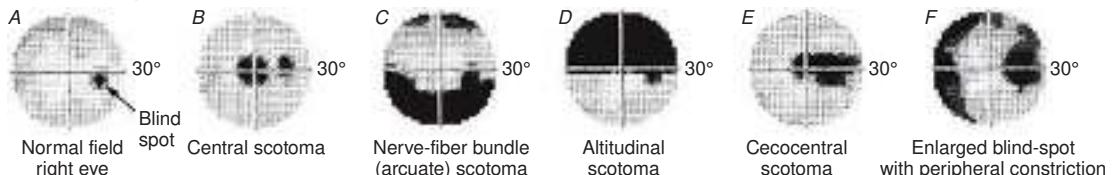
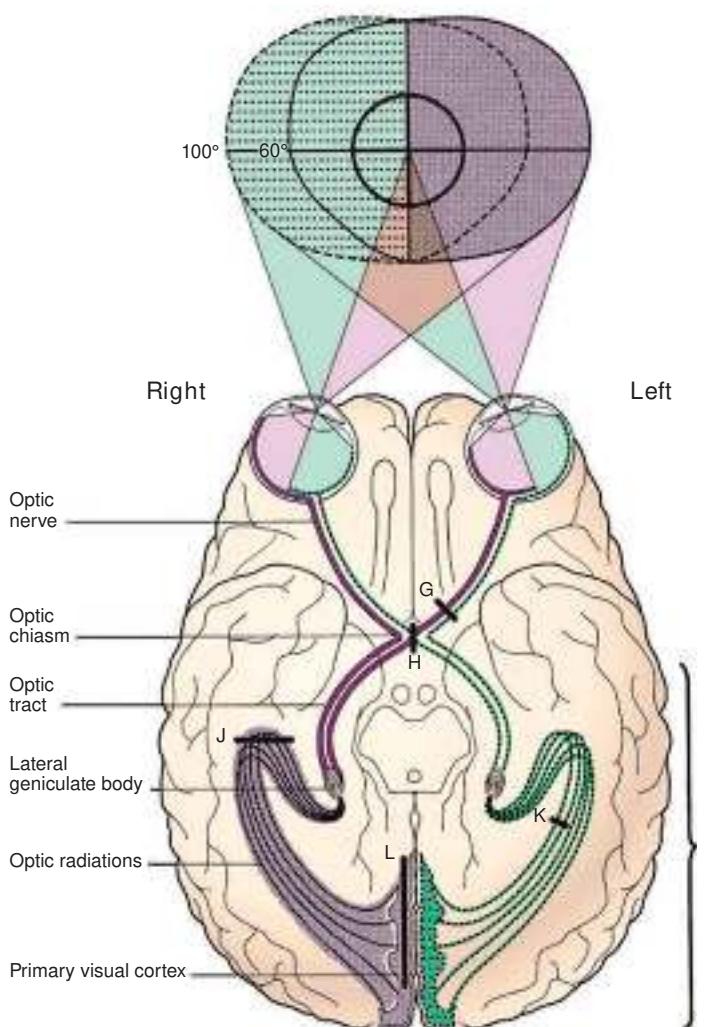
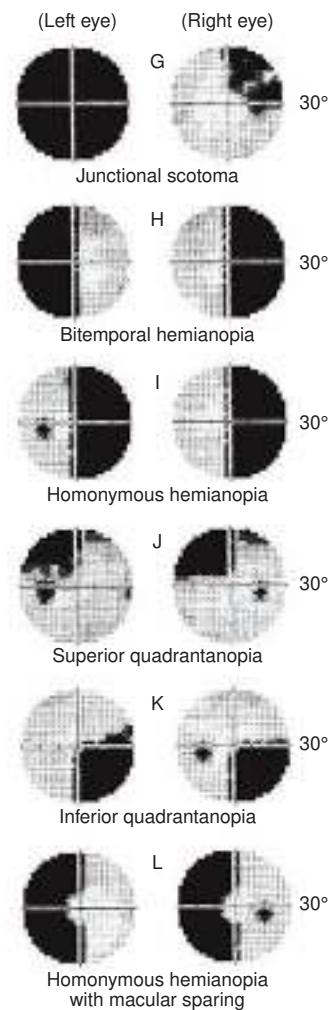
It is difficult to localize a postchiasmal lesion accurately, because injury anywhere in the optic tract, lateral geniculate body, optic radiations, or visual cortex can produce a homonymous hemianopia (i.e., a temporal hemifield defect in the contralateral eye and a matching nasal hemifield defect in the ipsilateral eye) (Fig. 32-3I). A unilateral postchiasmal lesion leaves the visual acuity in each eye unaffected, although the patient may read the letters on only the left or right half of the eye chart. Lesions of the optic radiations tend to cause poorly matched or incongruous field defects in each eye. Damage to the optic radiations in the temporal lobe (Meyer's loop) produces a superior quadrantic homonymous hemianopia (Fig. 32-3J), whereas injury to the optic radiations in the parietal lobe results in an inferior quadrantic homonymous hemianopia (Fig. 32-3K). Lesions of the primary visual cortex give rise to dense, congruous hemianopic field defects. Occlusion of the posterior cerebral artery supplying the occipital lobe is a common cause of total homonymous hemianopia. Some patients have macular sparing, because the central field representation at the tip of the occipital lobe is supplied by collaterals from the middle cerebral artery (Fig. 32-3L). Destruction of both occipital lobes produces cortical blindness. This condition can be distinguished from bilateral prechiasmal visual loss by noting that the pupil responses and optic fundi remain normal.

Partial recovery of homonymous hemianopia has been reported through computer-based rehabilitation therapy. During daily training sessions, patients fixate a central target while visual stimuli are presented within the blind region. The premise of vision restoration programs is that extra stimulation can promote recovery of partially damaged tissue located at the fringe of a cortical lesion. When fixation is controlled rigorously, however, no improvement of the visual fields can be demonstrated. No effective treatment exists for homonymous hemianopia caused by permanent brain damage.

## DISORDERS

### ■ RED OR PAINFUL EYE

**Corneal Abrasions** Corneal abrasions are seen best by placing a drop of fluorescein in the eye and looking with the slit lamp, using a cobalt-blue light. A penlight with a blue filter will suffice if a slit lamp is not available. Damage to the corneal epithelium is revealed by yellow fluorescence of the basement membrane exposed by loss of the overlying epithelium. It is important to check for foreign bodies. To search the conjunctival fornices, the lower lid should be pulled down and the upper lid everted. A foreign body can be removed with a moistened cotton-tipped applicator after a drop of a topical anesthetic such as proparacaine has been placed in the eye. Alternatively, it may be possible to flush the foreign body from the eye by irrigating copiously with saline or artificial tears. If the corneal epithelium has been abraded, antibiotic ointment and a patch may be applied to the eye. A drop of an intermediate-acting cycloplegic such as cyclopentolate hydrochloride 1% helps reduce pain by relaxing the ciliary body. The eye should be reexamined the next day. Minor abrasions may not require patching, antibiotics, or cycloplegia.

**Monocular prechiasmal field defects:****Binocular chiasmal or postchiasmal field defects:**

**FIGURE 32-3** Ventral view of the brain, correlating patterns of visual field loss with the sites of lesions in the visual pathway. The visual fields overlap partially, creating 120° of central binocular field flanked by a 40° monocular crescent on either side. The visual field maps in this figure were done with a computer-driven perimeter (Humphrey Instruments, Carl Zeiss, Inc.). It plots the retinal sensitivity to light in the central 30° by using a gray scale format. Areas of visual field loss are shown in black. The examples of common monocular, prechiasmal field defects are all shown for the right eye. By convention, the visual fields are always recorded with the left eye's field on the left and the right eye's field on the right, just as the patient sees the world.

**Subconjunctival Hemorrhage** This results from rupture of small vessels bridging the potential space between the episclera and the conjunctiva. Blood dissecting into this space can produce a spectacular red eye, but vision is not affected and the hemorrhage resolves without treatment. Subconjunctival hemorrhage is usually spontaneous but can result from blunt trauma, eye rubbing, or vigorous coughing. Occasionally, it is a clue to an underlying bleeding disorder.

**Pinguecula** Pinguecula is a small, raised conjunctival nodule, usually at the nasal limbus. In adults, such lesions are extremely common

and have little significance unless they become inflamed (pingueculitis). They are more apt to occur in workers with outdoor exposure. A *pterygium* resembles a pinguecula but has crossed the limbus to encroach on the corneal surface. Removal is justified when symptoms of irritation or blurring develop, but recurrence is common.

**Blepharitis** This refers to inflammation of the eyelids. The most common form occurs in association with acne rosacea or seborrheic dermatitis. The eyelid margins usually are colonized heavily by staphylococci. Upon close inspection, they appear greasy, ulcerated, and

crusted with scaling debris that clings to the lashes. Treatment consists of strict eyelid hygiene, applying warm compresses, and eyelash scrubs with baby shampoo. An external *hordeolum* (sty) is caused by staphylococcal infection of the superficial accessory glands of Zeis or Moll located in the eyelid margins. An internal hordeolum occurs after suppurative infection of the oil-secreting meibomian glands within the tarsal plate of the eyelid. Topical antibiotics such as bacitracin/polymyxin B ophthalmic ointment can be applied. Systemic antibiotics, usually tetracyclines or azithromycin, sometimes are necessary for treatment of meibomian gland inflammation (meibomitis) or chronic, severe blepharitis. A *chalazion* is a painless, chronic granulomatous inflammation of a meibomian gland that produces a pealike nodule within the eyelid. It can be incised and drained, but injection with glucocorticoids is equally effective. Basal cell, squamous cell, or meibomian gland carcinoma should be suspected with any nonhealing ulcerative lesion of the eyelids.

**Dacryocystitis** An inflammation of the lacrimal drainage system, dacryocystitis can produce epiphora (tearing) and ocular injection. Gentle pressure over the lacrimal sac evokes pain and reflux of mucus or pus from the tear puncta. Dacryocystitis usually occurs after obstruction of the lacrimal system. It is treated with topical and systemic antibiotics, followed by probing, silicone stent intubation, or surgery to reestablish patency. *Entropion* (inversion of the eyelid) or *ectropion* (sagging or eversion of the eyelid) can also lead to epiphora and ocular irritation.

**Conjunctivitis** Conjunctivitis is the most common cause of a red, irritated eye. Pain is minimal, and visual acuity is reduced only slightly. The most common viral etiology is adenovirus infection. It causes a watery discharge, a mild foreign-body sensation, and photophobia. Bacterial infection tends to produce a more mucopurulent exudate. Mild cases of infectious conjunctivitis usually are treated empirically with broad-spectrum topical ocular antibiotics such as sulfacetamide 10%, polymyxin-bacitracin, or a trimethoprim-polymyxin combination. Smears and cultures usually are reserved for severe, resistant, or recurrent cases of conjunctivitis. To prevent contagion, patients should be admonished to wash their hands frequently, not to touch their eyes, and to avoid direct contact with others.

**Allergic Conjunctivitis** This condition is extremely common and often is mistaken for infectious conjunctivitis. Itching, redness, and epiphora are typical. The palpebral conjunctiva may become hypertrophic with giant excrescences called cobblestone papillae. Irritation from contact lenses or any chronic foreign body also can induce formation of cobblestone papillae. *Atopic conjunctivitis* occurs in subjects with atopic dermatitis or asthma. Symptoms caused by allergic conjunctivitis can be alleviated with cold compresses, topical vasoconstrictors, antihistamines (olopatadine), and mast cell stabilizers (cromolyn). Topical glucocorticoid solutions provide dramatic relief of immune-mediated forms of conjunctivitis, but their long-term use is ill advised because of the complications of glaucoma, cataract, and secondary infection. Topical nonsteroidal anti-inflammatory drugs (NSAIDs; ketorolac) are better alternatives.

**Keratoconjunctivitis Sicca** Also known as dry eye, this produces a burning foreign-body sensation, injection, and photophobia. In mild cases, the eye appears surprisingly normal, but tear production measured by wetting of a filter paper (Schirmer strip) is deficient. A variety of systemic drugs, including antihistaminic, anticholinergic, and psychotropic medications, result in dry eye by reducing lacrimal secretion. Disorders that involve the lacrimal gland directly, such as sarcoidosis and Sjögren's syndrome, also cause dry eye. Patients may develop dry eye after radiation therapy if the treatment field includes the orbits. Problems with ocular drying are also common after lesions affecting cranial nerve V or VII. Corneal anesthesia is particularly dangerous, because the absence of a normal blink reflex exposes the cornea to injury without pain to warn the patient. Dry eye is managed by frequent and liberal application of artificial tears and ocular lubricants. In severe cases, the tear puncta can be plugged or cauterized to reduce lacrimal outflow.

**Keratitis** Keratitis is a threat to vision because of the risk of corneal clouding, scarring, and perforation. Worldwide, the two leading causes

of blindness from keratitis are trachoma from chlamydial infection and vitamin A deficiency related to malnutrition. In the United States, contact lenses play a major role in corneal infection and ulceration. They should not be worn by anyone with an active eye infection. In evaluating the cornea, it is important to differentiate between a superficial infection (*keratoconjunctivitis*) and a deeper, more serious ulcerative process. The latter is accompanied by greater visual loss, pain, photophobia, redness, and discharge. Slit-lamp examination shows disruption of the corneal epithelium, a cloudy infiltrate or abscess in the stroma, and an inflammatory cellular reaction in the anterior chamber. In severe cases, pus settles at the bottom of the anterior chamber, giving rise to a hypopyon. Immediate empirical antibiotic therapy should be initiated after corneal scrapings are obtained for Gram's stain, Giemsa stain, potassium hydroxide (KOH) prep, and cultures. Fortified topical antibiotics are most effective, supplemented with subconjunctival antibiotics as required. A fungal etiology should always be considered in a patient with keratitis. Fungal infection is common in warm humid climates, especially after penetration of the cornea by plant or vegetable material. Acanthamoeba keratitis is associated with improper disinfection of contact lenses.

**Herpes Simplex** The *herpesviruses* are a major cause of blindness from keratitis. Most adults in the United States have serum antibodies to herpes simplex, indicating prior viral infection (Chap. 192). Primary ocular infection generally is caused by herpes simplex type 1 rather than type 2. It manifests as a unilateral follicular blepharoconjunctivitis that is easily confused with adenoviral conjunctivitis, unless telltale vesicles are present on the eyelids or conjunctiva. Recurrent ocular infection arises from reactivation of latent herpesvirus. A dendritic pattern of corneal epithelial ulceration revealed by fluorescein staining is pathognomonic for herpes infection but often not present. Involvement of both eyes is extremely rare. Corneal stromal inflammation produces edema, vascularization, and iridocyclitis. Herpes keratitis is treated with cycloplegia and either a topical antiviral (trifluridine, ganciclovir) or an oral antiviral (acyclovir, valacyclovir) agent. Topical glucocorticoids are effective in mitigating corneal scarring but generally are reserved for cases involving stromal damage. Risks include corneal melting, perforation, prolonged infection, and glaucoma.

**Herpes Zoster** Herpes zoster from reactivation of latent varicella (chickenpox) virus causes a dermatomal pattern of painful vesicular dermatitis (Chap. 193). Ocular symptoms can occur after zoster eruption in any branch of the trigeminal nerve but are particularly common when vesicles form on the nose, reflecting nasociliary (V1) nerve involvement (Hutchinson's sign). Herpes zoster ophthalmicus produces corneal dendrites, which can be difficult to distinguish from those seen in herpes simplex. Stromal keratitis, anterior uveitis, raised intraocular pressure, ocular motor nerve palsies, acute retinal necrosis, and posttherapeutic scarring and neuralgia are other common sequelae. Herpes zoster ophthalmicus is treated with antiviral agents and cycloplegics. In severe cases, glucocorticoids may be added to prevent permanent visual loss from corneal scarring. Shingles should be prevented by vaccination of all healthy adults aged 50 years and older.

**Episcleritis** This is an inflammation of the episclera, a thin layer of connective tissue between the conjunctiva and the sclera. Episcleritis resembles conjunctivitis, but it is a more localized process and discharge is absent. Most cases of episcleritis are idiopathic, but some occur in the setting of an autoimmune disease. *Scleritis* refers to a deeper, more severe inflammatory process that frequently is associated with a connective tissue disease such as rheumatoid arthritis, lupus erythematosus, polyarteritis nodosa, granulomatosis with polyangiitis, or relapsing polychondritis. The inflammation and thickening of the sclera can be diffuse or nodular. In anterior forms of scleritis, the globe assumes a violet hue and the patient complains of severe ocular tenderness and pain. With posterior scleritis, the pain and redness may be less marked, but there is often proptosis, choroidal effusion, reduced motility, and visual loss. Episcleritis and scleritis should be treated with NSAIDs. If these agents fail, topical or even systemic glucocorticoid therapy may be necessary, especially if an underlying autoimmune process is active.

**Anterior Uveitis** Involving the anterior structures of the eye, uveitis was previously called *iritis* or *iridocyclitis*. The diagnosis requires slit-lamp examination to identify inflammatory cells floating in the aqueous humor or deposited on the corneal endothelium (keratic precipitates). Anterior uveitis develops in sarcoidosis, ankylosing spondylitis, juvenile idiopathic arthritis, inflammatory bowel disease, psoriasis, reactive arthritis, and Behcet's disease. It also is associated with herpes infections, syphilis, Lyme disease, onchocerciasis, tuberculosis, and leprosy. Although anterior uveitis can occur in conjunction with many diseases, no cause is found to explain the majority of cases. For this reason, laboratory evaluation usually is reserved for patients with recurrent or severe anterior uveitis. Treatment is aimed at reducing inflammation and scarring by judicious use of topical glucocorticoids. Dilatation of the pupil reduces pain and prevents the formation of synechiae.

**Posterior Uveitis** This diagnosis is made by observing inflammation of the vitreous, retina, or choroid on fundus examination. It is more likely than anterior uveitis to be associated with an identifiable systemic disease. Some patients have panuveitis, or inflammation of both the anterior and posterior segments of the eye. Posterior uveitis is a manifestation of autoimmune diseases such as sarcoidosis, Behcet's disease, Vogt-Koyanagi-Harada syndrome, and inflammatory bowel disease. It also accompanies diseases such as toxoplasmosis, onchocerciasis, cysticercosis, coccidioidomycosis, toxocariasis, and histoplasmosis; infections caused by organisms such as *Candida*, *Pneumocystis carinii*, *Cryptococcus*, *Aspergillus*, herpes, and cytomegalovirus (see Fig. 195-1); and other diseases, such as syphilis, Lyme disease, tuberculosis, cat-scratch disease, Whipple's disease, and brucellosis. In multiple sclerosis, chronic inflammatory changes can develop in the extreme periphery of the retina (pars planitis or intermediate uveitis). Glucocorticoids have been the mainstay of treatment for noninfectious uveitis. Biologic agents that target proinflammatory cytokines, such as the tumor necrosis factor alpha (TNF- $\alpha$ ) inhibitor adalimumab, are effective at preventing vision loss in chronic uveitis.

**Acute Angle-Closure Glaucoma** This is an unusual but frequently misdiagnosed cause of a red, painful eye. Asian populations have a particularly high risk of angle-closure glaucoma. Susceptible eyes have a shallow anterior chamber because the eye has either a short axial length (hyperopia) or a lens enlarged by the gradual development of cataract. When the pupil becomes mid-dilated, the peripheral iris blocks aqueous outflow via the anterior chamber angle and the intraocular pressure rises abruptly, producing pain, injection, corneal edema, obscurations, and blurred vision. In some patients, ocular symptoms are overshadowed by nausea, vomiting, or headache, prompting a fruitless workup for abdominal or neurologic disease. The diagnosis is made by measuring the intraocular pressure during an acute attack or by performing gonioscopy, a procedure that allows one to observe a narrow chamber angle with a mirrored contact lens. Acute angle closure is treated with acetazolamide (PO or IV), topical beta blockers, prostaglandin analogues,  $\alpha_2$ -adrenergic agonists, and pilocarpine to induce miosis. If these measures fail, a laser can be used to create a hole in the peripheral iris to relieve pupillary block. Many physicians are reluctant to dilate patients routinely for fundus examination because they fear precipitating an angle-closure glaucoma. The risk is actually remote and more than outweighed by the potential benefit to patients of discovering a hidden fundus lesion visible only through a fully dilated pupil. Moreover, a single attack of angle closure after pharmacologic dilatation rarely causes any permanent damage to the eye and serves as an inadvertent provocative test to identify patients with narrow angles who would benefit from prophylactic laser iridectomy.

**Endophthalmitis** This results from bacterial, viral, fungal, or parasitic infection of the internal structures of the eye. It usually is acquired by hematogenous seeding from a remote site. Chronically ill, diabetic, or immunosuppressed patients, especially those with a history of indwelling IV catheters or positive blood cultures, are at greatest risk for endogenous endophthalmitis. Although most patients have ocular pain and injection, visual loss is sometimes the only symptom. Septic

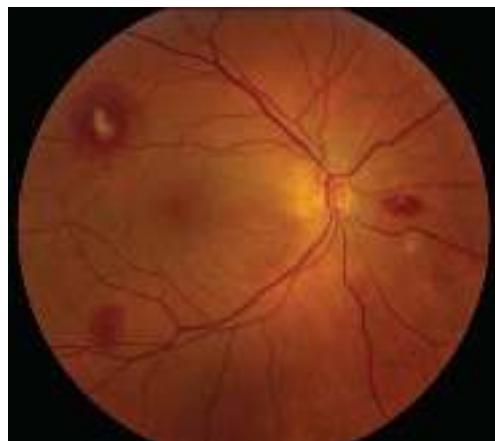


FIGURE 32-4 Roth's spot, cotton-wool spot, and retinal hemorrhages in a 48-year-old liver transplant patient with candidemia from immunosuppression.

emboli from a diseased heart valve or a dental abscess that lodge in the retinal circulation can give rise to endophthalmitis. White-centered retinal hemorrhages known as Roth's spots (Fig. 32-4) are considered pathognomonic for subacute bacterial endocarditis, but they also appear in leukemia, diabetes, and many other conditions. Endophthalmitis occurs as a complication of ocular surgery, especially glaucoma filtering, occasionally months or even years after the operation. An occult penetrating foreign body or unrecognized trauma to the globe should be considered in any patient with unexplained intraocular infection or inflammation.

## ■ TRANSIENT OR SUDDEN VISUAL LOSS

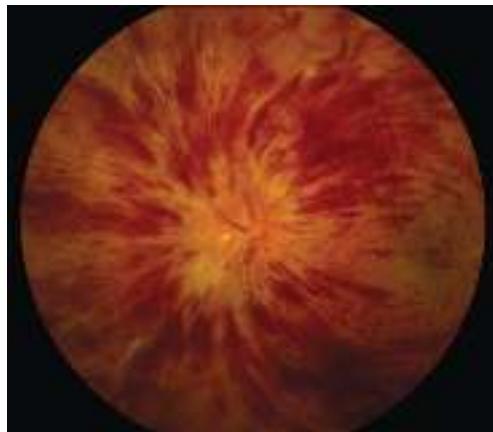
**Amaurosis Fugax** This term refers to a transient ischemic attack of the retina (Chap. 427). Because neural tissue has a high rate of metabolism, interruption of blood flow to the retina for more than a few seconds results in *transient monocular blindness*, a term used interchangeably with amaurosis fugax. Patients describe a rapid fading of vision like a curtain descending, sometimes affecting only a portion of the visual field. Amaurosis fugax usually results from an embolus that becomes stuck within a retinal arteriole (Fig. 32-5). If the embolus breaks up or passes, flow is restored and vision returns quickly to normal without permanent damage. With prolonged interruption of blood flow, the inner retina suffers infarction. Ophthalmoscopy reveals zones of whitened, edematous retina following the distribution of branch retinal arterioles. Complete occlusion of the central retinal artery



FIGURE 32-5 Hollenhorst plaque lodged at the bifurcation of a retinal arteriole proves that a patient is shedding emboli from the carotid artery, great vessels, or heart.



**FIGURE 32-6** Central retinal artery occlusion in a 78-year-old man reducing acuity to counting fingers in the right eye. Note the splinter hemorrhage on the optic disc and the slightly milky appearance to the macula with a cherry-red fovea.



**FIGURE 32-8** Central retinal vein occlusion can produce massive retinal hemorrhage (“blood and thunder”), ischemia, and vision loss.

produces arrest of blood flow and a milky retina with a cherry-red fovea (Fig. 32-6). Emboli are composed of cholesterol (Hollenhorst plaque), calcium, or platelet-fibrin debris. The most common source is an atherosclerotic plaque in the carotid artery or aorta, although emboli also can arise from the heart, especially in patients with diseased valves, atrial fibrillation, or wall motion abnormalities.

In rare instances, amaurosis fugax results from low central retinal artery perfusion pressure in a patient with a critical stenosis of the ipsilateral carotid artery and poor collateral flow via the circle of Willis. In this situation, amaurosis fugax develops when there is a dip in systemic blood pressure or a slight worsening of the carotid stenosis. Sometimes there is contralateral motor or sensory loss, indicating concomitant hemispheric cerebral ischemia.

Retinal arterial occlusion also occurs rarely in association with retinal migraine, lupus erythematosus, anticardiolipin antibodies, anticoagulant deficiency states (protein S, protein C, and antithrombin deficiency), Susac's syndrome, pregnancy, IV drug abuse, blood dyscrasias, dysproteinemias, and temporal arteritis.

Marked *systemic hypertension* causes sclerosis of retinal arterioles, splinter hemorrhages, focal infarcts of the nerve fiber layer (cotton-wool spots), and leakage of lipid and fluid (hard exudate) into the macula (Fig. 32-7). In hypertensive crisis, sudden visual loss can result from ischemia induced by vasoconstriction of retinal arterioles. In addition, visual loss can occur from ischemic optic disc swelling. Patients with acute hypertensive

retinopathy should be treated by lowering the blood pressure. However, the blood pressure should not be reduced precipitously, because there is a danger of optic disc infarction from sudden hypoperfusion.

Impending branch or *central retinal vein occlusion* can produce prolonged visual obscurations that resemble those described by patients with amaurosis fugax. The veins appear engorged and phlebitic, with numerous retinal hemorrhages (Fig. 32-8). In some patients, venous blood flow recovers spontaneously, whereas others evolve a frank obstruction with extensive retinal bleeding (“blood and thunder” appearance), infarction, and visual loss. Venous occlusion of the retina is often idiopathic, but hypertension, diabetes, and glaucoma are prominent risk factors. Polycythemia, thrombocytopenia, or other factors leading to an underlying hypercoagulable state should be corrected; aspirin treatment may be beneficial.

**Anterior Ischemic Optic Neuropathy (AION)** This is caused by insufficient blood flow through the posterior ciliary arteries that supply the optic disc. It produces painless monocular visual loss that is sudden in onset, followed sometimes by stuttering progression. The optic disc is edematous and usually bordered by nerve fiber layer splinter hemorrhages (Fig. 32-9). AION is divided into two forms: arteritic and nonarteritic. The nonarteritic form is most common. No specific cause is known, although diabetes, renal failure, and hypertension are common risk factors. Case reports have linked erectile dysfunction



**FIGURE 32-7** Hypertensive retinopathy with blurred optic disc, scattered hemorrhages, cotton-wool spots (nerve fiber layer infarcts), and foveal exudate in a 62-year-old man with chronic renal failure and a systolic blood pressure of 220.



**FIGURE 32-9** Anterior ischemic optic neuropathy from temporal arteritis in a 64-year-old woman with acute disc swelling, splinter hemorrhages, visual loss, and an erythrocyte sedimentation rate of 60 mm/h.

drugs to AION, but a causal association is doubtful. Evidence is strong that a crowded disc architecture and small optic cup predispose to the development of nonarteritic AION. In patients with such a “disc-at-risk,” the advent of AION in one eye increases the likelihood of the same event occurring in the other eye. No treatment is available for nonarteritic AION; glucocorticoids should not be prescribed.

About 5% of patients, especially Caucasian females aged >60, have the arteritic form of AION in conjunction with giant cell (temporal) arteritis (Chap. 363). It is urgent to recognize arteritic AION so that high doses of glucocorticoids can be instituted immediately to prevent blindness in the second eye. Tocilizumab, a monoclonal antibody against interleukin 6 receptor, is an effective alternative to glucocorticoids for sustained suppression of symptoms of giant cell arteritis. Symptoms of polymyalgia rheumatica may be present; the sedimentation rate and C-reactive protein level are usually elevated. In a patient with visual loss from suspected arteritic AION, temporal artery biopsy is mandatory to confirm the diagnosis. Administer glucocorticoids immediately, without waiting for the biopsy to be completed. The biopsy should be obtained as soon as practical, because prolonged glucocorticoid treatment can hide inflammatory changes. It is important to harvest an arterial segment at least 3 cm long and to examine a sufficient number of tissue sections. The histologic features of granulomatous inflammation are often quite subtle in temporal artery specimens. If the biopsy is declared negative by an experienced pathologist, the diagnosis of arteritic AION is highly unlikely and glucocorticoids should usually be discontinued.

**Posterior Ischemic Optic Neuropathy** This is an uncommon cause of acute visual loss, induced by the combination of severe anemia and hypotension. Cases have been reported after major blood loss during surgery (especially in patients undergoing cardiac or lumbar spine operations), shock, gastrointestinal bleeding, and renal dialysis. The fundus usually appears normal, although optic disc swelling develops if the process extends anteriorly far enough to reach the globe. Vision can be salvaged in some patients by immediate blood transfusion and reversal of hypotension.

**Optic Neuritis** This is a common inflammatory disease of the optic nerve. In the Optic Neuritis Treatment Trial (ONTT), the mean age of patients was 32 years, 77% were female, 92% had ocular pain (especially with eye movements), and 35% had optic disc swelling. In most patients, the demyelinating event was retrobulbar and the ocular fundus appeared normal on initial examination (Fig. 32-10), although optic disc pallor slowly developed over subsequent months.

Virtually all patients experience a gradual recovery of vision after a single episode of optic neuritis, even without treatment. This rule is so reliable that failure of vision to improve after a first attack of optic neuritis casts doubt on the original diagnosis. Treatment with high-dose

IV methylprednisolone (250 mg every 6 h for 3 days) followed by oral prednisone (1 mg/kg per day for 11 days) makes no difference in ultimate acuity 6 months after the attack, but the recovery of visual function occurs more rapidly. Therefore, when visual loss is severe (worse than 20/100), IV followed by PO glucocorticoids are often recommended.

For some patients, optic neuritis remains an isolated event. However, the ONTT showed that the 15-year cumulative probability of developing clinically definite multiple sclerosis after optic neuritis is 50%. A brain magnetic resonance (MR) scan is advisable in every patient with a first attack of optic neuritis. If two or more plaques are present on initial imaging, treatment should be considered to prevent the development of additional demyelinating lesions (Chap. 444).

A particularly severe optic neuritis, often involving a long segment of nerve, occurs in neuromyelitis optica (NMO); it may be bilateral and associated with myelitis. NMO can occur as a primary disorder, in the setting of systemic autoimmune disease, or rarely, as a paraneoplastic condition. Detection of circulating antibodies directed against aquaporin-4 or myelin oligodendrocyte glycoprotein (MOG) is diagnostic. Treatment for acute episodes consists of glucocorticoids followed by satalizumab, eculizumab, or inebilizumab to prevent relapse. **Neuromyelitis optica is discussed in detail in Chap. 445.**

### ■ LEBER'S HEREDITARY OPTIC NEUROPATHY

This disease usually affects young men, causing progressive, painless, severe central visual loss in one eye, followed weeks to years later by the same process in the other eye. Acutely, the optic disc appears mildly plethoric with surface capillary telangiectasias but no vascular leakage on fluorescein angiography. Eventually, optic atrophy ensues. Leber's optic neuropathy is caused by a point mutation at codon 11778 in the mitochondrial gene encoding nicotinamide adenine dinucleotide dehydrogenase (NADH) subunit 4. Additional mutations responsible for the disease have been identified, most in mitochondrial genes that encode proteins involved in electron transport. Mitochondrial mutations that cause Leber's neuropathy are maternally inherited by all children, but for unknown reasons, only 10% of cases occur in females. Clinical trials of gene therapy for this condition have been unsuccessful.

**Toxic Optic Neuropathy** This can result in acute visual loss with bilateral optic disc swelling and cecocentral scotomas. Cases have been reported from exposure to ethambutol, methyl alcohol (moonshine), ethylene glycol (antifreeze), or carbon monoxide. In toxic optic neuropathy, visual loss also can develop gradually and produce optic atrophy (Fig. 32-11) without a phase of acute optic disc edema. Many agents have been implicated in toxic optic neuropathy, but evidence supporting the association is often weak. The following is a partial list of potential offending drugs or toxins: disulfiram, ethchlorvynol, chloramphenicol,



FIGURE 32-10 Retrobulbar optic neuritis is characterized by a normal fundus examination initially, hence the rubric “the doctor sees nothing, and the patient sees nothing.” Optic atrophy develops after severe or repeated attacks.

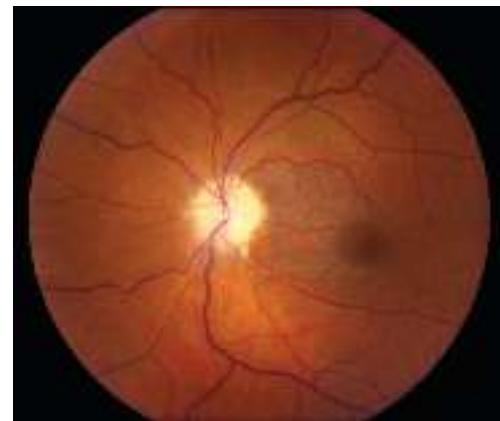
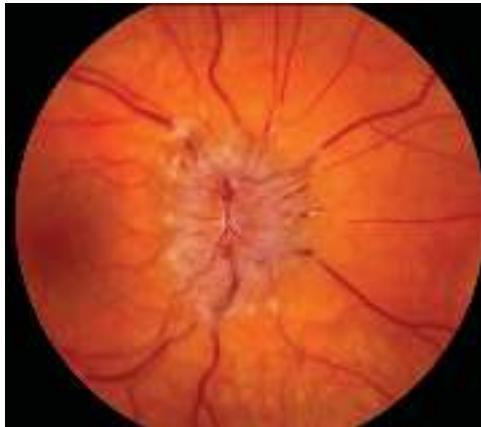


FIGURE 32-11 Optic atrophy is not a specific diagnosis but refers to the combination of optic disc pallor, arteriolar narrowing, and nerve fiber layer destruction produced by a host of eye diseases, especially optic neuropathies.

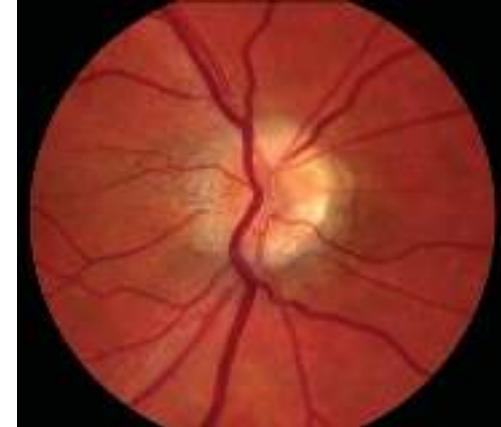


**FIGURE 32-12** Papilledema means optic disc edema from raised intracranial pressure. This young woman developed acute papilledema, with hemorrhages and cotton-wool spots, as a rare side effect of treatment with tetracycline for acne.

amiodarone, monoclonal anti-CD3 antibody, ciprofloxacin, digitalis, streptomycin, lead, arsenic, thallium, -penicillamine, isoniazid, emetine, and sulfonamides. Metallosis (chromium, cobalt, nickel) from hip implant failure is a rare cause of toxic optic neuropathy. Deficiency states induced by starvation, malabsorption, alcoholism, or gastric bypass can lead to insidious visual loss. Thiamine, vitamin B<sub>12</sub>, and folate levels should be checked in any patient with unexplained bilateral central scotomas and optic pallor.

**Papilledema** This connotes bilateral optic disc swelling from raised intracranial pressure (Fig. 32-12). Headache is a common but not invariable accompaniment. All other forms of optic disc swelling (e.g., from optic neuritis or ischemic optic neuropathy) should be called “optic disc edema.” This convention is arbitrary but serves to avoid confusion. Often it is difficult to differentiate papilledema from other forms of optic disc edema by fundus examination alone. Transient visual obscurations are a classic symptom of papilledema. They occur in only one eye or simultaneously in both eyes. They usually last seconds but can persist longer. Obscurations follow abrupt shifts in posture or happen spontaneously. When obscurations are prolonged or spontaneous, the papilledema is more threatening. Visual acuity is not affected by papilledema unless the papilledema is severe, long-standing, or accompanied by macular edema and hemorrhage. Visual field testing shows enlarged blind spots and peripheral constriction (Fig. 32-3F). With unremitting papilledema, peripheral visual field loss progresses in an insidious fashion while the optic nerve develops atrophy. In this setting, reduction of optic disc swelling is an ominous sign of a dying nerve rather than an encouraging indication of resolving papilledema.

Evaluation of papilledema requires neuroimaging to exclude an intracranial lesion. Noninvasive MR vascular imaging may be useful in selected cases to search for a dural venous sinus thrombosis or an arteriovenous shunt. If neuroradiologic studies are negative, the subarachnoid opening pressure should be measured in the lateral decubitus position by lumbar puncture. Inaccurate pressure readings are a common pitfall. An elevated pressure, with normal cerebrospinal fluid, points by exclusion to the diagnosis of *pseudotumor cerebri* (idiopathic intracranial hypertension). Almost all patients are female, and most are obese. Treatment with a carbonic anhydrase inhibitor such as acetazolamide lowers intracranial pressure by reducing the production of cerebrospinal fluid and improves the visual fields. Weight reduction is vital; bariatric surgery should be considered in patients who cannot lose weight by diet control. If vision loss is severe or progressive, a shunt should be performed without delay to prevent blindness. Placement of a stent across the junction of the transverse and sigmoid dural sinuses, where stenosis is usually present, has emerged as a new treatment option. Optic nerve sheath fenestration is a less effective approach and



**FIGURE 32-13** Optic disc drusen are calcified, mulberry-like deposits of unknown etiology within the optic disc, giving rise to “pseudopapilledema.”

does not address other neurologic symptoms. Occasionally, fulminant papilledema produces rapid onset of blindness. In such patients, emergency surgery should be performed to install a shunt.

**Optic Disc Drusen** These are refractile, glittering particles within the substance of the optic nerve head (Fig. 32-13). They are unrelated to drusen of the retina, which occur in age-related macular degeneration. Optic disc drusen are most common in people of northern European descent. Their diagnosis is obvious when they are visible on the surface of the optic disc. However, in many patients, they are hidden beneath the surface, producing pseudopapilledema. It is important to recognize optic disc drusen to avoid an unnecessary evaluation for papilledema. When optic disc drusen are buried, B-ultrasound is the most sensitive way to detect them. They appear hyperechoic because they contain calcium. They are also visible on computed tomography (CT) or optical coherence tomography (OCT), a technique for acquiring cross-section images of the retina. In most patients, optic disc drusen are an incidental, innocuous finding, but they can produce visual obscurations. On perimetry, they give rise to enlarged blind spots and arcuate scotomas from damage to the optic disc. With increasing age, drusen tend to become more exposed on the disc surface as optic atrophy develops. Hemorrhage, choroidal neovascular membrane, and AION are more likely to occur in patients with optic disc drusen. No treatment is available.

**Vitreous Degeneration** This occurs in all individuals with advancing age, leading to visual symptoms. Opacities develop in the vitreous, casting annoying shadows on the retina. As the eye moves, these distracting “floaters” move synchronously, with a slight lag caused by inertia of the vitreous gel. Vitreous traction on the retina causes mechanical stimulation, resulting in perception of flashing lights. This photopsia is brief and is confined to one eye, in contrast to the bilateral, prolonged scintillations of cortical migraine. Contraction of the vitreous can result in sudden separation from the retina, heralded by an alarming shower of floaters and photopsia. This process, known as *vitreous detachment*, is a common involutional event in the elderly. It is not harmful unless it damages the retina. A careful examination of the dilated fundus is important in any patient complaining of floaters or photopsia to search for peripheral tears or holes. If such a lesion is found, laser application can forestall a retinal detachment. Occasionally a tear ruptures a retinal blood vessel, causing vitreous hemorrhage and sudden loss of vision. On attempted ophthalmoscopy the fundus is hidden by a dark haze of blood. Ultrasound is required to examine the interior of the eye for a retinal tear or detachment. If the hemorrhage does not resolve spontaneously, the vitreous can be removed surgically. Vitreous hemorrhage also results from the fragile neovascular vessels that proliferate on the surface of the retina in diabetes, sickle cell anemia, and other ischemic ocular diseases.



**FIGURE 32-14** Retinal detachment appears as an elevated sheet of retinal tissue with folds. In this patient, the fovea was spared, so acuity was normal, but an inferior detachment produced a superior scotoma.

**Retinal Detachment** This produces symptoms of floaters, flashing lights, and a scotoma in the peripheral visual field corresponding to the detachment (Fig. 32-14). If the detachment includes the fovea, there is an afferent pupil defect and the visual acuity is reduced. In most eyes, retinal detachment starts with a hole, flap, or tear in the peripheral retina (rhegmatogenous retinal detachment). Patients with peripheral retinal thinning (lattice degeneration) are particularly vulnerable to this process. Once a break has developed in the retina, liquefied vitreous is free to enter the subretinal space, separating the retina from the pigment epithelium. The combination of vitreous traction on the retinal surface and passage of fluid behind the retina leads inexorably to detachment. Patients with a history of myopia, trauma, or prior cataract extraction are at greatest risk for retinal detachment. The diagnosis is confirmed by ophthalmoscopic examination of the dilated eye.

**Classic Migraine** (See also Chap. 430) This usually occurs with a visual aura lasting about 20 min. In a typical attack, a small central disturbance in the field of vision marches toward the periphery, leaving a transient scotoma in its wake. The expanding border of migraine scotoma has a scintillating, dancing, or zigzag edge, resembling the bastions of a fortified city, hence the term *fortification spectra*. Patients' descriptions of fortification spectra vary widely and can be confused with amaurosis fugax. Migraine patterns usually last longer and are perceived in both eyes, whereas amaurosis fugax is briefer and occurs in only one eye. Migraine phenomena also remain visible in the dark or with the eyes closed. Generally, they are confined to either the right or the left visual hemifield, but sometimes, both fields are involved simultaneously. Patients often have a long history of stereotypic attacks. After the visual symptoms recede, headache develops in most patients.

**Transient Ischemic Attacks** Vertebrobasilar insufficiency may result in acute homonymous visual symptoms. Many patients mistakenly describe symptoms in the left or right eye when in fact the symptoms are occurring in the left or right hemifield of both eyes. Interruption of blood supply to the visual cortex causes a sudden fogging or graying of vision, occasionally with flashing lights or other positive phenomena that mimic migraine. Cortical ischemic attacks are briefer in duration than migraine, occur in older patients, and are not followed by headache. There may be associated signs of brainstem ischemia, such as diplopia, vertigo, numbness, weakness, and dysarthria.

**Stroke** Stroke occurs when interruption of blood supply from the posterior cerebral artery to the visual cortex is prolonged. The only finding on examination is a homonymous visual field defect that stops abruptly at the vertical meridian. Occipital lobe stroke usually is due to thrombotic occlusion of the vertebrobasilar system, embolus, or dissection. Lobar hemorrhage, tumor, abscess, and arteriovenous malformation are other common causes of hemianopic cortical visual loss.

**Factitious (Functional, Nonorganic) Visual Loss** This is claimed by hysterics or malingeringers. The latter account for the vast majority, seeking sympathy, special treatment, or financial gain by feigning loss of sight. The diagnosis is suspected when the history is atypical, physical findings are lacking or contradictory, inconsistencies emerge on testing, and a secondary motive can be identified. In our litigious society, the fraudulent pursuit of recompense has spawned an epidemic of factitious visual loss.

## ■ CHRONIC VISUAL LOSS

**Cataract** Cataract is a clouding of the lens sufficient to reduce vision. Most cataracts develop slowly as a result of aging, leading to gradual impairment of vision. The formation of cataract occurs more rapidly in patients with a history of uveitis, diabetes mellitus, ocular trauma, or vitrectomy. Cataracts are acquired in a variety of genetic diseases, such as myotonic dystrophy, neurofibromatosis type 2, and galactosemia. Radiation therapy and glucocorticoid treatment can induce cataract as a side effect. The cataracts associated with radiation or glucocorticoids have a typical posterior subcapsular location. Cataract can be detected by noting an impaired red reflex when viewing light reflected from the fundus with an ophthalmoscope or by examining the dilated eye with the slit lamp.

The only treatment for cataract is surgical extraction of the opacified lens. Millions of cataract operations are performed each year around the globe. The operation generally is done under local anesthesia on an outpatient basis. A plastic or silicone intraocular lens is placed within the empty lens capsule in the posterior chamber, substituting for the natural lens and leading to rapid recovery of sight. More than 95% of patients who undergo cataract extraction can expect an improvement in vision. In some patients, the lens capsule remaining in the eye after cataract extraction eventually turns cloudy, causing secondary loss of vision. A small opening, called a posterior capsulotomy, is made in the lens capsule with a laser to restore clarity.

**Glaucoma** Glaucoma is a slowly progressive, insidious optic neuropathy that usually is associated with chronic elevation of intraocular pressure. After cataract, it is the most common cause of blindness in the world. It is especially prevalent in people of African descent. The mechanism by which raised intraocular pressure injures the optic nerve is not understood. Axons entering the inferotemporal and superotemporal aspects of the optic disc are damaged first, producing typical nerve fiber bundle defects called arcuate scotomas. As fibers are destroyed, the neural rim of the optic disc shrinks and the physiologic cup within the optic disc enlarges (Fig. 32-15). This process is referred to as pathologic "cupping." The cup-to-disc diameter is expressed as a fraction (e.g., 0.2). The cup-to-disc ratio ranges widely in normal individuals, making it difficult to diagnose glaucoma reliably simply by



**FIGURE 32-15** Glaucoma results in "cupping" as the neural rim is destroyed and the central cup becomes enlarged and excavated. The cup-to-disc ratio is about 0.8 in this patient.

observing an unusually large or deep optic cup. Careful documentation of serial examinations is helpful. In a patient with physiologic cupping, the large cup remains stable, whereas in a patient with glaucoma, it expands relentlessly over the years. Observation of progressive cupping and detection of an arcuate scotoma or a nasal step on computerized visual field testing is sufficient to establish the diagnosis of glaucoma. OCT reveals corresponding loss of fibers along the arcuate pathways in the nerve fiber layer.

The preponderance of patients with glaucoma have open anterior chamber angles. In most affected individuals, the intraocular pressure is elevated. The cause of elevated intraocular pressure is unknown, but it is associated with gene mutations in the heritable forms. Surprisingly, a third of patients with open-angle glaucoma have an intraocular pressure within the normal range of 10–20 mmHg. For this so-called normal or low-tension form of glaucoma, high myopia is a risk factor.

Chronic angle-closure glaucoma and chronic open-angle glaucoma are usually asymptomatic. Only acute angle-closure glaucoma causes a red or painful eye, from abrupt elevation of intraocular pressure. In all forms of glaucoma, foveal acuity is spared until end-stage disease is reached. For these reasons, severe and irreversible damage can occur before either the patient or the physician recognizes the diagnosis. Screening of patients for glaucoma by noting the cup-to-disc ratio on ophthalmoscopy and by measuring intraocular pressure is vital. Glaucoma is treated with topical adrenergic agonists, cholinergic agonists, beta blockers, prostaglandin analogues, and carbonic anhydrase inhibitors. Occasionally, systemic absorption of beta blocker from eyedrops can be sufficient to cause side effects of bradycardia, hypotension, heart block, bronchospasm, or depression. Laser treatment of the trabecular meshwork in the anterior chamber angle improves aqueous outflow from the eye. If medical or laser treatments fail to halt optic nerve damage from glaucoma, a filter must be constructed surgically (trabeculectomy) or a drainage device placed to release aqueous from the eye in a controlled fashion.

**Macular Degeneration** This is a major cause of gradual, painless, bilateral central visual loss in the elderly. It occurs in a nonexudative (dry) form and an exudative (wet) form. Inflammation may be important in both forms of macular degeneration; susceptibility is associated with variants in the gene for complement factor H, an inhibitor of the alternative complement pathway. The nonexudative process begins with the accumulation of extracellular deposits called drusen underneath the retinal pigment epithelium. On ophthalmoscopy, they are pleomorphic but generally appear as small discrete yellow lesions clustered in the macula (Fig. 32-16). With time, they become larger, more numerous, and confluent. The retinal pigment epithelium becomes focally detached and atrophic, causing visual loss by interfering with photoreceptor function. Treatment with vitamins C and E, beta-carotene, and zinc may retard dry macular degeneration.

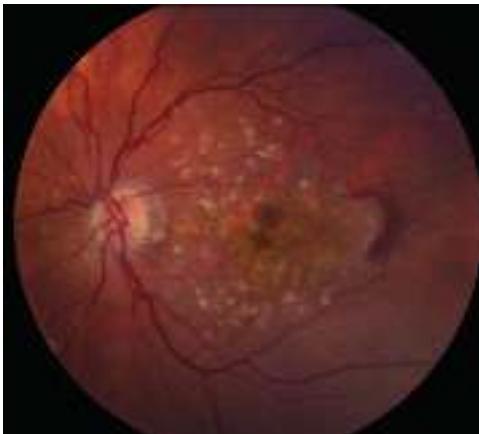


FIGURE 32-16 Age-related macular degeneration consisting of scattered yellow drusen in the macula (dry form) and a crescent of fresh hemorrhage temporal to the fovea from a subretinal neovascular membrane (wet form).

Exudative macular degeneration, which develops in only a minority of patients, occurs when neovascular vessels from the choroid grow through defects in Bruch's membrane and proliferate underneath the retinal pigment epithelium or the retina. Leakage from these vessels produces elevation of the retina, with distortion (metamorphopsia) and blurring of vision. Although the onset of these symptoms is usually gradual, bleeding from a subretinal choroidal neovascular membrane sometimes causes acute visual loss. Neovascular membranes can be difficult to see on fundus examination because they are located beneath the retina. Fluorescein angiography and OCT are extremely useful for their detection. Major or repeated hemorrhage under the retina from neovascular membranes results in fibrosis, development of a round (disciform) macular scar, and permanent loss of central vision.

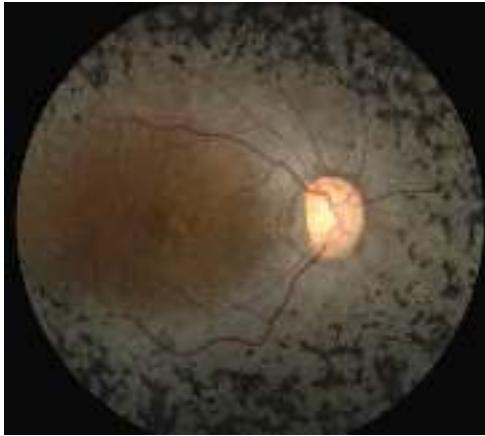
A major therapeutic advance has occurred with the discovery that exudative macular degeneration can be treated with intraocular injection of antagonists to vascular endothelial growth factor. Bevacizumab, ranibizumab, afibercept, or brolucizumab is administered by direct injection into the vitreous cavity, beginning on a monthly basis. These antibodies cause the regression of neovascular membranes by blocking the action of vascular endothelial growth factor, thereby improving visual acuity.

**Central Serous Chorioretinopathy** This primarily affects males between the ages of 20 and 50 years. Leakage of serous fluid from the choroid causes small, localized detachment of the retinal pigment epithelium and the neurosensory retina. These detachments produce acute or chronic symptoms of metamorphopsia and blurred vision when the macula is involved. They are difficult to visualize with a direct ophthalmoscope because the detached retina is transparent and only slightly elevated. OCT shows fluid beneath the retina, and fluorescein angiography shows dye streaming into the subretinal space. The cause of central serous chorioretinopathy is unknown. Symptoms may resolve spontaneously if the retina reattaches, but recurrent detachment is common. Laser photocoagulation has benefited some patients with this condition.

**Diabetic Retinopathy** A rare disease until 1921, when the discovery of insulin resulted in a dramatic improvement in life expectancy for patients with diabetes mellitus, diabetic retinopathy is now a leading cause of blindness in the United States. The retinopathy takes years to develop but eventually appears in nearly all cases. Regular surveillance of the dilated fundus is crucial for any patient with diabetes. In advanced diabetic retinopathy, the proliferation of neovascular vessels leads to blindness from vitreous hemorrhage, retinal detachment, and glaucoma (Fig. 32-17). These complications can be avoided in most patients by administration of panretinal laser photocoagulation at the appropriate point in the evolution of the disease. Anti-vascular



FIGURE 32-17 Proliferative diabetic retinopathy in a 25-year-old man with an 18-year history of diabetes, showing neovascular vessels emanating from the optic disc, retinal and vitreous hemorrhage, cotton-wool spots, and macular exudate. Round spots in the periphery represent recently applied panretinal photocoagulation.



**FIGURE 32-18** Retinitis pigmentosa with black clumps of pigment known as “bone spicules.” The patient had peripheral visual field loss with sparing of central (macular) vision.

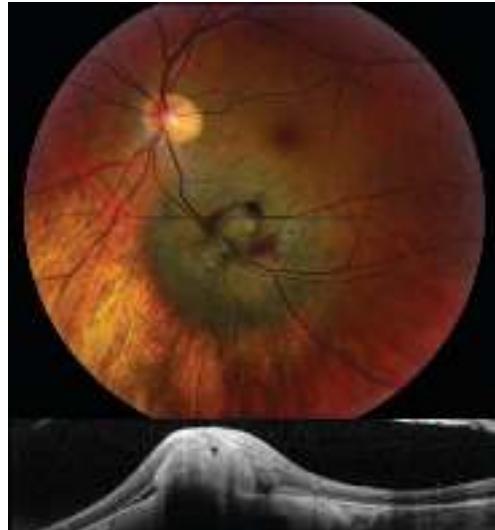
endothelial growth factor antibody treatment is equally effective, but intraocular injections must be given repeatedly. **For further discussion of the manifestations and management of diabetic retinopathy, see Chaps. 403–405.**

**Retinitis Pigmentosa** This is a general term for a disparate group of rod-cone dystrophies characterized by progressive night blindness, visual field constriction with a ring scotoma, loss of acuity, and an abnormal electroretinogram (ERG). It occurs sporadically or in an autosomal recessive, dominant, or X-linked pattern. Irregular black deposits of clumped pigment in the peripheral retina, called *“bone spicules”* because of their vague resemblance to the spicules of cancellous bone, give the disease its name (Fig. 32-18). The name is actually a misnomer because retinitis pigmentosa is not an inflammatory process. Genetic testing usually identifies a mutation in the gene for rhodopsin, the rod photopigment, or in the gene for peripherin, a glycoprotein located in photoreceptor outer segments. Vitamin A (15,000 IU/d) slightly retards the deterioration of the ERG in patients with retinitis pigmentosa but has no beneficial effect on visual acuity or fields.

Leber’s congenital amaurosis, a rare cone dystrophy, has been treated by replacement of the missing RPE65 protein through gene therapy, resulting in slight improvement in visual function. Some forms of retinitis pigmentosa occur in association with rare, hereditary systemic diseases (olivopontocerebellar degeneration, Bassen-Kornzweig disease, Kearns-Sayre syndrome, Refsum’s disease). Chronic treatment with chloroquine, hydroxychloroquine, and phenothiazines (especially thioridazine) can produce visual loss from a toxic retinopathy that resembles retinitis pigmentosa. Patients receiving long-term treatment with hydroxychloroquine require regular eye examinations to monitor for potential development of a bull’s eye maculopathy.

**Epiretinal Membrane** This is a fibrocellular tissue that grows across the inner surface of the retina, causing metamorphopsia and reduced visual acuity from distortion of the macula. A crinkled, cellophane-like membrane is visible on the retinal examination. Epiretinal membrane is most common in patients aged >50 years and is usually unilateral. Most cases are idiopathic, but some occur as a result of hypertensive retinopathy, diabetes, retinal detachment, or trauma. When visual acuity is reduced to the level of about 6/24 (20/80), vitrectomy and surgical peeling of the membrane to relieve macular puckering are recommended. Contraction of an epiretinal membrane sometimes gives rise to a *“macular hole”*. Most macular holes, however, are caused by local vitreous traction within the fovea. Vitrectomy can improve acuity in selected cases.

**Melanoma and Other Tumors** Melanoma is the most common primary tumor of the eye (Fig. 32-19). Approximately 2000 cases occur annually in the United States. It causes photopsia, an enlarging



**FIGURE 32-19** Melanoma of the choroid, appearing as an elevated dark mass in the inferior fundus, with overlying hemorrhage. The black line denotes the plane of the optical coherence tomography scan (below) showing the subretinal tumor.

scotoma, and loss of vision. A small melanoma is often difficult to differentiate from a benign choroidal nevus. Serial examinations are required to document a malignant pattern of growth. Risk factors include light skin, hair, and eyes. Uveal origin accounts for 85% of cases. *GNAQ* and *GNA11* mutations are common. About half metastasize, mainly to the liver. Small and medium-sized tumors may be treated with radiation therapy; enucleation is the best treatment for large tumors. *Metastatic tumors* to the eye outnumber primary tumors. Breast and lung carcinomas have a special propensity to spread to the choroid or iris. Leukemia and lymphoma also commonly invade ocular tissues. Sometimes their only sign on eye examination is cellular debris in the vitreous, which can masquerade as a chronic posterior uveitis.

In a patient with vision loss, CT or MR scanning should be considered if the cause remains unknown after careful review of the history, visual fields, and thorough examination of the eye. Optic nerve sheath meningioma is a common retrobulbar tumor. It produces the classic triad of optociliary shunt vessels, optic atrophy, and progressive visual loss. Optic disc swelling and proptosis are also frequent signs. Optic nerve glioma in young patients is usually a pilocytic astrocytoma and has a good prognosis for preservation of vision, especially in neurofibromatosis type 1 (Chap. 90). In adults, optic nerve glioma is rare and highly malignant. Chiasmal tumors (pituitary adenoma, meningioma, craniopharyngioma) produce visual loss with few objective findings except for optic disc pallor. Loss of the temporal visual field in each eye is typically described, but in fact, patients complain of vision loss in just one eye. A high degree of vigilance is necessary to avoid missing chiasmal tumors. Although symptoms progress gradually, in rare instances, the sudden expansion of a pituitary adenoma from infarction and bleeding (*pituitary apoplexy*) causes acute retrobulbar visual loss, with headache, nausea, and ocular motor nerve palsies.

### ■ PROPTOSIS

When the globes appear asymmetric, the clinician must first decide which eye is abnormal. Is one eye recessed within the orbit (*enophthalmos*), or is the other eye protuberant (*exophthalmos*, or *proptosis*)? A small globe or Horner’s syndrome can give the appearance of enophthalmos. True enophthalmos occurs commonly after trauma, from atrophy of retrobulbar fat, or from fracture of the orbital floor. The position of the eyes within the orbits is measured by using a Hertel exophthalmometer, a handheld instrument that records the position of the anterior corneal surface relative to the lateral orbital rim. If this instrument is not available, relative eye position can be judged by bending the patient’s head forward and looking down upon the orbits.

A proptosis of only 2 mm in one eye is detectable from this perspective. The development of proptosis implies a space-occupying lesion in the orbit and usually warrants CT or MR imaging.

**Graves' Ophthalmopathy** This is the leading cause of proptosis in adults (Chap. 382). The proptosis is often asymmetric and can even appear to be unilateral. Orbital inflammation and engorgement of the extraocular muscles, particularly the medial rectus and the inferior rectus, account for the protrusion of the globe. Corneal exposure, lid retraction, lid lag on downgaze, conjunctival injection, restriction of gaze, diplopia, and visual loss from optic nerve compression are cardinal symptoms. Graves' eye disease is a clinical diagnosis, but laboratory testing can be useful. The serum level of thyroid-stimulating immunoglobulins is often elevated. Orbital imaging usually reveals enlarged extraocular eye muscles, but not always. Topical lubricants, taping the eyelids closed at night, and moisture chambers are helpful to limit exposure of ocular tissues. Graves' ophthalmopathy can be treated with oral prednisone (60 mg/d) for 1 month, followed by a taper over several months, but worsening of symptoms upon glucocorticoid withdrawal is common. Infusions of tepratuzumab, an inhibitor of the insulin-like growth factor I receptor, reduce proptosis and diplopia. Radiation therapy is not effective. Orbital decompression should be performed for severe, symptomatic exophthalmos or if visual function is reduced by optic nerve compression. In patients with diplopia, prisms or eye muscle surgery can be used to restore ocular alignment in primary gaze.

**Orbital Pseudotumor** This is an idiopathic, inflammatory orbital syndrome that is distinguished from Graves' ophthalmopathy by the prominent complaint of pain. Other symptoms include diplopia, ptosis, proptosis, and orbital congestion. Evaluation for sarcoidosis, granulomatosis with polyangiitis, and other types of orbital vasculitis or collagen-vascular disease is negative. Imaging often shows swollen eye muscles (orbital myositis) with enlarged tendons. By contrast, in Graves' ophthalmopathy, the tendons of the eye muscles usually are spared. The Tolosa-Hunt syndrome (Chap. 441) may be regarded as an extension of orbital pseudotumor through the superior orbital fissure into the cavernous sinus. The diagnosis of orbital pseudotumor is difficult. Biopsy of the orbit frequently yields nonspecific evidence of fat infiltration by lymphocytes, plasma cells, and eosinophils. A dramatic response to a therapeutic trial of systemic glucocorticoids indirectly provides the best confirmation of the diagnosis.

**Orbital Cellulitis** This causes pain, lid erythema, proptosis, conjunctival chemosis, restricted motility, decreased acuity, afferent pupillary defect, fever, and leukocytosis. It often arises from the paranasal sinuses, especially by contiguous spread of infection from the ethmoid sinus through the lamina papyracea of the medial orbit. A history of recent upper respiratory tract infection, chronic sinusitis, thick mucus secretions, or dental disease is significant in any patient with suspected orbital cellulitis. Blood cultures should be obtained, but they are usually negative. Most patients respond to empirical therapy with broad-spectrum IV antibiotics. Occasionally, orbital cellulitis follows an overwhelming course, with massive proptosis, blindness, septic cavernous sinus thrombosis, and meningitis. To avert this disaster, orbital cellulitis should be managed aggressively in the early stages, with immediate imaging of the orbits and antibiotic therapy that includes coverage of methicillin-resistant *Staphylococcus aureus* (MRSA). Prompt surgical drainage of an orbital abscess or paranasal sinusitis is indicated if optic nerve function deteriorates despite antibiotics.

**Tumors** Tumors of the orbit cause painless, progressive proptosis. The most common primary tumors are cavernous hemangioma, lymphangioma, neurofibroma, schwannoma, dermoid cyst, adenoid cystic carcinoma, optic nerve glioma, optic nerve meningioma, and benign mixed tumor of the lacrimal gland. Metastatic tumor to the orbit occurs frequently in breast carcinoma, lung carcinoma, and lymphoma. Diagnosis by fine-needle aspiration followed by urgent radiation therapy sometimes can preserve vision.

**Carotid Cavernous Fistulas** With anterior drainage through the orbit, these fistulas produce proptosis, diplopia, glaucoma, and

corkscrew, arterialized conjunctival vessels. Direct fistulas usually result from trauma. They are easily diagnosed because of the prominent signs produced by high-flow, high-pressure shunting. Indirect fistulas, or dural arteriovenous malformations, are more likely to occur spontaneously, especially in older women. The signs are more subtle, and the diagnosis frequently is missed. The combination of slight proptosis, diplopia, enlarged muscles, and an injected eye often is mistaken for thyroid ophthalmopathy. A bruit heard upon auscultation of the head or reported by the patient is a valuable diagnostic clue. Imaging shows an enlarged superior ophthalmic vein in the orbits. Carotid cavernous shunts can be eliminated by intravascular embolization.

## ■ PTOSIS

**Blepharoptosis** This is an abnormal drooping of the eyelid. Unilateral or bilateral ptosis can be congenital, from dysgenesis of the levator palpebrae superioris, or from abnormal insertion of its aponeurosis into the eyelid. Acquired ptosis can develop so gradually that the patient is unaware of the problem. Inspection of old photographs is helpful in dating the onset. A history of prior trauma, eye surgery, contact lens use, diplopia, systemic symptoms (e.g., dysphagia or peripheral muscle weakness), or a family history of ptosis should be sought. Fluctuating ptosis that worsens late in the day is typical of myasthenia gravis. Ptosis evaluation should focus on evidence for proptosis, eyelid masses or deformities, inflammation, pupil inequality, or limitation of motility. The width of the palpebral fissures is measured in primary gaze to determine the degree of ptosis. The ptosis will be underestimated if the patient compensates by lifting the brow with the frontalis muscle.

**Mechanical Ptosis** This occurs in many elderly patients from stretching and redundancy of eyelid skin and subcutaneous fat (dermatochalasis). The extra weight of these sagging tissues causes the lid to droop. Enlargement or deformation of the eyelid from infection, tumor, trauma, or inflammation also results in ptosis on a purely mechanical basis.

**Aponeurotic Ptosis** This is an acquired dehiscence or stretching of the aponeurotic tendon, which connects the levator muscle to the tarsal plate of the eyelid. It occurs commonly in older patients, presumably from loss of connective tissue elasticity. Aponeurotic ptosis is also a common sequela of eyelid swelling from infection or blunt trauma to the orbit, cataract surgery, or contact lens use.

**Myogenic Ptosis** The causes of *myogenic ptosis* include myasthenia gravis (Chap. 448) and a number of rare myopathies that manifest with ptosis. The term *chronic progressive external ophthalmoplegia* refers to a spectrum of systemic diseases caused by mutations of mitochondrial DNA. As the name implies, the most prominent findings are symmetric, slowly progressive ptosis and limitation of eye movements. In general, diplopia is a late symptom because all eye movements are reduced equally. In the *Kearns-Sayre* variant, retinal pigmentary changes and abnormalities of cardiac conduction develop. Peripheral muscle biopsy shows characteristic "ragged-red fibers." *Oculopharyngeal dystrophy* is a distinct autosomal dominant disease with onset in middle age, characterized by ptosis, limited eye movements, and trouble swallowing. *Myotonic dystrophy*, another autosomal dominant disorder, causes ptosis, ophthalmoparesis, cataract, and pigmentary retinopathy. Patients have muscle wasting, myotonia, frontal balding, and cardiac abnormalities.

**Neurogenic Ptosis** This results from a lesion affecting the innervation to either of the two muscles that open the eyelid: Müller's muscle or the levator palpebrae superioris. Examination of the pupil helps distinguish between these two possibilities. In Horner's syndrome, the eye with ptosis has a smaller pupil and the eye movements are full. In an oculomotor nerve palsy, the eye with the ptosis has a larger or a normal pupil. If the pupil is normal but there is limitation of adduction, elevation, and depression, a pupil-sparing oculomotor nerve palsy is likely (see next section). Rarely, a lesion affecting the small, central subnucleus of the oculomotor complex will cause bilateral ptosis with normal eye movements and pupils.

## ■ DOUBLE VISION DIPLOPIA

The first point to clarify is whether diplopia persists in either eye after the opposite eye is covered. If it does, the diagnosis is monocular diplopia. The cause is usually intrinsic to the eye and therefore has no dire implications for the patient. Corneal aberrations (e.g., keratoconus, pterygium), uncorrected refractive error, cataract, or foveal traction may give rise to monocular diplopia. Occasionally, it is a symptom of malingering or psychiatric disease. Diplopia alleviated by covering one eye is binocular diplopia and is caused by disruption of ocular alignment. Inquiry should be made into the nature of the double vision (purely side-by-side versus partial vertical displacement of images), mode of onset, duration, intermittency, diurnal variation, and associated neurologic or systemic symptoms. If the patient has diplopia while being examined, motility testing should reveal a deficiency corresponding to the patient's symptoms. However, subtle limitation of ocular excursions is often difficult to detect. For example, a patient with a slight left abducens nerve paresis may appear to have full eye movements despite a complaint of horizontal diplopia upon looking to the left. In this situation, the cover test provides a more sensitive method for demonstrating the ocular misalignment. It should be conducted in primary gaze and then with the head turned and tilted in each direction while the patient fixates a central, distant target. In the above example, a cover test with the head turned to the right bringing the eyes into left gaze will maximize the fixation shift evoked by the cover test.

Occasionally, a cover test performed in an asymptomatic patient during a routine examination will reveal an ocular deviation. If the eye movements are full and the ocular misalignment is equal in all directions of gaze (comitant deviation), the diagnosis is strabismus. In this condition, which affects about 1% of the population, fusion is disrupted in infancy or early childhood. To avoid diplopia, retinal input from the nonfixating eye may be partially suppressed. In some children, this leads to impaired vision (amblyopia, or "lazy" eye) in the deviated eye.

Binocular diplopia results from a wide range of processes: infectious, neoplastic, metabolic, degenerative, inflammatory, and vascular. One must decide whether the diplopia is neurogenic in origin or is due to restriction of globe rotation by local disease in the orbit. Orbital pseudotumor, myositis, infection, tumor, thyroid disease, and muscle entrapment (e.g., from a blowout fracture) cause restrictive diplopia. The diagnosis of restriction is usually made by recognizing other associated signs and symptoms of local orbital disease. Dedicated, high-resolution orbital imaging is helpful when the cause of diplopia is not evident.

**Myasthenia Gravis** (See also Chap. 448) This is a major cause of painless diplopia. The diplopia is often intermittent, variable, and not confined to any single ocular motor nerve distribution. The pupils are always normal. Serial observation of a fatigable ptosis, often accompanied by diplopia from fluctuating ocular misalignment, establishes the diagnosis. Many patients have a purely ocular form of the disease, with no evidence of systemic muscular weakness. Classically, the diagnosis was confirmed by an IV edrophonium injection, which produces a transient reversal of eyelid or eye muscle weakness, but this drug is discontinued in the United States. Blood tests for antibodies against the acetylcholine receptor or the MuSK protein are frequently negative in the purely ocular form of myasthenia gravis. *Botulism* from food or wound poisoning can mimic ocular myasthenia.

If restrictive orbital disease and myasthenia gravis are excluded, a lesion of a cranial nerve supplying innervation to the extraocular muscles is the most likely cause of binocular diplopia.

**Oculomotor Nerve** The third cranial nerve innervates the medial, inferior, and superior recti; inferior oblique; levator palpebrae superioris; and the iris sphincter. Total palsy of the oculomotor nerve causes ptosis, a dilated pupil, and leaves the eye "down and out" because of the unopposed action of the lateral rectus and superior oblique. This combination of findings is obvious. More challenging is the diagnosis of early or partial oculomotor nerve palsy. In this setting, any combination of ptosis, pupil dilation, and weakness of the eye muscles

supplied by the oculomotor nerve may be encountered. Frequent serial examinations during the rapidly evolving phase of the palsy help ensure that the diagnosis is not missed. The advent of an oculomotor nerve palsy with a pupil involvement, especially when accompanied by pain, suggests a compressive lesion, such as a tumor or circle of Willis aneurysm. Urgent neuroimaging should be obtained, along with a CT or MR angiogram. The resolution of these noninvasive techniques has advanced to the point that catheter angiography is rarely necessary to exclude an aneurysm.

A lesion of the oculomotor nucleus in the rostral midbrain produces signs that differ from those caused by a lesion of the nerve itself. There is bilateral ptosis because the levator muscle is innervated by a single central subnucleus. There is also weakness of the contralateral superior rectus, because it is supplied by the oculomotor nucleus on the other side. Occasionally both superior recti are weak. Isolated nuclear oculomotor palsy is rare. Usually, neurologic examination reveals additional signs that suggest brainstem damage from infarction, hemorrhage, tumor, or infection.

Injury to structures surrounding fascicles of the oculomotor nerve descending through the midbrain has given rise to a number of classic eponymic designations. In *Nothnagel's syndrome*, injury to the superior cerebellar peduncle causes ipsilateral oculomotor palsy and contralateral cerebellar ataxia. In *Benedikt's syndrome*, injury to the red nucleus results in ipsilateral oculomotor palsy and contralateral tremor, chorea, and athetosis. *Claude's syndrome* incorporates features of both of these syndromes, by injury to both the red nucleus and the superior cerebellar peduncle. Finally, in *Weber's syndrome*, injury to the cerebral peduncle causes ipsilateral oculomotor palsy with contralateral hemiparesis.

In the subarachnoid space, the oculomotor nerve is vulnerable to aneurysm, meningitis, tumor, infarction, and compression. In cerebral herniation, the nerve becomes trapped between the edge of the tentorium and the uncus of the temporal lobe. Oculomotor palsy also can result from midbrain torsion and hemorrhage during herniation. In the cavernous sinus, oculomotor palsy arises from carotid aneurysm, carotid cavernous fistula, cavernous sinus thrombosis, tumor (pituitary adenoma, meningioma, metastasis), herpes zoster infection, and the Tolosa-Hunt syndrome.

The etiology of an isolated, pupil-sparing oculomotor palsy often remains an enigma even after neuroimaging and extensive laboratory testing. Most cases are thought to result from microvascular infarction of the nerve somewhere along its course from the brainstem to the orbit. Usually, the patient complains of pain. Diabetes, hypertension, and vascular disease are major risk factors. Spontaneous recovery over a period of months is the rule. If this fails to occur or if new findings develop, the diagnosis of microvascular oculomotor nerve palsy should be reconsidered. Aberrant regeneration is common when the oculomotor nerve is injured by trauma or compression (tumor, aneurysm). Miswiring of sprouting fibers to the levator muscle and the rectus muscles results in elevation of the eyelid upon downgaze or adduction. The pupil also constricts upon attempted adduction, elevation, or depression of the globe. Aberrant regeneration is not seen after oculomotor palsy from microvascular infarct and hence vitiates that diagnosis.

**Trochlear Nerve** The fourth cranial nerve originates in the midbrain, just caudal to the oculomotor nerve complex. Fibers exit the brainstem dorsally and cross to innervate the contralateral superior oblique. The principal actions of this muscle are to depress and intort the globe. A palsy therefore results in hypertropia and exocyclotorsion. The cyclotorsion seldom is noticed by patients. Instead, they complain of vertical diplopia, especially upon reading or looking down. Vertical diplopia is exacerbated by tilting the head toward the side with the muscle palsy and alleviated by tilting it away. This "head tilt test" is a cardinal diagnostic feature. Review of old photographs will sometimes reveal a habitual head tilt, signifying a patient with a decompensated, congenital trochlear nerve palsy.

New, isolated trochlear nerve palsy results from all the causes listed above for the oculomotor nerve except aneurysm. The trochlear nerve is particularly apt to suffer injury after closed head trauma. The free edge of the tentorium impinges on the nerve during a concussive blow.

Most isolated trochlear nerve palsies are idiopathic and hence are diagnosed by exclusion as “microvascular.” Spontaneous improvement occurs over a period of months in most patients. A base-down prism (conveniently applied to the patient’s glasses as a stick-on Fresnel lens) may serve as a temporary measure to alleviate diplopia. If the palsy does not resolve, the eyes can be realigned by weakening the inferior oblique muscle.

**Abducens Nerve** The sixth cranial nerve innervates the lateral rectus muscle. A palsy produces horizontal diplopia, worse on gaze to the side of the lesion. A nuclear lesion has different consequences, because the abducens nucleus contains interneurons that project via the medial longitudinal fasciculus to the medial rectus subnucleus of the contralateral oculomotor complex. Therefore, an abducens nuclear lesion produces a complete lateral gaze palsy from weakness of both the ipsilateral lateral rectus and the contralateral medial rectus. *Foville’s syndrome* after dorsal pontine injury includes lateral gaze palsy, ipsilateral facial palsy, and contralateral hemiparesis incurred by damage to descending corticospinal fibers. *Millard-Gubler syndrome* from ventral pontine injury is similar except for the eye findings. There is lateral rectus weakness only, instead of gaze palsy, because the abducens fascicle is injured rather than the nucleus. Infarct, tumor, hemorrhage, vascular malformation, and multiple sclerosis are the most common etiologies of brainstem abducens palsy.

After leaving the ventral pons, the abducens nerve runs forward along the clivus to pierce the dura at the petrous apex, where it enters the cavernous sinus. Along its subarachnoid course, it is susceptible to meningitis, tumor (meningioma, chordoma, carcinomatous meningitis), subarachnoid hemorrhage, trauma, and compression by aneurysm or dolichoectatic vessels. At the petrous apex, mastoiditis can produce deafness, pain, and ipsilateral abducens palsy (*Gradenigo’s syndrome*). In the cavernous sinus, the nerve can be affected by carotid aneurysm, carotid cavernous fistula, tumor (pituitary adenoma, meningioma, nasopharyngeal carcinoma), herpes infection, and Tolosa-Hunt syndrome.

Unilateral or bilateral abducens palsy is a classic sign of raised intracranial pressure. The diagnosis can be confirmed if papilledema is observed on fundus examination. The mechanism is still debated but probably is related to rostral-caudal displacement of the brainstem. The same phenomenon accounts for abducens palsy from Chiari malformation or low intracranial pressure (e.g., after lumbar puncture, spinal anesthesia, or spontaneous dural cerebrospinal fluid leak).

Treatment of abducens palsy is aimed at prompt correction of the underlying cause. However, the cause remains obscure in many instances despite diligent evaluation. As was mentioned above for isolated trochlear or oculomotor palsy, most cases are assumed to represent microvascular infarcts because they often occur in the setting of diabetes or other vascular risk factors. Some cases may develop as a postinfectious mononeuritis (e.g., after a viral flu). Patching one eye, occluding one eyeglass lens with tape, or applying a temporary prism will provide relief of diplopia until the palsy resolves. If recovery is incomplete, eye muscle surgery nearly always can realign the eyes, at least in primary position. A patient with an abducens palsy that fails to improve should be reevaluated for an occult etiology (e.g., chordoma, carcinomatous meningitis, carotid cavernous fistula, myasthenia gravis). Skull base tumors are easily missed even on contrast-enhanced neuroimaging studies.

**Multiple Ocular Motor Nerve Palsies** These should not be attributed to spontaneous microvascular events affecting more than one cranial nerve at a time. This remarkable coincidence does occur, especially in diabetic patients, but the diagnosis is made only in retrospect after all other diagnostic alternatives have been exhausted. Neuroimaging should focus on the cavernous sinus, superior orbital fissure, and orbital apex, where all three ocular motor nerves are in close proximity. In a diabetic or immunocompromised host, fungal infection (*Aspergillus*, *Mucorales*, *Cryptococcus*) is a common cause of multiple nerve palsies. In a patient with systemic malignancy, carcinomatous meningitis is a likely diagnosis. Cytologic examination may be

negative despite repeated sampling of the cerebrospinal fluid. The cancer-associated Lambert-Eaton myasthenic syndrome also can produce ophthalmoplegia. Giant cell (temporal) arteritis occasionally manifests as diplopia from ischemic palsies of extraocular muscles. Fisher’s syndrome, an ocular variant of Guillain-Barré, produces ophthalmoplegia with areflexia and ataxia. Often the ataxia is mild, and the reflexes are normal. Antiganglioside antibodies (GQ1b) can be detected in about 50% of cases.

**Supranuclear Disorders of Gaze** These are often mistaken for multiple ocular motor nerve palsies. For example, Wernicke’s encephalopathy can produce nystagmus and a partial deficit of horizontal and vertical gaze that mimics a combined abducens and oculomotor nerve palsy. The disorder occurs in patients who are malnourished, alcoholic, or following bariatric surgery, and can be reversed by thiamine. Infarct, hemorrhage, tumor, multiple sclerosis, encephalitis, vasculitis, and Whipple’s disease are other important causes of supranuclear gaze palsy. Disorders of vertical gaze, especially downward saccades, are an early feature of progressive supranuclear palsy. Smooth pursuit is affected later in the course of the disease. Parkinson’s disease, Huntington’s disease, and olivopontocerebellar degeneration also can affect vertical gaze.

The *frontal eye field* of the cerebral cortex is involved in generation of saccades to the contralateral side. After hemispheric stroke, the eyes usually deviate toward the lesioned side because of the unopposed action of the frontal eye field in the normal hemisphere. With time, this deficit resolves. Seizures generally have the opposite effect: the eyes deviate conjugately away from the irritative focus. *Parietal lesions* disrupt smooth pursuit of targets moving toward the side of the lesion. Bilateral parietal lesions produce *Bálint’s syndrome*, which is characterized by impaired eye-hand coordination (optic ataxia), difficulty initiating voluntary eye movements (ocular apraxia), and visuospatial disorientation (simultanagnosia).

**Horizontal Gaze** Descending cortical inputs mediating horizontal gaze ultimately converge at the level of the pons. Neurons in the paramedian pontine reticular formation are responsible for controlling conjugate gaze toward the same side. They project directly to the ipsilateral abducens nucleus. A lesion of either the paramedian pontine reticular formation or the abducens nucleus causes an ipsilateral conjugate gaze palsy. Lesions at either locus produce nearly identical clinical syndromes, with the following exception: vestibular stimulation (oculocephalic maneuver or caloric irrigation) will succeed in driving the eyes conjugately to the side in a patient with a lesion of the paramedian pontine reticular formation but not in a patient with a lesion of the abducens nucleus.

**INTERNUCLEAR OPHTHALMOPLEGIA** This results from damage to the medial longitudinal fasciculus ascending from the abducens nucleus in the pons to the oculomotor nucleus in the midbrain (hence, “internuclear”). Damage to fibers carrying the conjugate signal from abducens interneurons to the contralateral medial rectus motoneurons results in a failure of adduction on attempted lateral gaze. For example, a patient with a left internuclear ophthalmoplegia (INO) will have slowed or absent adducting movements of the left eye (Fig. 32-20). A patient with bilateral injury to the medial longitudinal fasciculus will have bilateral INO. Multiple sclerosis is the most common cause, although tumor, stroke, trauma, or any brainstem process may be responsible. *One-and-a-half syndrome* is due to a lesion of the medial longitudinal fasciculus combined with a lesion of either the abducens nucleus or the paramedian pontine reticular formation on the same side. The patient’s only horizontal eye movement is abduction of the eye on the other side.

**Vertical Gaze** This is controlled at the level of the midbrain. The neuronal circuits affected in disorders of vertical gaze are not fully elucidated, but lesions of the rostral interstitial nucleus of the medial longitudinal fasciculus and the interstitial nucleus of Cajal cause supranuclear paresis of upgaze, downgaze, or all vertical eye movements. Distal basilar artery ischemia is the most common etiology.



**FIGURE 32-20** Left internuclear ophthalmoplegia (INO). *A*, In primary position of gaze, the eyes appear normal. *B*, Horizontal gaze to the left is intact. *C*, On attempted horizontal gaze to the right, the left eye fails to adduct. In mildly affected patients, the eye may adduct partially or more slowly than normal. Nystagmus is usually present in the abducted eye. *D*, T2-weighted axial magnetic resonance image through the pons showing a demyelinating plaque in the left medial longitudinal fasciculus (arrow).

**Skew deviation** refers to a vertical misalignment of the eyes, usually constant in all positions of gaze. The finding has poor localizing value because skew deviation has been reported after lesions in widespread regions of the brainstem and cerebellum.

**PARINAUD'S SYNDROME** Also known as dorsal midbrain syndrome, this is a distinct supranuclear vertical gaze disorder caused by damage to the posterior commissure. It is a classic sign of hydrocephalus from aqueductal stenosis. Pineal region or midbrain tumors, cysticercosis, and stroke also cause Parinaud's syndrome. Features include loss of upgaze (and sometimes downgaze), convergence-retraction nystagmus on attempted upgaze, downward ocular deviation ("setting sun" sign), lid retraction (Collier's sign), skew deviation, pseudoabducens palsy, and light-near dissociation of the pupils.

**Nystagmus** This is a rhythmic oscillation of the eyes, occurring physiologically from vestibular and optokinetic stimulation or pathologically in a wide variety of diseases (Chap. 22). Abnormalities of the eyes or optic nerves, present at birth or acquired in childhood, can produce a complex, searching nystagmus with irregular pendular (sinusoidal) and jerk features. Examples are albinism, Leber's congenital amaurosis, and bilateral cataract. This nystagmus is commonly referred to as *congenital sensory nystagmus*. This is a poor term because even in children with congenital lesions, the nystagmus does not appear until weeks after birth. *Congenital motor nystagmus*, which looks similar to congenital sensory nystagmus, develops in the absence of any abnormality of the sensory visual system. Visual acuity also is reduced in congenital motor nystagmus, probably by the nystagmus itself, but seldom below a level of 20/200.

**JERK NYSTAGMUS** This is characterized by a slow drift off the target, followed by a fast corrective saccade. By convention, the nystagmus is named after the quick phase. Jerk nystagmus can be downbeat, upbeat, horizontal (left or right), and torsional. The pattern of nystagmus may vary with gaze position. Some patients will be oblivious to their nystagmus. Others will complain of blurred vision or a subjective to-and-fro movement of the environment (oscillopsia) corresponding to the nystagmus. Fine nystagmus may be difficult to see on gross examination of the eyes. Observation of nystagmoid movements of the optic disc on ophthalmoscopy is a sensitive way to detect subtle nystagmus.

**GAZE EVOKED NYSTAGMUS** This is the most common form of jerk nystagmus. When the eyes are held eccentrically in the orbits, they have a natural tendency to drift back to primary position. The subject compensates by making a corrective saccade to maintain the deviated eye position. Many normal patients have mild gaze-evoked nystagmus. Exaggerated gaze-evoked nystagmus can be induced by drugs (sedatives, anticonvulsants, alcohol); muscle paresis; myasthenia gravis; demyelinating disease; and cerebellopontine angle, brainstem, and cerebellar lesions.

**VESTIBULAR NYSTAGMUS** *Vestibular nystagmus* results from dysfunction of the labyrinth (Ménière's disease), vestibular nerve, or vestibular nucleus in the brainstem. Peripheral vestibular nystagmus often occurs in discrete attacks, with symptoms of nausea and vertigo. There may be associated tinnitus and hearing loss. Sudden shifts in head position may provoke or exacerbate symptoms.

**DOWNBEAT NYSTAGMUS** *Downbeat nystagmus* results from lesions near the craniocervical junction (Chiari malformation, basilar invagination). It also has been reported in brainstem or cerebellar stroke, lithium or anticonvulsant intoxication, alcoholism, and multiple sclerosis. *Upbeat nystagmus* is associated with damage to the pontine tegmentum from stroke, demyelination, or tumor.

**Opsoclonus** This rare, dramatic disorder of eye movements consists of bursts of consecutive saccades (saccadomania). When the saccades are confined to the horizontal plane, the term *ocular flutter* is preferred. It can result from viral encephalitis, trauma, or a paraneoplastic effect of neuroblastoma, breast carcinoma, and other malignancies. It has also been reported as a benign, transient phenomenon in otherwise healthy patients.

## FURTHER READING

- A AP et al: Building on the success of anti-vascular endothelial growth factor therapy: A vision for the next decade. *Eye* 34:1966, 2020.
- D RS: Teprotumumab for the treatment of active thyroid eye disease. *N Engl J Med* 382:341, 2020.
- D JE: Restoring vision to the blind. *Science* 368:827, 2020.
- G JG et al: Panretinal photocoagulation vs intravitreous ranibizumab for proliferative diabetic retinopathy. *JAMA* 314:2137, 2015.
- J GJ et al: Adalimumab in patients with active noninfectious uveitis. *N Engl J Med* 375:932, 2016.
- M ML: Development of a gene-editing approach to restore vision loss in Leber congenital amaurosis type 10. *Nat Med* 25:229, 2019.
- P MH: Primary care vasculitis: Polymyalgia rheumatica and giant cell arteritis. *Prim Care* 45:305, 2018.
- S JH et al: Trial of tocilizumab in giant-cell arteritis. *N Engl J Med* 377:317, 2017.
- Y M, D J: *Ophthalmology*, 5th ed. Atlanta, Saunders, 2019.

## 33

## Disorders of Smell and Taste

Richard L. Doty, Steven M. Bromley



All environmental chemicals necessary for life enter the body by the nose and mouth. The senses of smell (olfaction) and taste (gustation) monitor such chemicals, determine the flavor and palatability of foods and beverages, and warn of dangerous environmental conditions, including fire, air pollution, leaking natural gas, and bacteria-laden foodstuffs. These senses contribute significantly to quality of life and, when dysfunctional, can have untoward physical and psychological consequences. A longitudinal study of 1162 nondemented elderly persons found, even after controlling for confounders, that those with the lowest baseline olfactory test scores had a 45% mortality rate over a 4-year period, compared to an 18% mortality rate for those with the highest olfactory test scores. A basic understanding of these senses in health and disease is critical for the physician, because thousands of patients present to doctors' offices each year with complaints of chemosensory dysfunction. Among the more important recent developments in neurology is the discovery that decreased smell function is among the first

signs of such neurodegenerative diseases as Parkinson's disease (PD) and Alzheimer's disease (AD), signifying their "presymptomatic" phase.

## ANATOMY AND PHYSIOLOGY

**Olfactory System** Odorous chemicals enter the front of nose during inhalation and active sniffing, as well as the back of the nose (nasopharynx) during deglutition. After reaching the highest recesses of the nasal cavity, they dissolve in the olfactory mucus and diffuse or are actively transported by specialized proteins to receptors located on the cilia of olfactory receptor cells. The cilia, dendrites, cell bodies, and proximal axonal segments of these bipolar cells are located within a unique neuroepithelium covering the cribriform plate, the superior nasal septum, superior turbinate, and sectors of the middle turbinate (Fig. 33-1). Nearly 400 types of G-protein-coupled odor receptors (GPCRs) are expressed on the cilia of the receptor cells, with only one type of GPCR being expressed on a given cell. Other receptors, including trace amine-associated receptors and members of the non-GPCR membrane-spanning 4-domain family, subfamily A (MS4A) protein family, are also present on some receptor cells. Such a plethora of receptor cell types does not exist in any other sensory system. Importantly, when damaged, the receptor cells can be replaced by stem cells near the basement membrane, although such replacement is often incomplete.

After coalescing into bundles surrounded by glia-like ensheathing cells (termed fila), the receptor cell axons pass through the cribriform plate to the olfactory bulbs, where they synapse with dendrites of other cell types within the glomeruli (Fig. 33-2). These spherical structures, which make up a distinct layer of the olfactory bulb, are a site of convergence of information, because many more fibers enter than leave them. Receptor cells that express the same type of receptor project to the same glomeruli, effectively making each glomerulus a functional unit. The major projection neurons of the olfactory system—the mitral and tufted cells—send primary dendrites into the glomeruli, connecting not only with the incoming receptor cell axons, but with dendrites of periglomerular cells. The activity of the mitral/tufted cells is modulated by the periglomerular cells, secondary dendrites from other mitral/tufted cells, and granule cells, the most numerous cells of the bulb. The latter cells, which are largely GABAergic, receive inputs from central brain structures and modulate the output of the mitral/tufted cells. Interestingly, like the olfactory receptor cells, some cells within the bulb undergo replacement. Thus, neuroblasts formed within the anterior subventricular zone of the brain migrate along the rostral migratory stream, ultimately becoming granule and periglomerular cells.

The axons of the mitral and tufted cells synapse within secondary olfactory structures, which largely compose the primary olfactory cortex (POC) (Fig. 33-3). The POC is defined as those cortical structures that receive direct projections from the olfactory bulb, most notably the piriform and entorhinal cortices. Although olfaction is unique

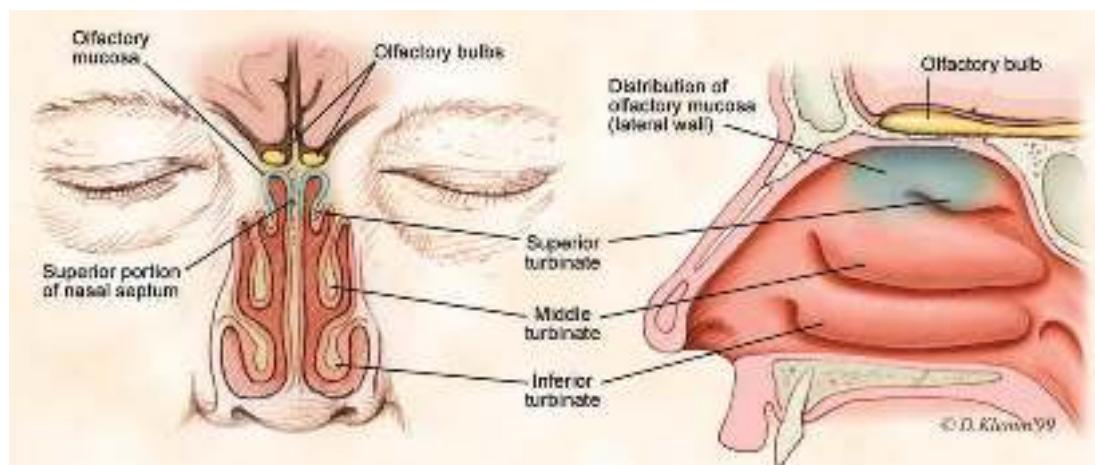
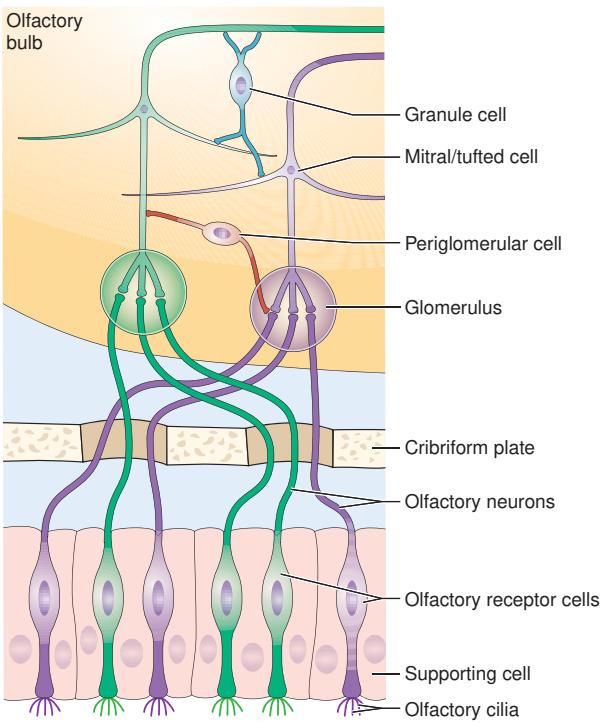


FIGURE 33-1 Anatomy of the nose, showing the distribution of olfactory receptors in the roof of the nasal cavity. (Copyright David Klemm, Faculty and Curriculum Support [FACS], Georgetown University Medical Center.)



**FIGURE 33-2** Schematic of the layers and wiring of the olfactory bulb. Each receptor type (red, green, blue) projects to a common glomerulus. The neural activity within each glomerulus is modulated by periglomerular cells. The activity of the primary projection cells, the mitral and tufted cells, is modulated by granule cells, periglomerular cells, and secondary dendrites from adjacent mitral and tufted cells. (Adapted from [www.med.yale.edu/neurosurg/treloar/index.html](http://www.med.yale.edu/neurosurg/treloar/index.html).)

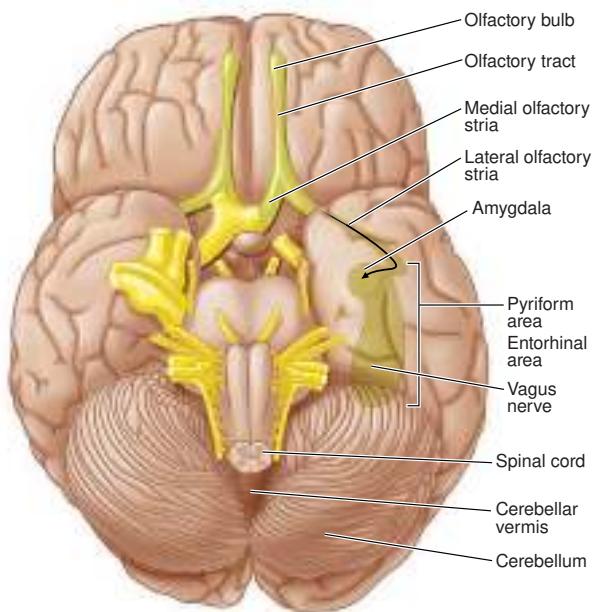
in that its initial afferent projections bypass the thalamus, persons with damage to the thalamus can exhibit olfactory deficits, particularly ones of odor identification. Such deficits likely reflect the involvement of thalamic connections between the POC and the orbitofrontal cortex (OFC), where odor identification largely occurs. The close anatomic ties between the olfactory system and the amygdala, hippocampus,

and hypothalamus help to explain the intimate associations between odor perception and cognitive functions such as memory, motivation, arousal, autonomic activity, digestion, and sex.

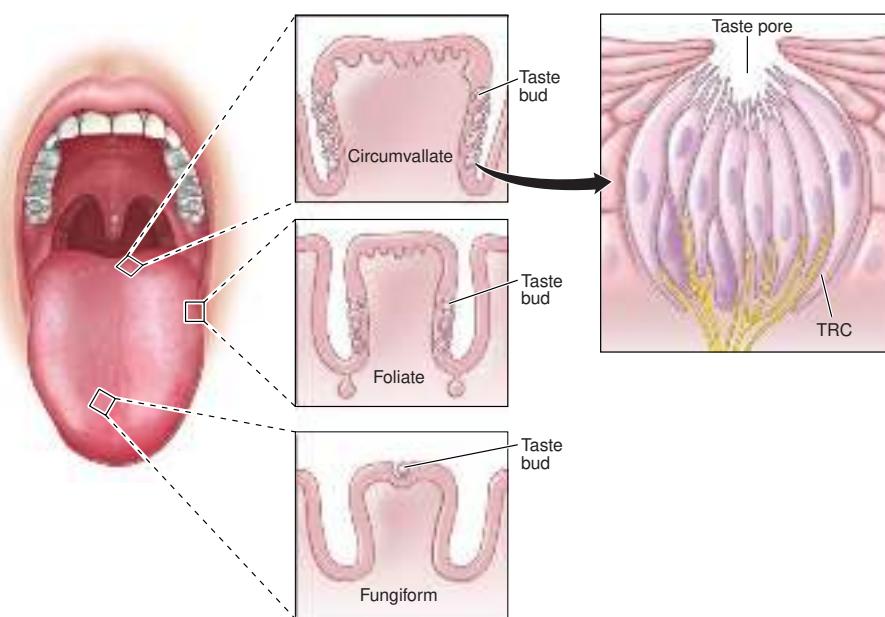
**Taste System** Tastants are sensed by specialized receptor cells present within taste buds—small grapefruit-like segmented structures located on the lateral margins and dorsum of the tongue, roof of the mouth, pharynx, larynx, and superior esophagus (Fig. 33-4). Lingual taste buds are embedded in well-defined protuberances, termed fungiform, foliate, and circumvallate papillae. After dissolving in a liquid, tastants enter the opening of the taste bud—the taste pore—and bind to receptors on microvilli, small extensions of receptor cells within each taste bud. Such binding changes the electrical potential across the taste cell, resulting in neurotransmitter release onto the first-order taste neurons. Although humans have ~7500 taste buds, not all harbor taste-sensitive cells; some contain only one class of receptor (e.g., cells responsive only to sugars), whereas others contain cells sensitive to more than one class. The number of taste receptor cells per taste bud ranges from zero to well over 100. A small family of three GPCRs, namely TIR1, TIR2, and TIR3, mediate sweet and umami taste sensations. Bitter sensations, on the other hand, depend on T2R receptors, a family of ~30 GPCRs expressed on cells different from those that express the sweet and umami receptors. T2Rs sense a wide range of bitter substances but do not distinguish among them. Sour tastants are sensed by the PKD2L1 receptor, a member of the transient receptor potential protein (TRP) family. Perception of salty sensations, such as induced by sodium chloride, arises from the entry of  $\text{Na}^+$  ions into the cells via specialized membrane channels, such as the amiloride-sensitive  $\text{Na}^+$  channel.

It is now well established that both bitter and sweet taste-related receptors are also present elsewhere in the body, most notably in the alimentary and respiratory tracts. This important discovery generalizes the concept of taste-related chemoreception to areas of the body beyond the mouth and throat, with  $\alpha$ -gustducin, the taste-specific G-protein  $\alpha$ -subunit, expressed in so-called brush cells found specifically within the human trachea, lung, pancreas, and gallbladder. These brush cells are rich in nitric oxide (NO) synthase, known to defend against xenobiotic organisms, protect the mucosa from acid-induced lesions, and, in the case of the gastrointestinal tract, stimulate vagal and splanchnic afferent neurons. NO further acts on nearby cells, including enteroendocrine cells, absorptive or secretory epithelial cells, mucosal blood vessels, and cells of the immune system. Members of the T2R family of bitter receptors and the sweet receptors of the T1R family have been identified within the gastrointestinal tract and in enteroendocrine cell lines. In some cases, these receptors are important for metabolism, with the T1R3 receptors and gustducin playing decisive roles in the sensing and transport of dietary sugars from the intestinal lumen into absorptive enterocytes via a sodium-dependent glucose transporter and in regulation of hormone release from gut enteroendocrine cells. In other cases, these receptors may be important for airway protection, with a number of T2R bitter receptors in the motile cilia of the human airway that respond to bitter compounds by increasing their beat frequency. One specific T2R38 taste receptor is expressed in human upper respiratory epithelia and responds to acyl-monoserine lactone quorum-sensing molecules secreted by *Pseudomonas aeruginosa* and other gram-negative bacteria. Differences in T2R38 functionality, as related to TAS2R38 genotype, correlate with susceptibility to upper respiratory infections in humans.

Taste information is sent to the brain via three cranial nerves (CNS): CN VII (the *facial nerve*, which involves the intermediate nerve with its branches, the greater petrosal and chorda tympani nerves), CN IX (the *glossopharyngeal nerve*), and CN X (the *vagus nerve*) (Fig. 33-5). CN VII innervates the anterior tongue and all of the soft palate, CN IX innervates the posterior tongue, and CN X innervates the laryngeal surface of the epiglottis, larynx, and proximal portion of the esophagus. The mandibular branch of CN V ( $V_3$ ) conveys somatosensory information (e.g., touch, burning, cooling, irritation) to the brain. Although not technically a gustatory nerve, CN V shares primary nerve routes with many of the gustatory nerve fibers and adds temperature, texture, pungency, and spiciness to the taste experience. The chorda tympani



**FIGURE 33-3** Anatomy of the base of the brain showing the primary olfactory cortex.



**FIGURE 33-4** Schematic of the taste bud and its opening (pore), as well as the location of buds on the three major types of papillae: fungiform (anterior), foliate (lateral), and circumvallate (posterior). TRC, taste receptor cell.

nerve is famous for taking a recurrent course through the facial canal in the petrosal portion of the temporal bone, passing through the middle ear, and then exiting the skull via the petrotympanic fissure, where it joins the lingual nerve (a division of CN V) near the tongue. This nerve also carries parasympathetic fibers to the submandibular and sublingual glands, whereas the greater petrosal nerve supplies the palatine glands, thereby influencing saliva production.

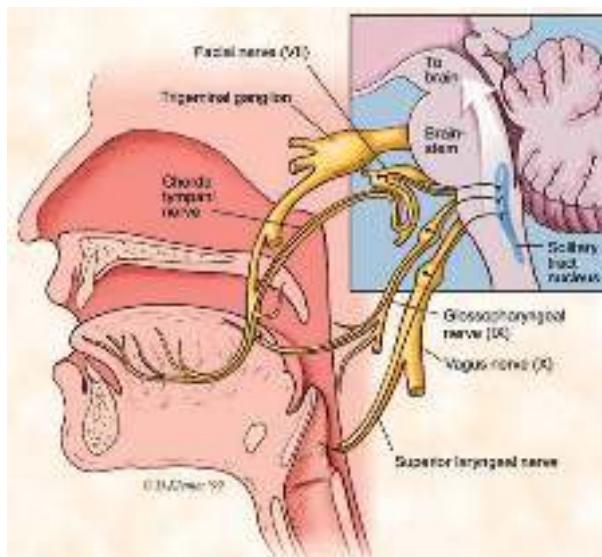
The axons of the projection cells, which synapse with taste buds, enter the rostral portion of the nucleus of the solitary tract (NTS) within the medulla of the brainstem (Fig. 33-5). From the NTS, neurons then project to a division of the ventroposteromedial thalamic nucleus (VPM) via the medial lemniscus. From here, projections are made to the rostral part of the frontal operculum and adjoining insula,

a brain region considered the *primary taste cortex* (PTC). Projections from the PTC then go to the *secondary taste cortex*, namely the caudolateral OFC. This brain region is involved in the conscious recognition of taste qualities. Moreover, because it contains cells that are activated by several sensory modalities, it is likely a center for establishing “flavor.”

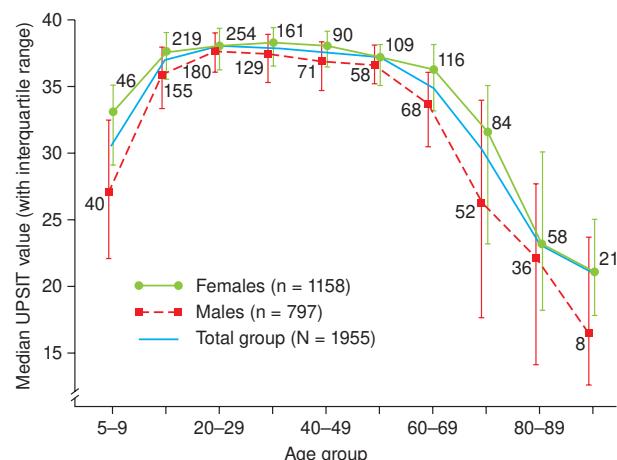
### ■ DISORDERS OF OLFACTION

The ability to smell is influenced, in everyday life, by such factors as age, gender, general health, nutrition, smoking, and reproductive state. Women typically outperform men on tests of olfactory function and retain normal smell function to a later age than do men.

Estimates of the prevalence of olfactory dysfunction in the general population vary; a cross-sectional analysis from the National Health and Nutrition Examination Survey (NHANES 2013–2014) found an overall prevalence of 13.5%. However, it is apparent that significant decrements in the ability to smell are present in >50% of the population between 65 and 80 years of age and in 75% of those aged ≥80 years (Fig. 33-6). Such presbyosmia helps to explain why many elderly report



**FIGURE 33-5** Schematic of the cranial nerves (CNs) that mediate taste function, including the chorda tympani nerve (CN VII), the glossopharyngeal nerve (CN IX), and the vagus nerve (CN X). (Copyright David Klemm, Faculty and Curriculum Support [FACS], Georgetown University Medical Center.)



**FIGURE 33-6** Scores on the University of Pennsylvania Smell Identification Test (UPSiT) as a function of subject age and sex. Numbers by each data point indicate sample sizes. Note that women identify odorants better than men at all ages. (RL Doty et al: Smell identification ability: Changes with age. *Science* 226:4631, 1984. Copyright © 1984 American Association for the Advancement of Science. Reprinted with permission from AAAS.)

TABLE 33-1 Disorders and Conditions Associated with Compromised Olfactory Function, as Measured by Olfactory Testing

Endocrine and Metabolic Conditions	Nasosinus Disorders	Viral, Bacterial, and Fungal Infections
Adrenal cortical insufficiency (Addison's disease)	Adenoid hypertrophy	Candidiasis
Chromatin-negative gonadal dysgenesis (Turner's syndrome)	Bacterial and viral upper respiratory infections	COVID-19
Cushing's syndrome	Laryngopharyngeal reflux disease	Hepatitis C
Diabetes	Rhinosinusitis/polyposis	Herpetic meningoencephalitis
Hypertension	Neurologic Diseases/Disorders	Human immunodeficiency virus
Hypothyroidism	Alzheimer's disease	Legionnaires' disease
Idiopathic hypogonadotropic hypogonadism	Amyotrophic lateral sclerosis (ALS)	Leprosy (Hansen's disease)
Kallmann's syndrome	Bell's palsy	Lyme disease
Liver disease	Degenerative ataxias	Poliomyelitis
Renal disease/kidney failure	Down's syndrome	Rhinosinusitis
Pregnancy	Epilepsy	Upper respiratory infections
Pseudohypoparathyroidism	Facial paralysis	Other Disorders or Factors
Wilson's disease	Fibromyalgia	Alcoholism
Immune-Related Diseases	Frontotemporal lobe degeneration	Bardet-Biedl syndrome
Acute disseminated encephalomyelitis	Guamanian ALS/Parkinson's disease/dementia syndrome	Chemical exposure
Allergic rhinitis	Head trauma	Congenital
Asthma	Huntington's disease	Iatrogenesis, including chemotherapy and radiation
Autoimmune pancreatitis	Idiopathic inflammatory myopathies	Nutritional deficiencies
Behçet's disease	Korsakoff psychosis	Obesity
Churg-Strauss syndrome	Lubag disease	Tobacco smoking
Cystic fibrosis	Migraine	Toxic chemical exposures
Fibromyalgia	Multi-infarct dementia	Vitamin B <sub>12</sub> deficiency
Giant cell arteritis	Narcolepsy with cataplexy	
Hereditary angioedema	Neoplasms, cranial/nasal	
Idiopathic inflammatory myopathies	Orthostatic tremor	
Inflammatory bowel diseases	Parkinson's disease	
Lupus	Pick's disease	
Mikulicz's disease	Rapid eye movement behavioral sleep disorder	
Multiple sclerosis	Stroke	
Myasthenia gravis	Psychiatric-Related Diseases/Disorders	
Neuromyelitis optica	Anorexia nervosa	
Pemphigus vulgaris	Asperger's syndrome	
Psoriasis vulgaris	Attention deficit/hyperactivity disorder	
Rheumatoid arthritis	Depression	
Sjögren's syndrome	Obsessive compulsive disorder	
Systemic sclerosis (scleroderma)	Panic disorder	
Wegener's granulomatosis	Posttraumatic stress disorder	
	Psychopathy	
	Schizophrenia	
	Seasonal affective disorder	
	22q11 deletion syndrome	

Note: These disease/disorder classifications are not necessarily mutually exclusive.

that food has little flavor, a problem that can result in nutritional disturbances. This also helps to explain why a disproportionate number of elderly die in accidental gas poisonings. A relatively complete listing of conditions and disorders that have been associated with olfactory dysfunction is presented in Table 33-1.

Aside from aging, the three most common identifiable causes of long-lasting or permanent smell loss seen in the clinic are, in order of frequency, severe upper respiratory infections, head trauma, and chronic rhinosinusitis. The physiologic basis for most head trauma-related losses is the shearing and subsequent scarring of the olfactory fila as they pass from the nasal cavity into the brain cavity. The cribriform plate does not have to be fractured or show pathology for smell loss to be present. Severity of trauma, as indexed by a poor Glasgow Coma Scale score on presentation and the length of posttraumatic amnesia, is associated with higher risk of olfactory impairment. Less than 10% of posttraumatic anosmic patients will recover age-related normal function over time. This increases to nearly 25% of those with less-than-total

loss. Respiratory infections, such as those associated with the common cold, influenza, pneumonia, HIV, and COVID-19 can directly and permanently damage the olfactory epithelium, decreasing receptor cell number, damaging cilia on remaining receptor cells, and inducing the replacement of sensory epithelium with respiratory epithelium. The smell loss associated with chronic rhinosinusitis is related to disease severity, with most loss occurring in cases where rhinosinusitis and polypsis are both present. Smell loss is among the first signs of the SARS-CoV-2 infection responsible for COVID-19, a loss that is seemingly independent of nasal inflammation. Although in rhinosinusitis cases systemic glucocorticoid therapy can usually induce short-term functional improvement, it does not, on average, return smell test scores to normal, implying that chronic permanent neural loss is present and/or that short-term administration of systemic glucocorticoids does not completely mitigate the inflammation. It is well established that microinflammation in an otherwise seemingly normal epithelium can influence smell function.

A number of neurodegenerative diseases are accompanied by olfactory impairment, including PD, AD, Huntington's disease, parkinsonism-dementia complex of Guam, dementia with Lewy bodies (DLB), multiple system atrophy, corticobasal degeneration, frontotemporal dementia, and Down's syndrome; smell loss can also occur in idiopathic rapid eye movement (REM) behavioral sleep disorder (iRBD), as well as in multiple sclerosis (MS) related to lesions within olfaction-related structures. Olfactory impairment in PD often predates the clinical diagnosis by a number of years. In staged cases, studies of the sequence of formation of abnormal  $\alpha$ -synuclein aggregates and Lewy bodies suggest that the olfactory bulbs may be, along with the dorsomotor nucleus of the vagus, the first site of neural damage in PD. In postmortem studies of patients with very mild "presymptomatic" signs of AD, poorer smell function has been associated with higher levels of AD-related pathology. Smell loss is more marked in patients with early clinical manifestations of DLB than in those with mild AD. Interestingly, smell loss is minimal or nonexistent in progressive supranuclear palsy and 1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine (MPTP)-induced parkinsonism. The relative contributions of disease-specific pathology or differential damage to forebrain neuromodulator/neurotransmitter systems in explaining different degrees of olfactory dysfunction among the various neurodegenerative diseases are presently unknown.

The smell loss seen in iRBD is of the same magnitude as that found in PD. This is of particular interest because patients with iRBD frequently develop PD and hyposmia. REM behavior disorder is not only seen in its idiopathic form, but can also be associated with narcolepsy (Chap. 31). A study of narcoleptic patients with and without REM behavior disorder demonstrated that narcolepsy, independent of REM behavior disorder, was associated with impairments in olfactory function. Loss of hypothalamic neurons expressing orexin (also known as hypocretin) neuropeptides is believed to be responsible for narcolepsy and cataplexy. Orexin-containing neurons project throughout the entire olfactory system (from the olfactory epithelium to the olfactory cortex), and damage to these projections may be one underlying mechanism for impaired olfactory performance in narcoleptic patients. Administration of intranasal orexin A (hypocretin-1) improved olfactory function, supporting the notion that mild olfactory impairment is not only a primary feature of narcolepsy with cataplexy, but that orexin deficiency may be directly responsible for the loss of smell in this condition.

## ■ DISORDERS OF TASTE

The majority of patients who present with taste dysfunction exhibit olfactory, not taste, loss. This is because most flavors attributed to taste actually depend on retronasal stimulation of the olfactory receptors during deglutition. As noted earlier, taste buds only mediate basic tastes such as sweet, sour, bitter, salty, and umami. Significant impairment of whole-mouth gustatory function is rare outside of generalized metabolic disturbances or systemic use of some medications, because taste bud regeneration occurs and peripheral damage alone would require the involvement of multiple CN pathways. Taste function can be influenced by age, diet, smoking behavior, use of medications, and other subject-related factors including (1) the release of foul-tasting materials from the oral cavity from oral medical conditions (e.g., gingivitis, purulent sialadenitis) or appliances; (2) transport problems of tastants to the taste buds (e.g., drying, infections, or inflammatory conditions of the orolingual mucosa), (3) damage to the taste buds themselves (e.g., local trauma, invasive carcinomas), (4) damage to the neural pathways innervating the taste buds (e.g., middle ear infections), (5) damage to central structures (e.g., multiple sclerosis, tumor, epilepsy, stroke), and (6) systemic disturbances of metabolism (e.g., diabetes, thyroid disease, medications).

Unlike CN VII, CN IX is relatively protected along its path, although iatrogenic interventions such as tonsillectomy, bronchoscopy, laryngoscopy, endotracheal intubation, and radiation therapy can result in selective injury. CN VII damage commonly results from mastoidectomy, tympanoplasty, and stapedectomy, in some cases inducing persistent metallic sensations. Bell's palsy (Chap. 441) is one of the most common causes of CN VII injury that results in taste disturbance. On

rare occasions, migraine (Chap. 430) is associated with a gustatory prodrome or aura, and in some cases, tastants can trigger a migraine attack. Interestingly, dysgeusia occurs in some cases of *burning mouth syndrome* (also termed *glossodynia* or *glossalgia*), as does dry mouth and thirst. Burning mouth syndrome is likely associated with dysfunction of the trigeminal nerve (CN V). Some of the etiologies suggested for this poorly understood syndrome are amenable to treatment, including (1) nutritional deficiencies (e.g., iron, folic acid, B vitamins, zinc), (2) diabetes mellitus (possibly predisposing to oral candidiasis), (3) denture allergy, (4) mechanical irritation from dentures or oral devices, (5) repetitive movements of the mouth (e.g., tongue thrusting, teeth grinding, jaw clenching), (6) tongue ischemia as a result of temporal arteritis, (7) periodontal disease, (8) reflux esophagitis, and (9) geographic tongue.

Although both taste and smell can be adversely influenced by drugs, taste alterations are more common. Indeed, >250 medications have been reported to alter the ability to taste. Major offenders include antineoplastic agents, antirheumatic drugs, antibiotics, and blood pressure medications. Terbinafine, a commonly used antifungal, has been linked to taste disturbance lasting up to 3 years. In a recent controlled trial, nearly two-thirds of individuals taking eszopiclone (Lunesta) for insomnia experienced a bitter dysgeusia that was stronger in women, systematically related to the time since drug administration, and positively correlated with both blood and saliva levels of the drug. Intranasal use of nasal gels and sprays containing zinc, which are common over-the-counter prophylactics for upper respiratory viral infections, has been implicated in loss of smell function. Whether their efficacy in preventing such infections, which are the most common cause of anosmia and hyposmia, outweighs their potential detriment to smell function requires study. Dysgeusia occurs commonly in the context of drugs used to treat or minimize symptoms of cancer, with a weighted prevalence from 56% to 76% depending on the type of cancer treatment. Attempts to prevent taste problems from such drugs using prophylactic zinc sulfate or amifostine have proven to be minimally beneficial. Although antiepileptic medications are occasionally used to treat smell or taste disturbances, the use of topiramate has been reported to result in a reversible loss of an ability to detect and recognize tastes and odors during treatment.

As with olfaction, a number of systemic disorders can affect taste. These include, but are not limited to, chronic renal failure, end-stage liver disease, vitamin and mineral deficiencies, diabetes mellitus, and hypothyroidism. In diabetes, there appears to be a progressive loss of taste beginning with glucose and then extending to other sweeteners, salty stimuli, and then all stimuli. Psychiatric conditions can be associated with chemosensory alterations (e.g., depression, schizophrenia, bulimia). A recent review of tactile, gustatory, and olfactory hallucinations demonstrated that no one type of hallucinatory experience is pathognomonic to any given diagnosis.

Pregnancy is a unique condition with regard to taste function. There appears to be an increase in dislike and intensity of bitter tastes during the first trimester that may help to ensure that pregnant women avoid poisons during a critical phase of fetal development. Similarly, a relative increase in the preference for salt and bitter in the second and third trimesters may support the ingestion of much needed electrolytes to expand fluid volume and support a varied diet.

## ■ CLINICAL EVALUATION

In most cases, a careful clinical history will establish the probable etiology of a chemosensory problem, including questions about its nature, onset, duration, and pattern of fluctuations. *Sudden loss* suggests the possibility of head trauma, ischemia, infection, or a psychiatric condition. *Gradual loss* can reflect the development of a progressive obstructive lesion, although gradual loss can also follow head trauma. *Intermittent loss* suggests the likelihood of an inflammatory process. The patient should be asked about potential precipitating events, such as cold or flu infections, prior to symptom onset, because these often go underappreciated. Information regarding head trauma, smoking habits, drug and alcohol abuse (e.g., intranasal cocaine, chronic alcoholism), exposures to pesticides and other toxic agents, and medical

interventions is also informative. A determination of all the medications that the patient was taking before and at the time of symptom onset is important, because many can cause chemosensory disturbances. Comorbid medical conditions associated with smell impairment, such as renal failure, liver disease, hypothyroidism, diabetes, or dementia, should be assessed. Delayed puberty in association with anosmia (with or without midline craniofacial abnormalities, deafness, and renal anomalies) suggests the possibility of Kallmann's syndrome. Recollection of epistaxis, discharge (clear, purulent, or bloody), nasal obstruction, allergies, and somatic symptoms, including headache or irritation, may have localizing value. Questions related to memory, parkinsonian symptoms, and seizure activity (e.g., automatisms, blackouts, auras, *déjà vu*) should be posed. Pending litigation and the possibility of malingering should be considered. Modern forced-choice olfactory tests can detect malingering from improbable responses.

Neurologic and otorhinolaryngologic (ORL) examinations, along with appropriate brain and nasosinus imaging, aid in the evaluation of patients with olfactory or gustatory complaints. The neural evaluation should focus on CN function, with particular attention to possible skull base and intracranial lesions. Visual acuity, field, and optic disc examinations aid in detection of intracranial mass lesions that produce raised intracranial pressure (papilledema) and optic atrophy. Foster Kennedy syndrome refers to raised intracranial pressure plus a compressive optic neuropathy; typical causes are olfactory groove meningiomas or other frontal lobe tumors. The ORL examination should thoroughly assess the intranasal architecture and mucosal surfaces. Polyps, masses, and adhesions of the turbinates to the septum may compromise the flow of air to the olfactory receptors, because less than a fifth of the inspired air traverses the olfactory cleft in the unobstructed state. Blood tests may be helpful to identify such conditions as diabetes, infection, heavy metal exposure, nutritional deficiency (e.g., vitamin B<sub>6</sub> or B<sub>12</sub>), allergy, and thyroid, liver, and kidney disease.

As with other sensory disorders, quantitative sensory testing is advised. Self-reports of patients can be misleading, and a number of patients who complain of chemosensory dysfunction have normal function for their age and gender. Quantitative smell and taste testing provides objective information for worker's compensation and other legal claims, as well as a way to accurately assess the effects of treatment interventions. A number of standardized olfactory and taste tests are commercially available. The most widely used olfactory test, the 40-item University of Pennsylvania Smell Identification Test (UPSIT), uses norms based on nearly 4000 normal subjects. A determination is made of both absolute dysfunction (i.e., mild loss, moderate loss, severe loss, total loss, probable malingering) and relative dysfunction (percentile rank for age and gender). Although electrophysiologic testing is available at some smell and taste centers (e.g., odor event-related potentials), they require complex stimulus presentation and recording equipment and rarely provide additional diagnostic information. With the exception of electrogustometers, commercially available taste tests have only recently become available. Most use filter paper strips or similar materials impregnated with tastants, so no stimulus preparation is required.

## TREATMENT AND MANAGEMENT

Given the various mechanisms by which olfactory and gustatory disturbance can occur, management of patients tends to be condition-specific. For example, patients with hypothyroidism, diabetes, or infections often benefit from specific treatments to correct the underlying disease process that is adversely influencing chemoreception. For most patients who present primarily with obstructive/transport loss affecting the nasal and paranasal regions (e.g., allergic rhinitis, polypsis, intranasal neoplasms, nasal deviations), medical and/or surgical intervention is often beneficial. Antifungal and antibiotic treatments may reverse taste problems secondary to candidiasis or other oral infections. Chlorhexidine mouthwash mitigates some salty or bitter dysgeusias, conceivably as a result of its strong positive charge. Excessive dryness of the oral mucosa is a problem with many medications and conditions, and artificial saliva (e.g., Xerolube) or oral pilocarpine treatments may prove beneficial. Other methods to improve salivary flow include the

use of mints, lozenges, or sugarless gum. Flavor enhancers may make food more palatable (e.g., monosodium glutamate), but caution is advised to avoid overusing ingredients containing sodium or sugar, particularly in circumstances when a patient also has underlying hypertension or diabetes. Medications that induce distortions of taste can often be discontinued and replaced with other types of medications or modes of therapy. As mentioned earlier, pharmacologic agents result in taste disturbances much more frequently than smell disturbances. It is important to note, however, that many drug-related effects are long lasting and not reversed by short-term drug discontinuance.

A study of endoscopic sinus surgery in patients with chronic rhinosinusitis and hyposmia revealed that patients with severe olfactory dysfunction prior to the surgery had a more dramatic and sustained improvement over time compared to patients with more mild olfactory dysfunction prior to intervention. In the case of intranasal and sinus-related inflammatory conditions, such as seen with allergy, viruses, and traumas, the use of intranasal or systemic glucocorticoids may also be helpful. One common approach is to use a tapering course of oral prednisone. Topical intranasal administration of glucocorticoids was found to be less effective in general than systemic administration; however, the effects of different nasal administration techniques were not analyzed. For example, intranasal glucocorticoids are more effective if administered in the Moffett's position (head in the inverted position such as over the edge of the bed with the bridge of the nose perpendicular to the floor). After head trauma, an initial trial of glucocorticoids may help to reduce local edema and the potential deleterious deposition of scar tissue around olfactory fila at the level of the cribriform plate.

Treatments are limited for patients with chemosensory loss or primary injury to neural pathways. Nonetheless, spontaneous recovery can occur. In a follow-up study of 542 patients presenting to our center with smell loss from a variety of causes, modest improvement occurred over an average time period of 4 years in about half of the participants. However, only 11% of the anosmic and 23% of the hyposmic patients regained normal age-related function. Interestingly, the amount of dysfunction at the time of presentation, not etiology, was the best predictor of prognosis. Other predictors were age and the duration of dysfunction prior to initial testing.

Several studies have reported that patients with hyposmia may benefit from repeated smelling of odors over the course of weeks or months, although it remains to be determined how much improvement, if any, occurs over that known to occur spontaneously. The usual paradigm is to smell odors such as eucalyptol, citronella, eugenol, and phenyl ethyl alcohol before going to bed and immediately upon awakening each day. The rationale for such an approach comes from animal studies demonstrating that prolonged exposure to odorants can induce increased neural activity within the olfactory bulb. There is also limited evidence that α-lipoic acid (400 mg/d), an essential cofactor for many enzyme complexes with possible antioxidant effects, may be beneficial in mitigating smell loss following viral infection of the upper respiratory tract. However, double-blind studies are needed to confirm this observation. α-Lipoic acid has also been suggested to be useful in some cases of hypogeusia and burning mouth syndrome.

The use of zinc and vitamin A in treating olfactory disturbances is controversial, and there does not appear to be much benefit beyond replenishing established deficiencies. However, zinc has been shown to improve taste function secondary to hepatic deficiencies, and retinoids (bioactive vitamin A derivatives) are known to play an essential role in the survival of olfactory neurons. One protocol in which zinc was infused with chemotherapy treatments suggested a possible protective effect against developing taste impairment. Diseases of the alimentary tract can not only influence chemoreceptive function but also occasionally influence vitamin B<sub>12</sub> absorption. This can result in a relative deficiency of vitamin B<sub>12</sub>, theoretically contributing to olfactory nerve disturbance. Vitamin B<sub>2</sub> (riboflavin) and magnesium supplements are reported in the alternative literature to aid in the management of migraine that, in turn, may be associated with smell dysfunction. Because vitamin D deficiency is a cofactor of chemotherapy-induced mucocutaneous toxicity and dysgeusia, adding vitamin D<sub>3</sub>, 1000–2000

units per day, may benefit some patients with smell and taste complaints during or following chemotherapy.

A number of medications have reportedly been used with success in ameliorating olfactory symptoms, although strong scientific evidence for efficacy is generally lacking. A report that theophylline improved smell function was uncontrolled and failed to account for the fact that some meaningful improvement occurs without treatment; indeed, the percentage of responders was about the same (~50%) as that noted by others to show spontaneous improvement over a similar time period. Antiepileptics and some antidepressants (e.g., amitriptyline) have been used to treat dysosmias and smell distortions, particularly following head trauma. Ironically, amitriptyline is also frequently on the list of medications that can ultimately distort smell and taste function, possibly from its anticholinergic effects. One study suggested that the centrally acting acetylcholinesterase inhibitor donepezil in AD resulted in improvements on smell identification measures that correlated with overall clinician-based impressions of change in dementia severity scores.

Alternative therapies, such as acupuncture, meditation, cognitive-behavioral therapy, and yoga, can help patients manage uncomfortable experiences associated with chemosensory disturbance and oral pain syndromes and to cope with the psychosocial stressors surrounding the impairment. Additionally, modification of diet and eating habits is also important. By accentuating the other sensory experiences of a meal, such as food texture, aroma, temperature, and color, one can optimize the overall eating experience for a patient. In some cases, a flavor enhancer like monosodium glutamate (MSG) can be added to foods to increase palatability and encourage intake.

Proper oral and nasal hygiene and routine dental care are extremely important ways for patients to protect themselves from disorders of the mouth and nose that can ultimately result in chemosensory disturbance. Patients should be warned not to overcompensate for their taste loss by adding excessive amounts of sugar or salt. Smoking cessation and the discontinuance of oral tobacco use are essential in the management of any patient with smell and/or taste disturbance and should be repeatedly emphasized.

A major and often overlooked element of therapy comes from chemosensory testing itself. Confirmation or lack of conformation of loss is beneficial to patients who come to believe, in light of unsupportive family members and medical providers, that they may be "crazy." In cases where the loss is minor, patients can be informed of the likelihood of a more positive prognosis. Importantly, quantitative testing places the patient's problem into overall perspective. Thus, it is often therapeutic for an older person to know that, while his or her smell function is not what it used to be, it still falls above the average of his or her peer group. Without testing, many such patients are simply told that they are getting old and nothing can be done for them, leading in some cases to depression and decreased self-esteem.

## FURTHER READING

- D DP et al: Olfactory identification deficits are associated with increased mortality in a multiethnic urban community. *Ann Neurol* 78:401, 2015.
- D RL: Olfaction in Parkinson's disease and related disorders. *Neurobiol Dis* 46:527, 2012.
- D RL et al: Taste function in early stage treated and untreated Parkinson's disease. *J Neurol* 262:547, 2015.
- D RL et al: Systemic diseases and disorders. *Handbook Clin Neurol* 164:361, 2019.
- D RL et al: Treatments for smell and taste disorders: A critical review. *Handbook Clin Neurol* 164:455, 2019.
- F MA et al: Adherence and efficacy of olfactory training as a treatment for persistent olfactory loss. *Am J Rhinol Allergy* 34:238, 2020.
- H CH, D RL: *Smell and Taste Disorders*. Cambridge, Cambridge University Press, 2018.
- L G et al: Prevalence and risk factors of taste and smell impairment in a nationwide sample of the US population: A cross-sectional study. *BMJ Open* 6:e013246, 2016.

L B et al: Predictors of prognosis in patients with olfactory disturbance. *Ann Neurol* 63:159, 2008.

M ST et al: Smell dysfunction: A biomarker for COVID-19. *Int Forum Allergy Rhinol* 10:944, 2020.

P C et al: Smell and autoimmunity: A comprehensive review. *Clin Rev Allergy Immunol* 45:87, 2013.

## 34

# Disorders of Hearing

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Hearing loss can present at any age and is one of the most common sensory disorders in humans. Nearly 10% of the adult population has some hearing loss, and one-third of individuals age >65 years have a hearing loss of sufficient magnitude to require a hearing aid.

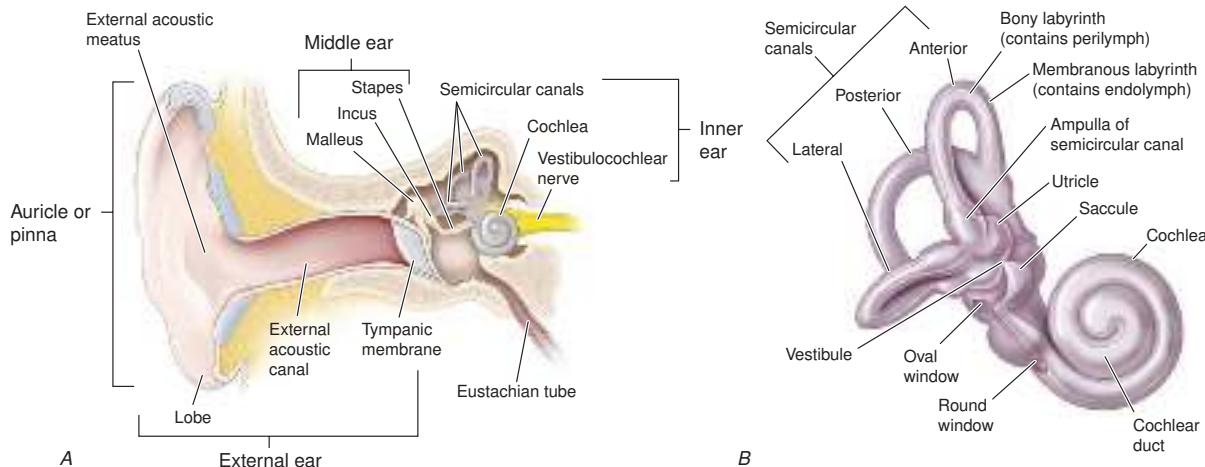
## PHYSIOLOGY OF HEARING

The function of the external and middle ear is to amplify sound to facilitate conversion of the mechanical energy of the sound wave into an electrical signal by the inner-ear hair cells, a process called mechanotransduction (Fig. 34-1). Sound waves enter the external auditory canal and set the tympanic membrane (eardrum) in motion, which in turn moves the malleus, incus, and stapes of the middle ear. Movement of the footplate of the stapes causes pressure changes in the fluid-filled inner ear, eliciting a traveling wave in the basilar membrane of the cochlea. The tympanic membrane and the ossicular chain in the middle ear serve as an impedance-matching mechanism, improving the efficiency of energy transfer from air to the fluid-filled inner ear. In its absence, nearly 99.9% of the acoustical energy would be reflected and thus not heard. Instead, the eardrum and the ossicles boost the sound energy nearly 200-fold by the time it reaches the inner ear.

Within the cochlea of the inner ear, there are two types of hair cells that aid in hearing: inner and outer. The inner and outer hair cells of the organ of Corti have different innervation patterns, but both are mechanoreceptors; they detect the mechanical energy of the acoustic signal and aid its conversion to an electrical signal that travels by the auditory nerve. The afferent innervation relates principally to the inner hair cells while the efferent innervation relates principally to the outer hair cells. The outer hair cells outnumber the inner hair cells by nearly 6:1 (20,000 vs 3500). The motility of the outer hair cells alters the micromechanics of the inner hair cells, creating a cochlear amplifier, which explains the exquisite sensitivity and frequency selectivity of the cochlea.

Stereocilia of the hair cells of the organ of Corti, which rests on the basilar membrane, are in contact with the tectorial membrane and are deformed by the traveling wave. The deformation stretches tiny filamentous connections (tip links) between stereocilia, leading to opening of ion channels, influx of potassium, and hair cell depolarization and subsequent neurotransmission. A point of maximal displacement of the basilar membrane is determined by the frequency of the stimulating tone. High-frequency tones cause maximal displacement of the basilar membrane near the base of the cochlea, whereas for low-frequency sounds, the point of maximal displacement is toward the apex of the cochlea.

Beginning in the cochlea, the frequency specificity is maintained at each point of the central auditory pathway: dorsal and ventral cochlear nuclei, trapezoid body, superior olive complex, lateral lemniscus, inferior colliculus, medial geniculate body, and auditory cortex. At low frequencies, individual auditory nerve fibers can respond more or less synchronously with the stimulating tone. At higher frequencies, phase-locking occurs so that neurons alternate in response to particular phases of the cycle of the sound wave. Intensity is encoded by the



**FIGURE 34-1** Ear anatomy. *A*, Drawing of modified coronal section through external ear and temporal bone, with structures of the middle and inner ear demonstrated. *B*, High-resolution view of inner ear.

amount of neural activity in individual neurons, the number of neurons that are active, and the specific neurons that are activated.

There is evidence that the right and left ears as well as the central nervous system may process speech asymmetrically. Generally, a sound is processed symmetrically from the peripheral to the central auditory system. However, a “right ear advantage” exists for dichotic listening tasks, in which subjects are asked to report on competing sounds presented to each ear. In most individuals, a perceptual right ear advantage for consonant-vowel syllables, stop consonants, and words also exists. Similarly, whereas central auditory processing for sounds is symmetric with minimal lateral specialization for the most part, speech processing is lateralized. There is specialization of the left auditory cortex for speech recognition and production, and of the right hemisphere for emotional and tonal aspects of speech. Left hemisphere dominance for speech is found in 95–98% of right-handed persons and 70–80% of left-handed persons.

## ■ DISORDERS OF THE SENSE OF HEARING

Hearing loss can result from disorders of the auricle, external auditory canal, middle ear, inner ear, or central auditory pathways (Fig. 34-2). In general, lesions in the auricle, external auditory canal, or middle ear that impede the transmission of sound from the external environment to the inner ear cause conductive hearing loss, whereas lesions that impair mechanotransduction in the inner ear or transmission of the electrical signal along the eighth nerve to the brain cause sensorineural hearing loss.

**Conductive Hearing Loss** The external ear, the external auditory canal, and the middle-ear apparatus are designed to collect and amplify sound and efficiently transfer the mechanical energy of the sound wave to the fluid-filled cochlea. Factors that obstruct the transmission of sound or dampen the acoustic energy result in conductive hearing loss. Conductive hearing loss can occur from obstruction of the external auditory canal by cerumen, debris, and foreign bodies; swelling of the lining of the canal; atresia or neoplasms of the canal; perforations of the tympanic membrane; disruption of the ossicular chain, as occurs with necrosis of the long process of the incus in trauma or infection; otosclerosis; or fluid, scarring, or neoplasms in the middle ear. Rarely, inner-ear malformations or pathologies that create a “third window” in the inner ear such as superior semicircular canal dehiscence, lateral semicircular canal dysplasia, incomplete partition of the inner ear, and large vestibular aqueduct, are also associated with conductive hearing loss. This pathologic third window is associated with loss of mechanical energy associated with the sound wave leading to conductive hearing loss (see below).

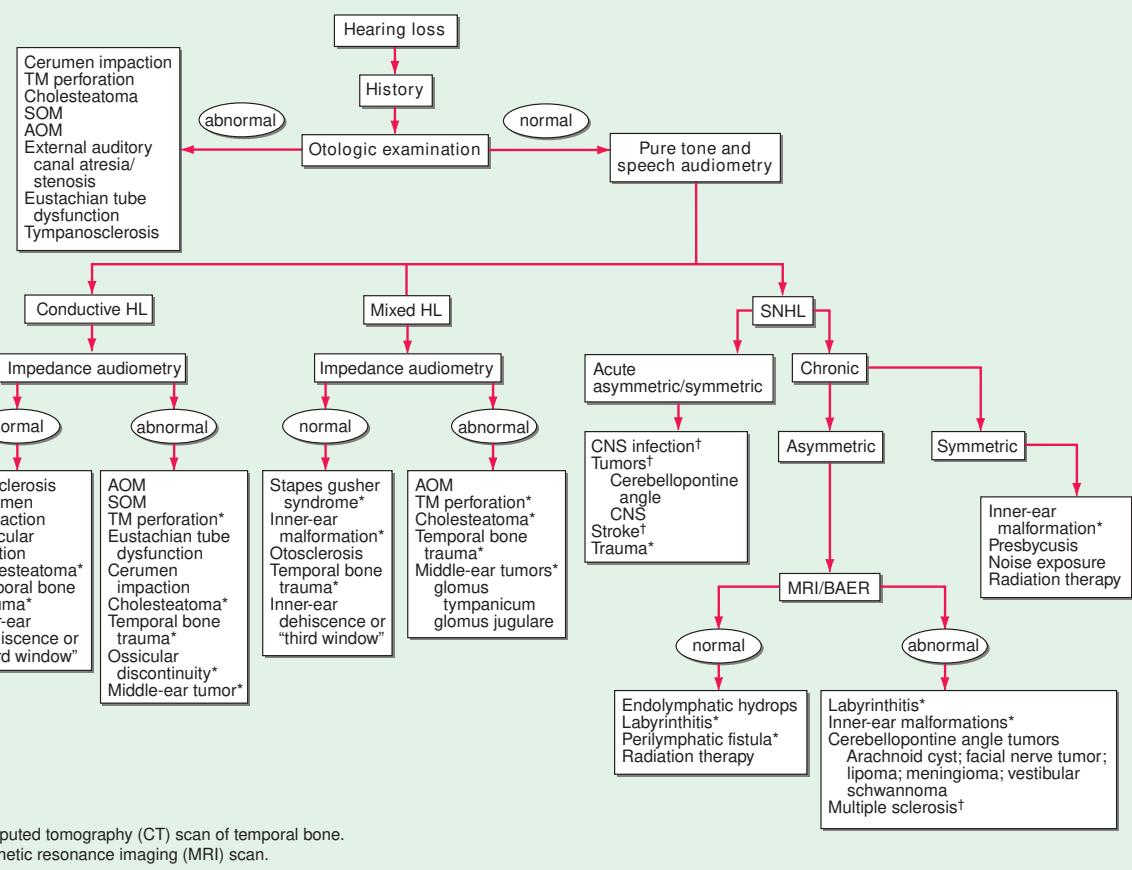
Eustachian tube dysfunction is extremely common in adults and may predispose to acute otitis media (AOM) or serous otitis media

(SOM). Recently, Eustachian tube balloon dilation has been shown to relieve acquired inflammatory obstruction of the Eustachian tube orifice and improve symptoms due to Eustachian tube dysfunction. Trauma, AOM, and chronic otitis media are the usual factors responsible for tympanic membrane perforation. While small perforations often heal spontaneously, larger defects usually require surgical intervention. Tympanoplasty is highly effective (>90%) in the repair of tympanic membrane perforations. Otoscopy is usually sufficient to diagnose AOM, SOM, chronic otitis media, cerumen impaction, tympanic membrane perforation, and Eustachian tube dysfunction; tympanometry and Eustachian tube function testing can be useful to confirm the clinical suspicion of these conditions.

**Cholesteatoma**, a benign tumor composed of stratified squamous epithelium in the middle ear or mastoid, occurs frequently in adults, often in the setting of severe Eustachian tube dysfunction. This is a slowly growing lesion that destroys bone and normal ear tissue. Theories of pathogenesis include traumatic immigration and invasion of squamous epithelium through a retraction pocket of the tympanic membrane, implantation of squamous epithelia in the middle ear through a perforation or surgery, and metaplasia following chronic infection and irritation. A chronically draining ear that fails to respond to appropriate antibiotic therapy should raise suspicion of a cholesteatoma. On examination, there is often a perforation of the tympanic membrane filled with cheesy white squamous debris. The presence of an aural polyp obscuring the tympanic membrane is highly suggestive of an underlying cholesteatoma. Conductive hearing loss secondary to ossicular erosion is common. Bony destruction visualized on CT of the temporal bone is also highly suggestive of cholesteatoma. Surgery is required to remove this destructive process and reconstruct the ossicles.

Conductive hearing loss with a normal ear canal and intact tympanic membrane suggests either ossicular pathology or the presence of a “third window” in the inner ear (see below). Fixation of the stapes from *otosclerosis* is a common cause of low-frequency conductive hearing loss. It occurs equally in men and women and is inherited as an autosomal dominant trait with incomplete penetrance; in some cases, it may be a manifestation of osteogenesis imperfecta. Hearing impairment usually presents between the late teens and the forties. In women, the otosclerotic process is accelerated during pregnancy, and the hearing loss is often first noticeable at this time. A hearing aid or a simple outpatient surgical procedure (stapedectomy) can provide excellent auditory rehabilitation. Extension of otosclerosis beyond the stapes footplate to involve the cochlea (cochlear otosclerosis) can lead to mixed or sensorineural hearing loss. Fluoride therapy to prevent hearing loss from cochlear otosclerosis is of uncertain value.

Disorders that lead to the formation of a pathologic “third window” in the inner ear can be associated with conductive hearing loss. There



**FIGURE 34-2** An algorithm for the approach to hearing loss. AOM, acute otitis media; BAER, brainstem auditory-evoked response; CNS, central nervous system; HL, hearing loss; SNHL, sensorineural hearing loss; SOM, serous otitis media; TM, tympanic membrane.

are normally two major openings, or windows, that connect the inner ear with the middle ear and serve as conduits for transmission of sound; these are, respectively, the oval and round windows. A third window is formed where the normally hard otic bone surrounding the inner ear is eroded; dissipation of the acoustic energy at the third window is responsible for the “inner-ear conductive hearing loss.” The superior semicircular canal dehiscence syndrome resulting from erosion of the otic bone over the superior circular canal can present with conductive hearing loss that mimics otosclerosis. A common symptom is vertigo evoked by loud sounds (Tullio phenomenon), by Valsalva maneuvers that change middle-ear pressure, or by applying positive pressure on the tragus (the cartilage anterior to the external opening of the ear canal). Patients with this syndrome also complain of fullness of the ear, pulsatile tinnitus, and being able to hear the movement of their eyes and neck. A large jugular bulb or jugular bulb diverticulum can create a “third window” by eroding into the vestibular aqueduct or posterior semicircular canal; the symptoms are similar to those of the superior semicircular canal dehiscence syndrome. Other inner-ear malformations such as lateral semicircular canal dysplasia, large vestibular aqueduct, or incomplete partition seen in stapes gusher syndrome can also be associated with inner-ear conductive hearing loss as a result of the third window. Low activation threshold on the vestibular-evoked myogenic potential test (VEMP test, see below) and inner-ear erosion on CT are diagnostic. Recalcitrant vertigo and dizziness may respond to surgical repair of the dehiscence.

**Sensorineural Hearing Loss** Sensorineural hearing loss results from either damage to the mechanotransduction apparatus of the cochlea or disruption of the electrical conduction pathway from the inner ear to the brain. Thus, injury to hair cells, supporting cells,

auditory neurons, or the central auditory pathway can cause sensorineural hearing loss. Damage to the hair cells of the organ of Corti may be caused by intense noise, viral infections, ototoxic drugs (e.g., salicylates, quinine and its synthetic analogues, aminoglycoside antibiotics, loop diuretics such as furosemide and ethacrynic acid, and cancer chemotherapeutic agents such as cisplatin), fractures of the temporal bone, meningitis, cochlear otosclerosis (see above), Ménière’s disease, and aging. Congenital malformations of the inner ear may be the cause of hearing loss in some adults. Genetic predisposition alone or in concert with environmental exposures may also be responsible (see below).

**Noise-Induced Hearing Loss** Exposure to loud noise, either a short burst or over a more prolonged period of time, can lead to noise-induced hearing loss. Acute exposure to noise can lead to either temporary or permanent threshold shifts, depending on the intensity and duration of sound, due to hair cell injury and/or death. Typically, with permanent hearing loss there is a “noise notch” with elevated hearing thresholds at 3000–4000 Hz. More recently, loud noise exposure has also been associated with “hidden hearing loss”—hidden, because routine audiometry shows the pure tone hearing to be normal. Patients usually complain of not being able to hear clearly and are more bothered by the presence of background noise. In contrast to hair cell loss, hidden hearing loss is thought to be due to loss of auditory synapses on hair cells following noise exposure. In an increasingly noisy world, avoiding acoustic trauma with earplugs or earmuffs is highly recommended to prevent noise-induced or hidden hearing loss.

**Presbycusis** (age-associated hearing loss) is the most common cause of sensorineural hearing loss in adults. It is estimated to affect over half of adults aged >75 years in the United States, a population that is expected to double in size over the next 40 years. In the early stages, it is

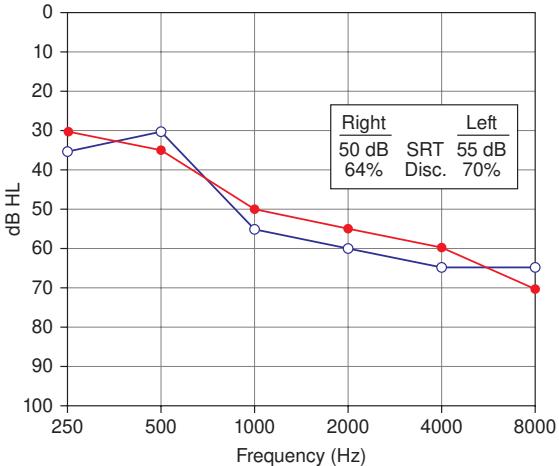


FIGURE 34-3 Presbycusis or age-related hearing loss. The audiogram shows a moderate to severe downsloping sensorineural hearing loss typical of presbycusis. The loss of high-frequency hearing is associated with a decreased speech discrimination score; consequently, patients complain of lack of clarity of hearing, especially in a noisy background. HL, hearing threshold level; SRT, speech reception threshold.

characterized by symmetric, gentle to sharply sloping, high-frequency hearing loss (Fig. 34-3). With progression, the hearing loss involves all frequencies. More importantly, the hearing impairment is associated with significant loss in clarity. There is a loss of discrimination for phonemes, recruitment (abnormal growth of loudness), and particular difficulty in understanding speech in noisy environments such as at restaurants and social events. Poor hearing is also associated with an increased incidence of cognitive impairment, rate of cognitive decline, and falls. In the elderly, left untreated, hearing loss leads to diminished quality of life, and has been shown to increase overall morbidity and mortality through falls and accidents. Hearing aids are helpful in enhancing the signal-to-noise ratio by amplifying sounds that are close to the listener. Hearing aid use has been shown to reduce cognitive decline and risk of falls. Although hearing aids are able to amplify sounds, they cannot restore the clarity of hearing. Thus, amplification with hearing aids may provide only limited rehabilitation once the word recognition score deteriorates below 50%. Cochlear implants are the treatment of choice when hearing aids prove inadequate, even when hearing loss is incomplete (see below).

*Ménière's disease* is characterized by episodic vertigo, fluctuating sensorineural hearing loss, tinnitus, and aural fullness. An absence of vertigo is inconsistent with the diagnosis of Ménière's disease, and the presence of fluctuating sensorineural hearing loss, tinnitus, and fullness without vertigo is more suggestive of cochlear hydrops. Tinnitus and/or deafness may be absent during the initial attacks of vertigo, but invariably appear as the disease progresses and increases in severity during acute attacks. The annual incidence of Ménière's disease is 0.5–7.5 per 1000; onset is most frequently in the fifth decade of life but may also occur in young adults or the elderly. Histologically, there is distension of the endolymphatic system (endolymphatic hydrops) leading to degeneration of vestibular and cochlear hair cells. This may result from endolymphatic sac dysfunction secondary to infection, trauma, autoimmune disease, inflammatory causes, or tumor; an idiopathic etiology constitutes the largest category and is most accurately referred to as Ménière's disease. Endolymphatic sac tumors, often associated with von Hippel Lindau disease, may clinically mimic Ménière's disease. Although any pattern of hearing loss can be observed, typically, low-frequency, unilateral sensorineural hearing impairment is present. An abnormal VEMP test (see below) may be helpful in detecting Ménière's disease in a clinically unaffected contralateral ear. MRI should be obtained to exclude retrocochlear pathology such as a cerebellopontine angle tumor, endolymphatic sac tumor, or demyelinating disorder. Therapy is directed toward the control of vertigo. A 2-g/d low-salt diet

is the mainstay of treatment for control of rotatory vertigo. Diuretics, a short course of oral glucocorticoids, intratympanic glucocorticoids, or intratympanic gentamicin may also be useful adjuncts in recalcitrant cases. Surgical therapy of vertigo is reserved for unresponsive cases and includes endolymphatic sac decompression, labyrinthectomy, and vestibular nerve section. Both labyrinthectomy and vestibular nerve section abolish rotatory vertigo in >90% of cases. Unfortunately, there is no effective therapy for hearing loss, tinnitus, or aural fullness from Ménière's disease.

Sensorineural hearing loss may also result from any neoplastic, vascular, demyelinating, infectious, degenerative disease, or trauma affecting the central auditory pathways. Characteristically, in hearing loss due to central nervous system pathology, a reduction in clarity of hearing and speech comprehension is much greater than the loss of the ability to hear pure tone. Auditory testing is consistent with an auditory neuropathy; normal otoacoustic emissions (OAEs) and an abnormal auditory brainstem response (ABR) are typical (see below). Hearing loss can accompany hereditary sensorimotor neuropathies and inherited disorders of myelin. Tumors of the cerebellopontine angle such as vestibular schwannoma and meningioma (Chap. 90) usually present with asymmetric sensorineural hearing loss with greater deterioration of speech understanding than pure tone hearing. Multiple sclerosis (Chap. 444) may present with acute unilateral or bilateral hearing loss; typically, pure tone testing remains relatively stable while speech understanding fluctuates. Isolated labyrinthine infarction can present with acute hearing loss and vertigo due to a cerebrovascular accident involving the posterior circulation, usually the anterior inferior cerebellar artery; it may also be the heralding sign of impending catastrophic basilar artery infarction (Chap. 426). HIV (Chap. 202), which can produce both peripheral and central auditory system pathology, is another consideration in the evaluation of sensorineural hearing impairment.

A finding of conductive and sensorineural hearing loss in combination is termed *mixed hearing loss*. Mixed hearing losses can result from pathology of both the middle and inner ear, as can occur in otosclerosis involving the ossicles and the cochlea, head trauma, chronic otitis media, cholesteatoma, middle-ear tumors, and some inner-ear malformations.

Trauma resulting in temporal bone fractures may be associated with conductive, sensorineural, or mixed hearing loss. If the fracture spares the inner ear, there may simply be conductive hearing loss due to rupture of the tympanic membrane or disruption of the ossicular chain. These abnormalities can be surgically corrected. Profound hearing loss and severe vertigo are associated with temporal bone fractures involving the inner ear. A perilymphatic fistula associated with leakage of inner-ear fluid into the middle ear can occur and may require surgical repair. An associated facial nerve injury is not uncommon. CT is best suited to assess fracture of the traumatized temporal bone, evaluate the ear canal, and determine the integrity of the ossicular chain and involvement of the inner ear. Cerebrospinal fluid leaks that accompany temporal bone fractures are usually self-limited; the value of prophylactic antibiotics is uncertain.

**Tinnitus** Tinnitus is defined as the perception of a sound when there is no sound in the environment. It can have a buzzing, roaring, or ringing quality and may be pulsatile (synchronous with the heartbeat). Tinnitus is often associated with either a conductive or sensorineural hearing loss. The pathophysiology of tinnitus is not well understood. The cause of the tinnitus can usually be determined by finding the cause of the associated hearing loss. Tinnitus may be the first symptom of a serious condition such as a vestibular schwannoma. Pulsatile tinnitus requires evaluation of the vascular system of the head to exclude vascular tumors such as glomus jugulare tumors, aneurysms, dural arteriovenous fistulas, and stenotic arterial lesions; it may also occur with SOM, superior semicircular dehiscence, and inner-ear dehiscence. It is most commonly associated with some abnormality of the jugular bulb such as a large jugular bulb or jugular bulb diverticulum. In absence of demonstrated pathology on MRA/MRV or CT angiography, pulsatile tinnitus is usually attributed to turbulent venous blood flow through the transverse sinus, sigmoid sinus, and the jugular bulb.

## ■ GENETIC CAUSES OF HEARING LOSS

 More than half of childhood hearing impairment is thought to be hereditary; hereditary hearing impairment (HHI) can also manifest later in life. HHI may be classified as either nonsyndromic, when hearing loss is the only clinical abnormality, or syndromic, when hearing loss is associated with anomalies in other organ systems. Nearly two-thirds of HHIs are nonsyndromic. Between 70% and 80% of nonsyndromic HHI is inherited in an autosomal recessive manner and designated DFNB; another 15–20% is autosomal dominant (DFNA). Less than 5% is X-linked (DFNX) or maternally inherited via the mitochondria.

More than 150 loci harboring genes for nonsyndromic HHI have been mapped, with recessive loci outnumbering dominant ones; numerous genes have now been identified (Table 34-1). The hearing genes fall into the categories of structural proteins (*MYH9*, *MYO7A*, *MYO15*, *TECTA*, *DIAPH1*), transcription factors (*POU3F4*, *POU4F3*), ion channels (*KCNQ4*, *SLC26A4*), and gap junction proteins (*GJB2*, *GJB3*, *GJB6*). Several of these genes, including *GJB2*, *TECTA*, and *TMCI*, cause both autosomal dominant and recessive forms of nonsyndromic HHI. In general, the hearing loss associated with dominant genes has its onset in adolescence or adulthood, varies in severity, and progresses with age, whereas the hearing loss associated with recessive inheritance is congenital and profound. Connexin 26, a product of the *GJB2* gene, is particularly important because it is responsible for nearly 20% of all cases of childhood deafness; half of genetic deafness in children is *GJB2* related. Two frameshift mutations, 35delG and 167delT, account for >50% of the cases; however, screening for these two mutations alone is insufficient, and sequencing of the entire gene is required to fully capture *GJB2*-related recessive deafness. The 167delT mutation is highly prevalent in Ashkenazi Jews; ~1 in 1765 individuals in this population is homozygous and affected. *GJB2* hearing loss can also vary among the members of the same family, suggesting that other genes or factors influence the auditory phenotype. A single mutation in *GJB2* in combination with a single mutation in *GJB6* (connexin 30) can also lead to hearing loss and is an example of digenic inheritance of hearing loss.

In addition to *GJB2*, several other nonsyndromic genes are associated with hearing loss that progresses with age. The contribution of genetics to presbycusis is also becoming better understood and likely reflects a combination of genetic susceptibility impacted by environmental exposure to sound. Sensitivity to aminoglycoside ototoxicity can be maternally transmitted through a mitochondrial mutation. Susceptibility to noise-induced hearing loss may also be genetically determined.

There are >400 syndromic forms of hearing loss. These include Usher's syndrome (retinitis pigmentosa and hearing loss), Waardenburg's syndrome (pigmentary abnormality and hearing loss), Pendred's syndrome (thyroid organification defect and hearing loss), Alport's syndrome (renal disease and hearing loss), Jervell and Lange-Nielsen syndrome (prolonged QT interval and hearing loss), neurofibromatosis type 2 (bilateral acoustic schwannoma), and mitochondrial disorders (mitochondrial encephalopathy, lactic acidosis, and stroke-like episodes [MELAS]; myoclonic epilepsy and ragged red fibers [MERRF]; and progressive external ophthalmoplegia [PEO]) (Table 34-2).

## APPROACH TO THE PATIENT

### Disorders of the Sense of Hearing

The goal in the evaluation of a patient with auditory complaints is to determine (1) the nature of the hearing impairment (conductive vs sensorineural vs mixed), (2) the severity of the impairment (mild, moderate, severe, or profound), (3) the anatomy of the impairment (external ear, middle ear, inner ear, or central auditory pathway), and (4) the etiology. The presence of signs and symptoms associated with hearing loss should be ascertained (Table 34-3). The history should elicit characteristics of the hearing loss, including the duration of deafness, unilateral versus bilateral involvement, nature of onset (sudden vs insidious), and rate of progression (rapid vs slow). Symptoms of tinnitus, vertigo, imbalance, aural fullness,

otorrhea, headache, facial nerve dysfunction, and head and neck paresthesias should be noted. Information regarding head trauma, exposure to ototoxins, occupational or recreational noise exposure, and family history of hearing impairment may also be important. A sudden onset of unilateral hearing loss, with or without tinnitus, may represent a viral infection of the inner ear, vestibular schwannoma, or a stroke. Patients with unilateral hearing loss (sensory or conductive) usually complain of reduced hearing, poor sound localization, and difficulty hearing clearly in the presence of background noise. Gradual progression of a hearing deficit is common with otosclerosis, noise-induced hearing loss, vestibular schwannoma, or Ménière's disease. Small vestibular schwannomas typically present with asymmetric hearing impairment, tinnitus, and imbalance (rarely vertigo); cranial neuropathy, in particular of the trigeminal or facial nerve, may accompany larger tumors. In addition to hearing loss, Ménière's disease may be associated with episodic vertigo, tinnitus, and aural fullness. Sound-induced vertigo, autophony, and being able to hear one's own neck or eye movement are highly suggestive of superior semicircular canal dehiscence. Hearing loss with otorrhea is most likely due to chronic otitis media or cholesteatoma.

Examination should include the auricle, external ear canal, and tympanic membrane. In the elderly, the external ear canal is often dry and fragile; it is preferable to clean cerumen with wall-mounted suction or cerumen loops and to avoid irrigation. Irrigation should also be avoided when a tympanic membrane perforation is present or the integrity of the eardrum cannot be established. In examining the eardrum, the topography of the tympanic membrane is more important than the presence or absence of the light reflex. In addition to the pars tensa (the lower two-thirds of the tympanic membrane), the pars flaccida (upper one-third of the tympanic membrane) above the short process of the malleus should also be examined for retraction pockets that may be evidence of chronic Eustachian tube dysfunction or cholesteatoma. Insufflation of the ear canal is necessary to assess tympanic membrane mobility and compliance. Careful inspection of the nose, nasopharynx, and upper respiratory tract is important. Unilateral serous effusion or unexplained otalgia should prompt a fiberoptic examination of the nasopharynx and larynx to exclude neoplasms. Cranial nerves should be evaluated with special attention to facial and trigeminal nerves, which are commonly affected with tumors involving the cerebellopontine angle.

The Rinne and Weber tuning fork tests, with a 512-Hz tuning fork, are used to screen for hearing loss, differentiate conductive from sensorineural hearing losses, and confirm the findings of audiologic evaluation. The Rinne test compares the ability to hear by air conduction with the ability to hear by bone conduction. The tines of a vibrating tuning fork are held near the opening of the external auditory canal, and then the stem is placed on the mastoid process; for direct contact, it may be placed on teeth or dentures. The patient is asked to indicate whether the tone is louder by air conduction or bone conduction. Normally, and in the presence of sensorineural hearing loss, a tone is heard louder by air conduction than by bone conduction; however, with conductive hearing loss of ≥30 dB (see "Audiologic Assessment," below), the bone-conduction stimulus is perceived as louder than the air-conduction stimulus. For the Weber test, the stem of a vibrating tuning fork is placed on the head in the midline and the patient is asked whether the tone is heard in both ears or better in one ear than in the other. With a unilateral conductive hearing loss, the tone is perceived in the affected ear. With a unilateral sensorineural hearing loss, the tone is perceived in the unaffected ear. A 5-dB difference in hearing between the two ears is required for lateralization.

## ■ LABORATORY ASSESSMENT OF HEARING

**Audiologic Assessment** The minimum audiologic assessment for hearing loss should include the measurement of pure tone air-conduction and bone-conduction thresholds, speech reception threshold, word recognition score, tympanometry, acoustic reflexes, and

TABLE 34-1 Hereditary Hearing Impairment Genes

DESIGNATION	GENE	FUNCTION	DESIGNATION	GENE	FUNCTION
Autosomal Dominant			Autosomal Recessive		
DFNA1	<i>DIAPH1</i>	Cytoskeletal protein	DFNB1A	<i>GJB2</i>	Gap junction
DFNA2A	<i>KCNQ4</i>	Potassium channel	DFNB1B	<i>GJB6</i>	Gap junction
DFNA2B	<i>GJB3</i>	Gap junction	DFNB2	<i>MYO7A</i>	Cytoskeletal protein
DFNA2C	<i>IFNLR1</i>	Class II cytokine receptor	DFNB3	<i>MYO15A</i>	Cytoskeletal protein
DFNA3A	<i>GJB2</i>	Gap junction	DFNB4	<i>SLC26A4</i>	Chloride/iodide transporter
DFNA3B	<i>GJB6</i>	Gap junction	DFNB6	<i>TMIE</i>	Transmembrane protein
DFNA4A	<i>MYH14</i>	Class II nonmuscle myosin	DFNB7/B11	<i>TMC1</i>	Transmembrane protein
DFNA4B	<i>CEACAM16</i>	Cell adhesion molecule	DFNB8/10	<i>TMPRSS3</i>	Transmembrane serine protease
DFNA5	<i>GSDME/DFNA5</i>	Executioner of pyroptosis	DFNB9	<i>OTOF</i>	Trafficking of membrane vesicles
DFNA6/14/38	<i>WFS1</i>	Transmembrane protein	DFNB12	<i>CDH23</i>	Intercellular adherence protein
DFNA7	<i>LMX1A</i>	Transcription factor	DFNB15/72/95	<i>GPC3</i>	PDZ domain-containing protein
DFNA8/12	<i>TECTA</i>	Tectorial membrane protein	DFNB16	<i>STRC</i>	Stereocilia protein
DFNA9	<i>COCH</i>	Unknown	DFNB18	<i>USH1C</i>	Unknown
DFNA10	<i>EYA4</i>	Developmental gene	DFNB18B	<i>OTOG</i>	Tectorial membrane protein
DFNA11	<i>MYO7A</i>	Cytoskeletal protein	DFNB21	<i>TECTA</i>	Tectorial membrane protein
DFNA13	<i>COL11A2</i>	Cytoskeletal protein	DFNB22	<i>OTOA</i>	Gel attachment to nonsensory cell
DFNA15	<i>POU4F3</i>	Transcription factor	DFNB23	<i>PCDH15</i>	Morphogenesis and cohesion
DFNA17	<i>MYH9</i>	Cytoskeletal protein	DFNB24	<i>RDX</i>	Cytoskeletal protein
DFNA20/26	<i>ACTG1</i>	Cytoskeletal protein	DFNB25	<i>GRXCR1</i>	Reversible S-glutathionylation of proteins
DFNA22	<i>MYO6</i>	Unconventional myosin	DFNB26	<i>GAB1</i>	Member of insulin receptor substrate 1-like multisubstrate docking adapter protein family
DFNA23	<i>SIX1</i>	Developmental gene	DFNB28	<i>TRIOBP</i>	Cytoskeletal-organizing protein
DFNA25	<i>SLC17A8</i>	Vesicular glutamate transporter	DFNB29	<i>CLDN14</i>	Tight junctions
DFNA27	<i>REST</i>	Transcriptional repressor	DFNB30	<i>MYO3A</i>	Hybrid motor-signaling myosin
DFNA28	<i>GRHL2</i>	Transcription factor	DFNB31	<i>WHRN</i>	PDZ domain-containing protein
DFNA34	<i>NLRP3</i>	Pyrin-like protein involved in inflammation	DFNB32/105	<i>CDC14A</i>	Protein phosphatase involved in hair cell ciliogenesis
DFNA36	<i>TMC1</i>	Transmembrane protein	DFNB35	<i>ESRRB</i>	Estradiol-related receptor beta protein
DNA37	<i>COL11A1</i>	Cytoskeletal protein	DFNB36	<i>ESPN</i>	Ca-insensitive actin-bundling protein
DFNA40	<i>CRYM</i>	Thyroid hormone-binding protein	DFNB37	<i>MYO6</i>	Unconventional myosin
DFNA41	<i>P2RX2</i>	Purinergic receptor	DFNB39	<i>HFG</i>	Hepatocyte growth factor
DFNA44	<i>CCDC50</i>	Effector of epidermal growth factor-mediated signaling	DFNB42	<i>ILDR1</i>	Ig-like domain-containing receptor
DFNA50	<i>MIRN96</i>	MicroRNA	DFNB44	<i>ADCY1</i>	Adenylate cyclase
DFNA51	<i>TJP2</i>	Tight junction protein	DFNB48	<i>CIB2</i>	Calcium and integrin binding protein
DFNA56	<i>TNC</i>	Extracellular matrix protein	DFNB49	<i>BDP1</i>	Subunit of RNA polymerase
DFNA64	<i>SMAC/DIABLO</i>	Mitochondrial proapoptotic protein	DFNB49	<i>MARVELD2</i>	Tight junction protein
DFNA65	<i>TBC1D24</i>	ARF6-interacting protein	DFNB53	<i>COL11A2</i>	Collagen protein
DFNA66	<i>CD164</i>	Sialomucin	DFNB59	<i>PJVK</i>	Zn-binding protein
DFNA67	<i>OSBPL2</i>	Intracellular lipid receptor	DFNB60	<i>SLC22A4</i>	Prestin, motor protein of cochlear outer hair cell
DFNA68	<i>HOMER2</i>	Stereociliary scaffolding protein	DFNB61	<i>SLC26A5</i>	Motor protein
DFNA69	<i>KITLG</i>	Ligand for KIT receptor	DFNB63	<i>LRTOMT/COMT2</i>	Putative methyltransferase
DFNA70	<i>MOM2</i>	Initiation and elongation during DNA replication	DFNB66	<i>DCDC2</i>	Ciliary protein
DFNA73	<i>PTPRQ</i>	Member of type III receptor-like protein-tyrosine phosphatase (PTPase) family	DFNB66/67	<i>LHFPL5</i>	Tetraspan protein
	<i>DMXL2</i>	Regulator of Notch signaling	DFNB68	<i>S1PR2</i>	Tetraspan membrane protein of hair cell stereocilia
	<i>MYO3A</i>	Member of myosin superfamily	DFNB70	<i>PNPT1</i>	Mitochondrial-RNA-import protein
	<i>PDE1C</i>	Catalyze hydrolysis of cAMP and cGMP	DFNB73	<i>BSND</i>	Beta subunit of chloride channel
	<i>TRRAP</i>	Transformation/transcription domain associated protein	DFNB74	<i>MSRB3</i>	Methionine sulfoxide reductase
	<i>PLS1</i>	Actin-bundling protein	DFNB76	<i>SYNE4</i>	Part of LINCtethering complex
	<i>SCD5</i>	Catalyzes formation of monounsaturated fatty acids from saturated fatty acids	DFNB77	<i>LOXHD1</i>	Stereociliary protein
	<i>SLC12A2</i>	Sodium-potassium-chloride transporter	DFNB79	<i>TPRN</i>	Unknown
	<i>MAP1B</i>	Microtubule binding protein	DFNB82	<i>GPSM2</i>	Gprotein signaling modulator
	<i>RIPOR2/FAM65B</i>	Membrane-associated protein in stereocilia	DFNB84	<i>PTPRQ</i>	Type III receptor-like protein-tyrosine phosphatase family

(Continued)

TABLE 34-1 Hereditary Hearing Impairment Genes (Continued)

DESIGNATION	GENE	FUNCTION	DESIGNATION	GENE	FUNCTION
DFNB84	<i>OTOG</i>	Otogelin-like protein		<i>WBP2</i>	Transcriptional coactivator for estrogen receptor-alpha and progesterone receptor
DFNB86	<i>TBC1D24</i>	GTPase-activating protein		<i>ESRP1</i>	Modulates activation of G proteins
DFNB88	<i>ELMOD3</i>	GTPase-activating protein		<i>MPZL2</i>	Mediates epithelial cell-cell interactions in developing tissues
DFNB89	<i>KARS</i>	Lysyl-tRNA synthetase		<i>CEACAM16</i>	Cell adhesion molecule
DFNB91	<i>SERPINB6</i>	Protease inhibitor		<i>GRAP</i>	Cytoplasmic signaling protein
DFNB93	<i>CABP2</i>	Calcium-binding protein		<i>SPNS2</i>	Sphingosine-1-phosphate (S1P) transporter
DFN94	<i>NARS2</i>	Mitochondrial asparaginyl-tRNA synthetase		<i>CLDN9</i>	Tight junctions
DFNA97	<i>MET</i>	Oncogene/hepatocyte growth factor receptor		<i>CLRN2</i>	Maintenance of transducing stereocilia in auditory hair cells
DFNB98	<i>TSPEAR</i>	Epilepsy-associated repeats containing protein	<b>X-linked</b>		
DFNB99	<i>TMEM132E</i>	Transmembrane protein	DFNX1	<i>PRPS1</i>	Catalyzes phosphoribosylation of ribose 5-phosphate to 5-phosphoribosyl-1-pyrophosphate
DFNB100	<i>PPIP5K2</i>	Diphosphoinositol-pentakisphosphate kinase	DFNX2	<i>POU3F4</i>	Transcription factor
DFNB101	<i>GRXCR2</i>	Maintaining stereocilia bundles	DFNX4	<i>SMPX</i>	Small muscle protein
DFNB102	<i>EPS8</i>	Epidermal growth factor receptor	DFNX5	<i>AIFM1</i>	Mitochondrial flavin adenine dinucleotide (FAD)-dependent oxidoreductase
DFNB103	<i>CLIC5</i>	Chloride ion transport	DFNX6	<i>COL4A6</i>	Collagen protein
DFNB104	<i>FAM65B/RIPOR2</i>	Membrane-associated protein in stereocilia			
DFNB106	<i>EPS8L2</i>	Actin remodeling in response to EGF stimulation			
DFNB108	<i>ROR1</i>	Receptor tyrosine kinase-like orphan receptor			

TABLE 34-2 Syndromic Hereditary Hearing Impairment Genes

SYNDROME	GENE	FUNCTION
Alport's syndrome	<i>COL4A3-5</i>	Cytoskeletal protein
BOR syndrome	<i>EYA1</i>	Developmental gene
	<i>SIX5</i>	Developmental gene
	<i>SIX1</i>	Developmental gene
Jervell and Lange-Nielsen syndrome	<i>KCNQ1</i>	Delayed rectifier K <sup>+</sup> channel
	<i>KCNQ1</i>	Delayed rectifier K <sup>+</sup> channel
Norrie's disease	<i>NDP</i>	Cell-cell interactions
Pendred's syndrome	<i>SLC26A4</i>	Chloride/iode transporter
	<i>FOX11</i>	Transcriptional activator of <i>SLC26A4</i>
	<i>KCNJ10</i>	Inwardly rectifying K <sup>+</sup> channel
Treacher Collins syndrome	<i>TOOF1</i>	Nucleolar-cytoplasmic transport
	<i>POLR1D</i>	Subunit of RNA polymerases I and III
	<i>POLR1C</i>	Subunit of RNA polymerases I and III
Usher's syndrome	<i>MYO7A</i>	Cytoskeletal protein
	<i>USH1C</i>	Unknown
	<i>CDH23</i>	Intercellular adherence protein
	<i>PCDH15</i>	Cell adhesion molecule
	<i>SANS</i>	Harmonin-associated protein
	<i>CIB2</i>	Calcium- and integrin-binding protein
	<i>USH2A</i>	Cell adhesion molecule
	<i>VLGR1</i>	G protein-coupled receptor
	<i>WHRN</i>	PDZ domain-containing protein
	<i>CLRN1</i>	Cellular synapse protein
	<i>HARS</i>	Histidyl-tRNA synthetase
	<i>PDZD7</i>	PDZ domain-containing protein
WS type I, III	<i>PAX3</i>	Transcription factor
WS type II	<i>MITF</i>	Transcription factor
	<i>SNAI2</i>	Transcription factor
WS type IV	<i>EDNRB</i>	Endothelin B receptor
	<i>EDN3</i>	Endothelin B receptor ligand
	<i>SOX10</i>	Transcription factor

Abbreviations: BOR, branchio-oto-renal syndrome; WS, Waardenburg's syndrome.

acoustic-reflex decay. This test battery provides a screening evaluation of the entire auditory system and allows one to determine whether further differentiation of a sensory (cochlear) from a neural (retrocochlear) hearing loss is indicated.

**Pure tone audiometry** assesses hearing acuity for pure tones. The test is administered by an audiologist and is performed in a sound-attenuated chamber. The pure tone stimulus is delivered with an audiometer, an electronic device that allows the presentation of specific frequencies (generally between 250–8000 Hz) at specific intensities. Air- and bone-conduction thresholds are established for each ear. Air-conduction thresholds are determined by presenting the stimulus in air with the use of headphones. Bone-conduction thresholds are determined by placing the stem of a vibrating tuning fork or an oscillator of an audiometer in contact with the head. In the presence of a hearing loss, broad-spectrum noise is presented to the nontest ear for masking purposes so that responses are based on perception from the ear under test.

The responses are measured in decibels (dBs). An **audiogram** is a plot of intensity in dBs of hearing threshold versus frequency. A dB is equal to 20 times the logarithm of the ratio of the sound pressure required to achieve threshold in the patient to the sound pressure required to achieve threshold in a normal-hearing person. Therefore, a change of 6 dB represents doubling of sound pressure, and a change of 20 dB represents a tenfold change in sound pressure. Loudness, which depends on the frequency, intensity, and duration of a sound, doubles with approximately each 10-dB increase in sound pressure level. Pitch, on the other hand, does not directly correlate with frequency. The

TABLE 34-3 Signs and Symptoms Suggestive of Hearing Loss

Saying "huh" a great deal
Reduced clarity of hearing
Difficulty understanding conversations in background noise
Family complaining of hearing loss
Tinnitus
Turning the volume up on radio or television
Sensitivity to noises
Fullness in the ear
Avoiding social settings

perception of pitch changes slowly in the low and high frequencies. In the middle tones, which are important for human speech, pitch varies more rapidly with changes in frequency.

Pure tone audiometry establishes the presence and severity of hearing impairment, unilateral versus bilateral involvement, and the type of hearing loss. Conductive hearing losses with a large mass component, as is often seen in middle-ear effusions, produce elevation of thresholds that predominate in the higher frequencies. Conductive hearing losses with a large stiffness component, as in fixation of the footplate of the stapes in early otosclerosis, produce threshold elevations in the lower frequencies. Often, the conductive hearing loss involves all frequencies, suggesting involvement of both stiffness and mass. In general, sensorineural hearing losses such as presbycusis affect higher frequencies more than lower frequencies (Fig. 34-3). An exception is Ménière's disease, which is characteristically associated with low-frequency sensorineural hearing loss (though any frequency can be affected). Noise-induced hearing loss has an unusual pattern of hearing impairment in which the loss at 3000–4000 Hz is greater than at higher frequencies. Vestibular schwannomas characteristically affect the higher frequencies, but any pattern of hearing loss can be observed.

Speech recognition requires greater synchronous neural firing than is necessary for appreciation of pure tones. *Speech audiometry* tests the clarity with which one hears. The *speech reception threshold (SRT)* is defined as the intensity at which speech is recognized as a meaningful symbol and is obtained by presenting two-syllable words with an equal accent on each syllable. The intensity at which the patient can repeat 50% of the words correctly is the SRT. Once the SRT is determined, discrimination or word recognition ability is tested by presenting one-syllable words at 25–40 dB above the SRT. The words are phonetically balanced in that the phonemes (speech sounds) occur in the list of words at the same frequency that they occur in ordinary conversational English. An individual with normal hearing or conductive hearing loss can repeat 88–100% of the phonetically balanced words correctly. Patients with a sensorineural hearing loss have variable loss of discrimination. As a general rule, neural lesions produce greater deficits in discrimination than do cochlear lesions. For example, in a patient with mild asymmetric sensorineural hearing loss, a clue to the diagnosis of vestibular schwannoma is the presence of greater than expected deterioration in discrimination ability. Deterioration in discrimination ability at higher intensities above the SRT also suggests a lesion in the eighth nerve or central auditory pathways.

*Tympanometry* measures the impedance of the middle ear to sound and is useful in diagnosis of middle-ear effusions. A *tympanogram* is the graphic representation of change in impedance or compliance as the pressure in the ear canal is changed. Normally, the middle ear is most compliant at atmospheric pressure, and the compliance decreases as the pressure is increased or decreased (type A); this pattern is seen with normal hearing or in the presence of sensorineural hearing loss. Compliance that does not change with change in pressure suggests middle-ear effusion (type B). With a negative pressure in the middle ear, as with Eustachian tube obstruction, the point of maximal compliance occurs with negative pressure in the ear canal (type C). A tympanogram in which no point of maximal compliance can be obtained is most commonly seen with discontinuity of the ossicular chain (type A<sub>1</sub>). A reduction in the maximal compliance peak can be seen in otosclerosis (type A<sub>2</sub>).

During tympanometry, an intense tone elicits contraction of the stapedius muscle. The change in compliance of the middle ear with contraction of the stapedius muscle can be detected. The presence or absence of this *acoustic reflex* is important in determining the etiology of hearing loss as well as in the anatomic localization of facial nerve paralysis. The acoustic reflex can help differentiate between conductive hearing loss due to otosclerosis and that caused by an inner-ear "third window": it is absent in otosclerosis and present in inner-ear conductive hearing loss. Normal or elevated acoustic reflex thresholds in an individual with sensorineural hearing impairment suggest a cochlear hearing loss. An absent acoustic reflex in the setting of sensorineural hearing loss is not helpful in localizing the site of lesion. Assessment of *acoustic reflex decay* helps differentiate sensory from neural hearing losses. In neural hearing loss, such as with vestibular schwannoma, the reflex adapts or decays with time.

OAEs generated by outer hair cells only can be measured with microphones inserted into the external auditory canal. The emissions may be spontaneous or evoked with sound stimulation. The presence of OAEs indicates that the outer hair cells of the organ of Corti are intact and can be used to assess auditory thresholds and to distinguish sensory from neural hearing losses.

**Evoked Responses** *Electrocochleography* measures the earliest evoked potentials generated in the cochlea and the auditory nerve. Receptor potentials recorded include the cochlear microphonic, generated by the outer hair cells of the organ of Corti, and the summating potential, generated by the inner hair cells in response to sound. The whole nerve action potential representing the composite firing of the first-order neurons can also be recorded during electrocochleography. Clinically, the test is useful in the diagnosis of Ménière's disease, in which an elevation of the ratio of summating potential to action potential is seen.

**Brainstem auditory-evoked responses (BAERs)**, also known as ABRs, are useful in differentiating the site of sensorineural hearing loss. In response to sound, five distinct electrical potentials arising from different stations along the peripheral and central auditory pathway (eighth nerve, cochlear nucleus, superior olive complex, lateral lemniscus, and inferior colliculus) can be identified using computer averaging from scalp surface electrodes. BAERs are valuable in situations in which patients cannot or will not give reliable voluntary thresholds. They are also used to assess the integrity of the auditory nerve and brainstem in various clinical situations, including intraoperative monitoring, and in determination of brain death.

The *VEMP test* investigates otolith and vestibular nerve function by presenting a high-level acoustic stimulus and evoking a short-latency electromyographic potential; cVEMP (or cervical VEMP) and oVEMP (or ocular VEMP) have been described. The cVEMP elicits a vestibulo-collic reflex whose afferent limb arises from acoustically sensitive cells in the saccule, with signals conducted via the inferior vestibular nerve. cVEMP is a biphasic, short-latency response recorded from the tonically contracted sternocleidomastoid muscle in response to loud auditory clicks or tones. cVEMPs may be diminished or absent in patients with early and late Ménière's disease, vestibular neuritis, benign paroxysmal positional vertigo, and vestibular schwannoma. On the other hand, the threshold for VEMPs may be lower in cases of superior canal dehiscence, other inner-ear dehiscence ("third window"), and perilymphatic fistula. The oVEMP, in contrast, is a response involving the utricle primarily and superior vestibular nerve. The oVEMP excitatory response is recorded from the extraocular muscle. The oVEMP is abnormal in superior vestibular neuritis.

**Imaging Studies** The choice of radiologic tests is largely determined by whether the goal is to evaluate the bony anatomy of the external, middle, and inner ear or to image the auditory nerve and brain. Axial and coronal CT of the temporal bone with fine 0.3-mm cuts is ideal for determining the caliber of the external auditory canal, integrity of the ossicular chain, and presence of middle-ear or mastoid disease; it can also detect inner-ear malformations. CT is also ideal for the detection of bone erosion with chronic otitis media and cholesteatoma. Pöschl reformatting in the plane of the superior semicircular canal is required for the identification of dehiscence or absence of bone over the superior semicircular canal. MRI is superior to CT for imaging of retrocochlear pathology such as vestibular schwannoma, meningioma, other lesions of the cerebellopontine angle, demyelinating lesions of the brainstem, and brain tumors. Both CT and MRI are equally capable of identifying inner-ear malformations and assessing cochlear patency for preoperative evaluation of patients for cochlear implantation.

## TREATMENT

### Disorders of the Sense of Hearing

In general, conductive hearing losses are amenable to surgical correction, whereas sensorineural hearing losses are usually managed medically. Atresia of the ear canal can be surgically repaired,

often with significant improvement in hearing. Alternatively, the conductive hearing loss associated with atresia can be addressed with a bone-anchored hearing aid (BAHA). Tympanic membrane perforations due to chronic otitis media or trauma can be repaired with an outpatient tympanoplasty. Likewise, conductive hearing loss associated with otosclerosis can be treated by stapedectomy, which is successful in >95% of cases. Tympanostomy tubes allow the prompt return of normal hearing in individuals with middle-ear effusions. Hearing aids are effective and well tolerated in patients with conductive hearing losses.

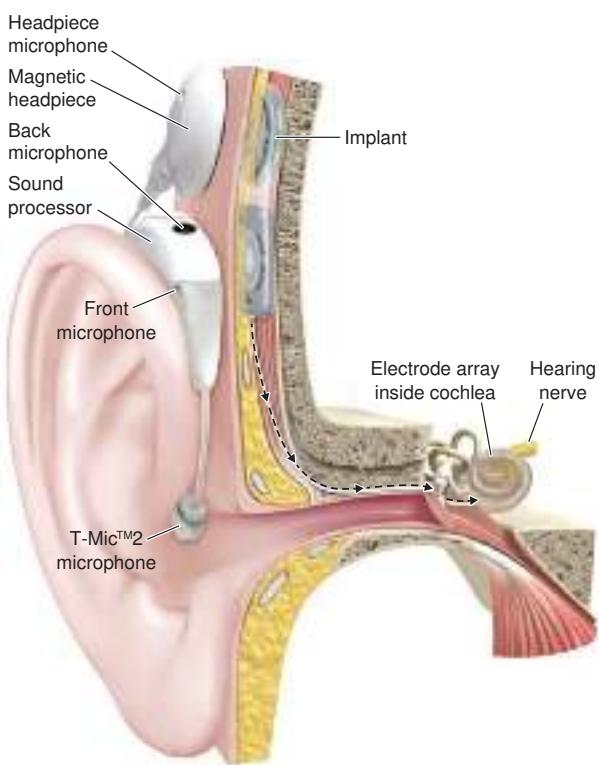
Patients with mild, moderate, and severe sensorineural hearing losses are regularly rehabilitated with hearing aids of varying configuration and strength. Hearing aids have been improved to provide greater fidelity and have been miniaturized. The current generation of hearing aids is nearly invisible, thus reducing stigma associated with their use. In general, the more severe the hearing impairment, the larger the hearing aid required for auditory rehabilitation. Digital hearing aids lend themselves to individual programming, and multiple and directional microphones at the ear level may be helpful in noisy surroundings. Because all hearing aids amplify noise as well as speech, the only absolute solution to the problem of noise is to place the microphone closer to the speaker than the noise source. This arrangement is not possible with a self-contained, cosmetically acceptable device. A significant limitation of rehabilitation with a hearing aid is that although it is able to enhance detection of sound with amplification, it cannot restore clarity of hearing that is lost with presbycusis.

The cost of a single hearing aid (~\$2300 US) is a significant obstacle for many hearing-impaired individuals and usually bilateral amplification is recommended. To reduce cost and spur innovation, a new category of over-the-counter amplification devices that can be purchased similar to reading eyeglasses by simply walking into a store has recently been approved by the US Food and Drug Administration. By reducing the cost of amplification devices to consumers, promoting innovation, and increasing competition, this new class of devices could fundamentally change the way hearing rehabilitation is delivered.

Patients with unilateral deafness have difficulty with sound localization and reduced clarity of hearing in background noise. They may benefit from contralateral routing of signal (CROS) hearing aid in which a microphone is placed on the hearing-impaired side, and the sound is transmitted to the receiver placed on the contralateral ear. The same result may be obtained with a BAHA, in which a hearing aid clamps to a screw integrated into the skull on the hearing-impaired side. Like the CROS hearing aid, the BAHA transfers the acoustic signal to the contralateral hearing ear, but it does so by vibrating the skull. Patients with profound deafness on one side and some hearing loss in the better ear are candidates for a BICROS hearing aid; it differs from the CROS hearing aid in that the patient wears a hearing aid, and not simply a receiver, in the better ear. Unfortunately, while CROS and BAHA devices provide benefit, they do not restore hearing in the deaf ear. Only cochlear implants can restore hearing (see below). Increasingly, cochlear implants are being used for the treatment of patients with single-sided deafness; they show great promise in not only restoring hearing and reducing tinnitus, but also improving sound localization and performance in background noise.

In many situations, including lectures and the theater, hearing impaired persons benefit from assistive devices that are based on the principle of having the speaker closer to the microphone than any source of noise. Assistive devices include infrared and frequency-modulated (FM) transmission as well as an electromagnetic loop around the room for transmission to the individual's hearing aid. Hearing aids with telecoils can also be used with properly equipped telephones in the same way. Bluetooth technology has revolutionized connectivity between hearing aids and other devices such as smart phones.

In the event that the hearing aid provides inadequate rehabilitation, cochlear implants may be appropriate (Fig. 34-4). Criteria for implantation include severe to profound hearing loss with open-set sentence cognition of ≤40% under best-aided conditions.



**FIGURE 34-4** A cochlear implant is composed of an external microphone and speech processor worn on the ear and a receiver implanted underneath the temporalis muscle. The internal receiver is attached to an electrode that is placed surgically in the cochlea.

Worldwide, >600,000 hearing-impaired individuals have received cochlear implants. Cochlear implants are neural prostheses that convert sound energy to electrical energy and can be used to stimulate the auditory division of the eighth nerve directly. In most cases of profound hearing impairment, the auditory hair cells are lost but the ganglionic cells of the auditory division of the eighth nerve are preserved. Cochlear implants consist of electrodes that are inserted into the cochlea through the round window, speech processors that extract acoustic elements of speech for conversion to electrical currents, and a means of transmitting the electrical energy through the skin. Patients with implants experience sound that helps with speech reading, allows open-set word recognition, and helps in modulating the person's own voice. Usually, within the first 3–6 months after implantation, adult patients can understand speech without visual cues. With the current generation of multichannel cochlear implants, nearly 75% of patients are able to converse on the telephone. Bilateral cochlear implantations are commonly performed, especially in children; these patients perform better in background noise, have better sound localization, and are less fatigued by the “work” compared to monaural hearing.

Hybrid cochlear implants are indicated for the treatment of high-frequency hearing loss in patients who do not have profound hearing loss and yet do not benefit from hearing aids. Patients with presbycusis typically have normal low-frequency hearing while suffering from high-frequency hearing loss associated with loss of clarity that cannot always be adequately rehabilitated with a hearing aid. However, these patients are not candidates for conventional cochlear implants because they have too much residual hearing. The hybrid implant has been specifically designed for this patient population; it has a shorter electrode than a conventional cochlear implant and can be introduced into the cochlea atraumatically, thus preserving low-frequency hearing. Individuals with a hybrid implant use their own natural low-frequency “acoustic” hearing and

rely on the implant for providing “electrical” high-frequency hearing. Patients who have received the hybrid implant perform better on speech discrimination tests in both quiet and noisy backgrounds.

For individuals who were born without cochlea or have had both eighth nerves destroyed by trauma or bilateral vestibular schwannomas (e.g., neurofibromatosis type 2), brainstem auditory implants placed near the cochlear nucleus may provide auditory rehabilitation. Currently, brainstem implants provide sound awareness but unfortunately speech understanding remains elusive.

Tinnitus often accompanies hearing loss. Similar to background noise, tinnitus can degrade speech comprehension in individuals with hearing impairment. Patients with tinnitus should be advised to minimize caffeine ingestion, avoid high dosage of nonsteroidal anti-inflammatory drugs (NSAIDs), and reduce stress. Therapy for tinnitus is usually directed toward minimizing the appreciation of tinnitus. Relief of the tinnitus may be obtained by masking it with background music or white noise. Hearing aids are also helpful in tinnitus suppression, as are tinnitus maskers, devices that present a sound to the affected ear that is more pleasant to listen to than the tinnitus. The use of a tinnitus masker is often followed by several hours of inhibition of the tinnitus. Antidepressants have also been shown to be beneficial in helping patients cope with tinnitus.

Hard-of-hearing individuals often benefit from a reduction in unnecessary noise in the environment (e.g., radio or television) to enhance the signal-to-noise ratio. Speech comprehension is aided by lip reading; therefore, the impaired listener should be seated so that the face of the speaker is well illuminated and easily seen. Although speech should be in a loud, clear voice, one should be aware that in sensorineural hearing losses in general and in hard-of-hearing elderly in particular, recruitment (abnormal perception of loud sounds) may be troublesome. Above all, optimal communication cannot take place without both parties giving it their full and undivided attention.

## ■ PREVENTION

Conductive hearing losses may be prevented by prompt antibiotic therapy of adequate duration for AOM and by ventilation of the middle ear with tympanostomy tubes in middle-ear effusions lasting  $\geq 12$  weeks. Loss of vestibular function and deafness due to aminoglycoside antibiotics can largely be prevented by careful monitoring of serum peak and trough levels.

Some 10 million Americans have noise-induced hearing loss, and 20 million are exposed to hazardous noise in their employment. Noise-induced hearing loss can be prevented by avoidance of exposure to loud noise or by regular use of earplugs or fluid-filled ear muffs to attenuate intense sound. **Table 34-4** lists loudness levels for a variety of environmental sounds. High-risk activities for noise-induced hearing loss include use of electrical equipment for wood- and metalworking, and target practice or hunting with small firearms. All internal-combustion

**TABLE 34-5 OSHA Daily Permissible Noise Level Exposure**

SOUND LEVEL (dB)	DURATION PER DAY (h)
90	8
92	6
95	4
97	3
100	2
102	1.5
105	1
110	0.5
115	$\leq 0.25$

Note: Exposure to impulsive or impact noise should not exceed 140-dB peak sound pressure level.

Source: From [https://www.osha.gov/pls/oshaweb/owadisp.show\\_document?p\\_table=standards&p\\_id=9735](https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9735).

and electric engines, including snow and leaf blowers, snowmobiles, outboard motors, and chainsaws, require protection of the user with hearing protectors. Virtually all noise-induced hearing loss is preventable through education, which should begin before the teenage years. Programs for conservation of hearing in the workplace are required by the Occupational Safety and Health Administration (OSHA) whenever the exposure over an 8-h period averages 85 dB. OSHA mandates that workers in such noisy environments have hearing monitoring and protection programs that include a preemployment screen, an annual audiologic assessment, and the mandatory use of hearing protectors. Exposure to loud sounds above 85 dB in the work environment is restricted by OSHA, with halving of allowed exposure time for each increment of 5 dB above this threshold; for example, exposure to 90 dB is permitted for 8 h; 95 dB for 4 h, and 100 dB for 2 h (**Table 34-5**).

## ■ FURTHER READING

- C ML: Cochlear implantation in adults. *N Engl J Med* 382:1531, 2020.
- E -S JM, L -E JA: Menière's disease. *Handb Clin Neurol* 137:257, 2016.
- M T, S A: Auditory neuropathy—neural and synaptic mechanisms. *Nat Rev Neurol* 12:135, 2016.
- P M et al: Intratympanic methylprednisolone versus gentamicin in patients with unilateral Menière's disease: a randomised, double-blind, comparative effectiveness trial. *Lancet* 388:2753, 2016.
- T C et al: Interventions to prevent occupational noise-induced hearing loss. *Cochrane Database Syst Rev* 7:CD006396, 2017.
- W BS et al: Global hearing health care: new findings and perspectives. *Lancet* 390:2503, 2017.

**TABLE 34-4 Decibel (Loudness) Level of Common Environmental Noise**

SOURCE	DECIBEL (dB)
Weakest sound heard	0
Whisper	30
Normal conversation	55–65
City traffic inside car	85
OSHA Monitoring Requirement Begins	90
Jackhammer	95
Subway train at 200 ft	95
Power mower	107
Power saw	110
Painful Sound	125
Jet engine at 100 ft	140
12-gauge shotgun blast	165
Loudest sound that can occur	194

Abbreviation: OSHA, Occupational Safety and Health Administration.

35

## Upper Respiratory Symptoms, Including Earache, Sinus Symptoms, and Sore Throat

Rachel L. Amdur, Jeffrey A. Linder



Upper respiratory symptoms are most commonly caused by viral infection but also can be caused by other infectious, inflammatory, allergic, autoimmune, and neoplastic conditions. This chapter will discuss ambulatory antibiotic prescribing and review the most common causes of upper respiratory symptoms, including nonspecific upper respiratory infections.

Ear pain is most commonly caused by otitis externa, acute otitis media (AOM), otitis media with effusion (OME), and acute mastoiditis. Sinus symptoms can be caused by acute sinusitis, invasive fungal sinusitis, nosocomial sinusitis, and chronic sinusitis. Sore throat and neck pain can be caused by streptococcal pharyngitis, nonstreptococcal pharyngitis, acute infectious mononucleosis, other types of bacterial pharyngitis, Lemierre's syndrome, gonococcal pharyngitis, diphtheria, acute HIV infection, head and neck abscesses, epiglottitis, and laryngitis. At the time of presentation, upper respiratory symptoms of most common viral and bacterial etiologies have generally lasted from hours up to a few days.

## UPPER RESPIRATORY INFECTIONS

Upper respiratory infections (URIs) are acute respiratory infections that occur above the vocal cords. URIs, including nonspecific upper respiratory tract infection, otitis media, sinusitis, and pharyngitis, are collectively the most common symptomatic reason for seeking care in the United States. In terms of etiology, symptoms, and signs, URIs overlap with lower acute respiratory infections that occur below the vocal cords, such as influenza (Chap. 200), acute bronchitis, and pneumonia (Chap. 126), as well as with noninfectious cough (Chap. 38). The average adult has 2–4 URIs per year; children can have 6–10 URIs annually. URIs can be prevented by hand washing or sanitization, physical distancing, use of facial masks, isolation of persons who are ill, and environmental cleaning (Chap. 199).

SARS-CoV-2, the pathogen that causes COVID-19, can cause virtually any upper respiratory symptom (Chap. 199). COVID-19 symptoms appear 2–14 days after exposure and may include fever, chills, cough, shortness of breath, fatigue, myalgias, headaches, rhinorrhea, sore throat, nausea, vomiting, or diarrhea. New loss of taste or smell appears to be specific for COVID-19. Until there is widespread natural or vaccine-induced immunity, any respiratory symptom occurring in areas where SARS-CoV-2 is circulating should be considered a potential manifestation of COVID-19.

### ■ IMPROVING AMBULATORY ANTIBIOTIC PRESCRIBING

The only common acute respiratory infections that should be treated with antibiotics are AOM, sinusitis, streptococcal pharyngitis, and pneumonia. Even for AOM, sinusitis, and pharyngitis, only a minority of cases meet the criteria for antibiotic prescribing. Common respiratory viruses (Chap. 199) cause the overwhelming majority of acute respiratory infections, and these infections are generally self-limited; antibiotics neither speed resolution nor prevent complications for the majority of acute respiratory infections. Unfortunately, for this reason, at least half of ambulatory antibiotic prescriptions for acute respiratory infections in the United States are inappropriate. Internationally, population rates of antibiotic prescribing vary nearly threefold, with no differences in infectious complications. Antibiotics cause adverse drug effects, alter the microbiome, cause *Clostridioides difficile* infection (Chap. 134), increase health care costs, and increase the prevalence of antibiotic-resistant bacteria (Chap. 145).

Clinicians prescribe inappropriate antibiotics because of time pressure; fear of missing a rare bacterial diagnosis; concern about preventing a rare bacterial complication; a lack of salience of adverse antibiotic effects; or a mistaken belief that most patients expect, demand, or will not be satisfied without an antibiotic prescription.

### ■ AMBULATORY ANTIBIOTIC STEWARDSHIP

Antibiotic stewardship has traditionally been an inpatient concern (Chap. 144), but ambulatory antibiotic use accounts for ~85% of antibiotic use by patients in most developed countries. In 2016, the Centers for Disease Control and Prevention published the "Core Elements of Outpatient Antibiotic Stewardship." The core elements include (1) committing to improving antibiotic prescribing; (2) implementing at least one policy or practice to improve antibiotic prescribing and assessing its effectiveness; (3) monitoring antibiotic prescribing and providing feedback; and (4) providing educational resources to clinicians and

patients on antibiotic prescribing. Effective interventions to decrease inappropriate ambulatory antibiotic prescribing include peer comparison, accountable justification, precommitment, clinical decision support, patient education, and multifaceted interventions. Communication training has been particularly effective when it includes making a clear diagnosis, focusing on positive actions patients can take to feel better, reviewing the expected course of illness, and informing patients about concerning symptoms (red flags) for which they should seek or reconnect with care. Telemedicine—synchronous telephone or video or asynchronous electronic messaging—has the potential to improve patient convenience and reduce inappropriate antibiotic prescribing.

Several techniques that seemed promising for the reduction of ambulatory antibiotic prescribing remain unproven, have been ineffective (e.g., procalcitonin testing), or are not durable (e.g., C-reactive protein testing). The practice of delayed antibiotic prescription—i.e., a prescription given to a patient who is asked not to fill it unless symptoms do not improve in a few days—is conceptually flawed and should be avoided. Delayed antibiotic prescriptions are usually given for antibiotic-inappropriate diagnoses (e.g., viral infections); they ignore the natural history of acute respiratory infections, which are self-limited and generally last from 5 to 14 days; they put the burden of clinical decision-making on patients; and they send a confusing, mixed message to patients about the appropriateness of antibiotics for respiratory infections.

## NONSPECIFIC UPPER RESPIRATORY INFECTION "THE COMMON COLD"

### ■ DEFINITION AND ETIOLOGY

Nonspecific URI, or the common cold, is a respiratory tract infection in which no single symptom predominates. Nonspecific URI is most commonly caused by respiratory viruses that are acquired through direct contact with infected individuals, contaminated surfaces, and large and small respiratory droplets. The most common viral causes of nonspecific URIs are rhinoviruses (well over 100 serotypes; Chap. 199), coronaviruses, parainfluenza virus, respiratory syncytial virus, influenza virus (Chap. 199), adenovirus (57 serotypes; Chap. 199), metapneumovirus, and bocavirus (Chap. 199). Making a specific viral diagnosis is not practical, cost-effective, or necessary. Multiplex panels of reverse transcription polymerase chain reaction are available but may be overly sensitive, as prior recent infection can cause false-positive results. Although the diagnosis is usually obvious, clinicians diagnosing a nonspecific URI should also consider influenza (Chap. 200), measles (cough, coryza, and conjunctivitis; Chap. 205), acute HIV infection (in which sore throat and rash often predominate; see below and Chap. 202), and COVID-19 (Chap. 199).

Individual susceptibility to nonspecific URIs depends on prior exposure, immunity, general health, genetics, microbiome-related factors, and mental health and social factors, including stress. Prior exposure leads to immunity to specific rhinoviruses and adenoviruses, but the number of serotypes makes reinfection likely. Immunity to non-COVID-19 coronaviruses, parainfluenza virus, respiratory syncytial virus, and metapneumoviruses is generally weak or of short duration.

### ■ SYMPTOMS AND SIGNS

Common respiratory viruses have incubation periods of 2–8 days after exposure. Symptoms generally begin gradually and include nasal fullness or obstruction, rhinorrhea, sore throat, laryngitis, lymphadenopathy, cough, and low-grade fever. Patients may have myalgias, but this feature usually is not as prominent as it is in influenza. Epistaxis is common with frequent nose blowing.

On physical examination, findings vary, but patients may have conjunctivitis, pharyngeal erythema, pharyngeal exudates, or pharyngeal cobblestoning. Depending on the phase of illness, the nasal mucosa may be pale, boggy, or red and swollen. Nasal mucus can range from watery to purulent. On auscultation, the lungs may be clear, or the patient may have diffuse wheezing or bronchial breath sounds consistent with a viral infection. Symptoms usually last 5–10 days but often last up to 14 days.

## TREATMENT

### Nonspecific Upper Respiratory Infection

For adults and older children, treatment of nonspecific URI is symptom-based. Fever, myalgias, and sore throat can be treated with acetaminophen or a nonsteroidal anti-inflammatory drug (NSAID) such as ibuprofen. Rhinorrhea can be treated with ipratropium bromide. Nasal congestion can be managed with nasal decongestants such as oxymetazoline (two sprays into each nostril twice a day for up to 5 days) or systemic decongestants such as pseudoephedrine. Products that combine a decongestant with analgesics, antihistamines, or both help relieve symptoms. Although supporting data are weak, cough may be relieved with dextromethorphan or benzonatate (Tessalon Perles). Opioids, while effective at relieving cough, are associated with somnolence, dysphoria, constipation, and addiction.

For children <6 years old, cough and cold medicines should not be prescribed, recommended, or used because of the risks of adverse effects. Honey can help soothe a sore throat for children >1 year old. Cool-mist humidifiers may help with breathing, and saline nasal drops and bulb suctioning can help with nasal congestion.

Patients need to be informed that symptoms generally peak early but can last for up to 14 days; that they are infectious as long as they have symptoms; and that they should rest and drink plenty of fluids to avoid dehydration. Red flags for which patients should seek care include a fever of >102°F, chest pain (other than from a pulled muscle), shortness of breath, dizziness, confusion, new ear or sinus pain, and symptoms lasting >14 days. Although nonspecific URI can be complicated by otitis media and bacterial sinusitis, for an individual patient, an antibiotic is more likely to cause an adverse reaction than to prevent complications.

Other remedies that are ineffective, of questionable benefit, or associated with significant adverse effects include echinacea, zinc, inhaled steam, vitamin C, vitamin D, garlic, antihistamines, Chinese medicinal herbs, intranasal glucocorticoids, *Pelargonium sidoides* herbal extract, saline nasal irrigation, and antiviral drugs.

## EAR PAIN

Ear pain is most commonly caused by otitis externa and otitis media. In adults, otologic disease is almost always associated with hearing changes. At >50 years of age, temporal arteritis should be considered in patients who have headache, malaise, weight loss, fever, anorexia, and a normal ear exam. Head and neck cancers should be considered in persons with a history of smoking and alcohol use. In children, the presence of a foreign body should be considered.

Ear pain can also result from other causes of local infection, inflammation, trauma, or tumors or can be referred. Innervation of the ear and surrounding areas includes cranial nerves V, VII, IX, and X and cervical nerves C2 and C3. Neuropathic and myopathic pain syndromes (e.g., trigeminal neuralgia) can cause ear pain. Ramsay Hunt syndrome (herpes zoster oticus) (Chap. 441) and Bell's palsy (Chap. 441) are both associated with ear pain.

Dental pathology can cause pain that radiates to the ear; caries and abscesses are most common. Bruxism, malocclusion, and temporomandibular disorder may be associated with tenderness in muscular attachments and the temporomandibular joint. Salivary gland pathology and cervical adenopathy can cause pain that radiates to the ear.

Sinusitis, tonsillitis, and pharyngitis cause pain that can radiate to the ear via cranial nerve IX. Gastroesophageal reflux disease (Chap. 321) is often associated with ear symptoms. Myocardial infarction can cause ear pain via cranial nerve X.

Relapsing polychondritis (Chap. 366) is a rare condition associated with recurrent, sometimes bilateral, erythematous, or violaceous swelling of the auricle (sparing the earlobe). Inflammation from relapsing polychondritis can involve nasal septal, laryngeal, or respiratory cartilage and can cause ocular inflammation, audiovestibular damage, and nonerosive seronegative inflammatory arthritis.

## ■ OTITIS EXTERNA

**Etiology and Clinical Manifestations** Otitis externa is an inflammation or infection of the external auditory canal manifesting as pain, redness, swelling, aural discharge, and hearing impairment. It is often associated with bacterial infection (frequently by *Pseudomonas aeruginosa* or *Staphylococcus aureus*), but fungi like *Aspergillus* or *Candida* can be implicated.

Otitis externa is most common among preteen and teenage children. Risk factors for otitis externa include swimming (with the resulting condition referred to as "swimmer's ear," which is more common in the summer), mechanical trauma (from cotton swabs or hearing aids), narrow ear canals, cerumen obstruction, eczema, and psoriasis. Classic swimmer's ear is associated with bacterial infection. Physical exam is notable for pain on movement of the auricle or tragus and an external auditory canal that is erythematous, edematous, inflamed, and sometimes coated with exudate on otoscopy. In contrast, fungal otitis externa often manifests with pruritus and ear discharge but without much pain.

Otitis externa can co-occur with otitis media. Preauricular, mastoid, parotid, or cervical lymphadenopathy may be present. AOM with tympanic membrane rupture (see below) can be associated with ear discharge and debris in the ear canal but (unlike otitis externa) without sensitivity to movement of the auricle.

**Malignant Otitis Externa** Malignant otitis externa is a potentially life-threatening form of otitis externa that involves the temporal bone and occurs in patients with diabetes or other types of immunosuppression, often in older adults. Patients may have fever. Progression of malignant otitis externa can affect cranial nerve VII, IX, XI, or XII.

## TREATMENT

### Otitis Externa

Analgesia should be provided with acetaminophen or an NSAID. The mainstay of treatment is one or more topical antibacterial drugs with a glucocorticoid for 7–10 days. Polymyxin B-neomycin-hydrocortisone is often used but should be avoided in patients with tympanic membrane perforation because of ototoxicity. Ciprofloxacin-hydrocortisone is an alternative.

Topical aluminum acetate may be as effective as a topical antibacterial-glucocorticoid regimen. For patients whose condition does not improve within 2–4 days with topical treatment, ear wicks or gauze impregnated with or soaked in anti-infective agents can be placed. Ineffective treatments include oral antibiotics and topical antifungals. Otitis externa frequently recurs; its recurrence may be prevented with periodic acetic acid or aluminum acetate drops.

For malignant otitis externa, oral antipseudomonal antibiotics are often prescribed. Patients sometimes require IV pain medication, fluids, or other antimicrobials.

## ■ ACUTE OTITIS MEDIA

**Epidemiology and Etiology** AOM—for which patients almost always present within days—is predominantly a disease of children, with incidence peaking at 6–24 months of age. By age 6, ~60% of children will have had an episode of AOM. Younger children appear to be susceptible because of a shorter, more horizontal eustachian tube that more easily accumulates fluid than it does in older children and adults and because their immune system is still developing.

AOM is caused by a viral URI leading to edema and inflammation of the nasopharynx and eustachian tube, collection of fluid, and infection by bacteria that colonize the nasopharynx. Viruses isolated include respiratory syncytial virus, rhinoviruses, enteroviruses, coronaviruses, influenza virus, adenoviruses, and human metapneumovirus. The bacteria most commonly isolated are *Streptococcus pneumoniae*, non-typeable *Haemophilus influenzae*, and *Moraxella catarrhalis*.

**Symptoms and Signs** Symptoms of AOM include ear pain, fever, irritability, otorrhea, and anorexia. Physical examination may be notable for a bulging, inflamed, cloudy tympanic membrane, with obscured landmarks, and immobility of the membrane on pneumatoscopy, the Valsalva maneuver, or swallowing while holding the nose shut. (An immobile tympanic membrane is also indicative of perforation, old middle-ear adhesions, a blocked auditory tube, or the presence of middle-ear fluid.) Patients have conductive hearing loss. Severe signs and symptoms include moderate to severe otalgia, otalgia lasting at least 2 days, and a temperature of  $>102.2^{\circ}\text{F}$ .

AOM should be diagnosed in children with moderate to severe bulging of the tympanic membrane or new-onset otorrhea (not due to otitis externa). With mild bulging of the tympanic membrane, AOM can also be diagnosed if the patient has had symptoms for  $<48$  h or if there is intense erythema of the tympanic membrane. AOM should *not* be diagnosed in children who do not have middle-ear effusion.

## TREATMENT

### Acute Otitis Media

Pain from AOM should be treated with NSAIDs or acetaminophen, which are effective for mild to moderate pain. Topical agents like benzocaine, procaine, or lidocaine may provide some additional, brief benefit beyond that offered by NSAIDs or acetaminophen.

In up to 80% of children, AOM resolves without antibiotics. Indications for antibiotic treatment in children include an age of  $<6$  months, bilateral ear findings in children 6 months to 2 years old, otorrhea in children  $>6$  months old, and—in children of all ages—ear findings with severe otalgia, ear pain for  $>48$  h, or a fever of  $>102.2^{\circ}\text{F}$  ([Table 35-1](#)).

The benefits of antibiotics are modest and are offset by adverse effects. Antibiotics do not result in early resolution of pain but do decrease pain by day 2 or 3 (number needed to treat, 20 patients treated with antibiotics for 1 patient to have decreased pain by day 2 or 3). More children who receive antibiotics have vomiting, diarrhea, and rash (number needed to harm, 14 patients treated with antibiotics for 1 to have vomiting, diarrhea, or rash). Severe complications like mastoiditis are rare, and the number needed to treat to prevent a case of mastoiditis is  $\sim 5000$  (i.e., 5000 otitis media patients treated with antibiotics to prevent 1 case of mastoiditis). The American Academy of Family Physicians recommends not routinely prescribing antibiotics for otitis media in children 2–12 years old who have nonsevere symptoms and for whom the observation option is reasonable.

The antibiotic of choice for AOM is high-dose amoxicillin (90 mg/kg per d, up to 3 g). Alternatives include cefdinir, cefuroxime, cefpodoxime, or IM ceftriaxone. If the patient has received amoxicillin in the prior 30 days, clinicians should prescribe amoxicillin/clavulanate (90/6.4 mg/kg per d) in two divided doses. The duration of antibiotic treatment is 10 days for children  $<2$  years old or children with severe symptoms; 5–7 days for children 2–5 years old with mild to moderate AOM; and 5 days for children  $\geq 6$  years old with mild or moderate symptoms.

If a patient's condition is not better after 48–72 h of treatment, the antibiotic regimen should be changed to amoxicillin/clavulanate, a second- or third-generation oral cephalosporin, or IM ceftriaxone.

**TABLE 35-1** Indications for Antibiotic Treatment of Acute Otitis Media

AGE	INDICATION
<6 months	Antibiotic treatment reasonable for all
6 months to 2 years	Bilateral ear findings
$\geq 6$ months	Oturrhea
>2 years	Symptoms worsening or not improving within 48–72 h
All ages	Ear findings with severe otalgia, otalgia lasting at least 2 days, or temperature of $>102.2^{\circ}\text{F}$

for 3 days. If, despite a change in antibiotics, the patient's condition still does not improve, that patient should be referred to a specialist. Middle-ear effusions are present in 60–70% of children with AOM; these should resolve over 3 months. Tympanostomy tubes should be considered for recurrent AOM (i.e., three episodes in 6 months or four episodes in 1 year). Mastoiditis is a rare complication of AOM that is suggested by postauricular tenderness, a postauricular mass, or protrusion of the ear lobe.

In adults, AOM is rare and there is little high-quality evidence to guide treatment. For adults, it remains important to differentiate AOM from OME, but AOM is generally treated with antibiotics, regardless of bilaterality or otorrhea. Amoxicillin is the drug of choice. Adults should also be treated with decongestants and analgesics. Adults with more than two episodes in a year or persistent effusion should be referred to an otolaryngologist.

## ■ OTITIS MEDIA WITH EFFUSION

**Definition and Etiology** OME, also called serous otitis media, occurs when there is fluid in the middle ear but no acute infection. Most patients with OME are young children; >60% of cases occur in children  $<2$  years old. Many children have recurrent episodes.

OME is most often a sequela of a viral infection causing AOM, but it can also be caused by allergies. In addition to allergies, predisposing factors include craniofacial abnormalities, gastroesophageal reflux, and enlarged adenoids.

**Symptoms and Signs** The most common symptoms are decreases in sound conduction and hearing. Children with OME may exhibit impaired language development or communication difficulties. More rarely, patients complain of intermittent ear fullness or earache, tinnitus, or balance problems. On examination, the tympanic membrane may be translucent or gray with fluid (often colorless or amber), air-fluid levels, or bubbles behind the membrane. There is a loss of the light reflex. The tympanic membrane has decreased mobility on pneumatic otoscopy. The evaluation may include audiology, tympanometry, and, in infants, measurement of auditory brainstem responses.

OME usually resolves spontaneously within 4–6 weeks. If it persists for  $>3$  months, the condition is referred to as chronic OME or chronic serous otitis media.

**Cholesteatomas** are accumulations of epithelium or keratin in the middle ear that can enlarge, perforate the tympanic membrane, envelop the ossicles, or destroy surrounding tissue. Cholesteatomas can cause labyrinthitis, hearing loss, cranial nerve palsies, vertigo, meningitis, extradural or brain abscess, and lateral sinus thrombophlebitis.

## TREATMENT

### Otitis Media with Effusion

OME is treated with myringotomy with tympanostomy tube insertion. For young children with nasal obstruction or recurrent infection, adenoidectomy may be considered. Medications, including antihistamines, glucocorticoids, or antibiotics, do not reliably help. Children at risk for speech or language delay may need earlier referral for more aggressive treatment.

## ■ ACUTE MASTOIDITIS

**Etiology** Acute mastoiditis is a serious infection with significant morbidity despite antibiotic and surgical treatment. This condition is most common among children  $<2$  years old but can occur at any age. Acute mastoiditis is often a complication of AOM but may develop without clinically apparent, prior AOM. In older children with acute mastoiditis, clinicians should suspect cholesteatoma.

The pathogenesis of mastoiditis involves spread of organisms from the middle-ear spaces through the aditus ad antrum to the mastoid air cells. *Incipient* mastoiditis consists of fluid within the mastoid air

cells, without bony destruction of the bony septa, and can progress to *coalescent* mastoiditis, with destruction of the bony septa. Acute mastoiditis often causes subperiosteal abscess laterally. The organisms most commonly involved in mastoiditis are *S. pneumoniae*, *Streptococcus pyogenes*, *H. influenzae*, *S. aureus* (including methicillin-resistant *S. aureus* [MRSA] strains), and *P. aeruginosa*.

**Symptoms and Signs** Symptoms of acute mastoiditis include ear pain, fever, lethargy, or fussiness despite adequate treatment of AOM. Patients—especially those with subperiosteal abscess—may have postauricular erythema, tenderness, warmth, fluctuance, and protrusion of the auricle. Otoscopic examination most often yields findings of AOM and may show superoposterior protrusion of the external auditory canal. Complications of mastoiditis include facial nerve palsy, labyrinthitis, skull osteomyelitis, temporal lobe abscess, cerebellar abscess, meningitis, epidural abscess, subdural abscess, venous sinus thrombosis, or Bezold's abscess (an abscess medial to the sternocleidomastoid that tracks into the deep cervical fascia).

**Evaluation** Laboratory evaluation reveals elevation of inflammatory markers and white blood cells with neutrophilia. Imaging is not necessary in children with a classic history and presentation but may be required if there is concern about complications or severity. CT may show disruption of bony septations, fluid, mucosal thickening, periosteal thickening, disruption of the periosteum, or subperiosteal abscess. MRI with gadolinium permits better visualization of abscesses and vascular problems.

**Differential Diagnosis** The differential diagnosis of acute mastoiditis includes cellulitis, otitis externa, postauricular lymphadenopathy, perichondritis, and tumors, including rhabdomyosarcoma, Ewing sarcoma, and myofibroblastic tumor.

## TREATMENT

### Mastoiditis

Patients with mastoiditis should be admitted to the hospital and treated with IV antibiotics and myringotomy, with or without tympanostomy tubes; if there is no improvement within 48 h, mastoidectomy should be undertaken. Tympanostomy or myringotomy samples or subperiosteal abscess drainage should be sent for culture and sensitivity testing. Depending on complications, additional drainage and surgical procedures may be necessary.

Empirical IV antibiotic therapy for children without recurrent AOM or recent antibiotic treatment consists of vancomycin (if there is concern about antibiotic-resistant *S. pneumoniae* or MRSA) or a cephalosporin (e.g., cefepime or ceftazidime). Patients with recurrent AOM or recent antibiotic treatment should be given vancomycin plus an antipseudomonal penicillin. Culture and sensitivity results will guide antibiotic changes. IV antibiotic therapy should be continued for 7–10 days, and patients should complete a 4-week course of oral antibiotics.

## SINUS SYMPTOMS

Sinus symptoms are commonly due to respiratory viruses. These symptoms are considered acute if they last <4 weeks, subacute if they last 4–12 weeks, and chronic if they last ≥12 weeks. Beyond sinus infection, the differential diagnosis of rhinitis includes the common cold, allergic rhinitis (Chap. 352), vasomotor rhinitis, rhinitis medicamentosa due to topical decongestants, drug-induced rhinitis (e.g., due to aspirin, ibuprofen, or beta blockers), autoimmune disease (e.g., granulomatosis with polyangiitis), and cerebrospinal fluid leak. Pain over the sinuses can be caused by headaches (Chap. 430), facial pain syndromes, temporomandibular disorder (Chap. 36), and dental pathology. Gastroesophageal reflux can cause referral of symptoms to the sinuses. Patients who have uncontrolled diabetes or are otherwise

immunocompromised can have rapidly progressing invasive fungal infections (Chap. 211). More indolent fungal infections should be considered in the event of recurrent or nonresolving sinusitis. In children, it is important to consider the presence of a foreign body as a cause of sinus symptoms.

## ■ ACUTE SINUSITIS

**Definition and Etiology** *Sinusitis* is an inflammation of the paranasal sinuses; *rhinosinusitis* also involves the nasal passages. The majority of acute sinusitis cases are caused by respiratory viruses. A diagnosis of sinusitis is a major reason for unnecessary antibiotic prescribing in adults: although <2% of sinusitis episodes are due to bacteria (most often *S. pneumoniae*, *H. influenzae*, or *M. catarrhalis*), antibiotics are prescribed at >70% of office visits for sinusitis. According to guideline criteria, no more than 50% of adults—and probably closer to 20%—meet the criteria for antibiotic prescribing.

**Symptoms and Signs** Sinusitis symptoms commonly include purulent nasal discharge, facial congestion or fullness, and facial pain or pressure. Other symptoms include fever; hyposmia or anosmia; ear pain, pressure, or fullness; postnasal drip; halitosis; maxillary toothache; cough; and fatigue. Risk factors for developing sinusitis include an age of 45–65 years, smoking, asthma, air travel, and allergies.

On physical examination, direct rhinoscopy reveals excess mucus or purulence. Patients may have tenderness over the maxillary sinuses and, in severe cases, erythema and swelling of the maxilla. Sinus transillumination is not accurate in diagnosing sinusitis.

**Complications** Complications from sinusitis can be dramatic but are extremely rare. These complications may include orbital cellulitis, osteomyelitis, meningitis, intracranial abscesses, and cavernous sinus thrombosis. New symptoms that might indicate a sinusitis complication include confusion, unilateral weakness, proptosis, limited ocular movements, and acute vision changes.

**RECURRENT ACUTE SINUSITIS** Patients who have four or more episodes of acute sinusitis in a year, without signs or symptoms between episodes, are said to have recurrent acute sinusitis.

**INVASIVE FUNGAL SINUSITIS** Invasive fungal sinusitis may develop in immunocompromised patients, such as those with uncontrolled diabetes or transplant recipients, and should be considered an emergency. Invasive fungal sinusitis is caused by Mucorales fungi or *Aspergillus* (Chap. 217). Patients may appear to have a rapidly progressive case of rhinosinusitis, with facial pain and pressure, headaches, and fever followed within days by cranial nerve involvement, orbital swelling, cellulitis, proptosis, chemosis, and ophthalmoplegia. Patients may be critically ill. Evaluation should include nasal endoscopy with biopsy and imaging with gadolinium-enhanced MRI as the preferred modality.

**NOSOCOMIAL SINUSITIS** Nosocomial sinusitis occurs in critically ill patients, often those who are nasotracheally intubated. Nosocomial sinusitis should be suspected in hospitalized patients who have fever without another identifiable cause.

## TREATMENT

### Acute Sinusitis

All patients with acute sinusitis should be counseled about symptom-based treatments, which may include decongestants, analgesic/antipyretics, nasal saline, or intranasal glucocorticoids. Intranasal decongestants (e.g., oxymetazoline, two sprays in each nostril twice a day for no more than 5 days) and oral decongestants (e.g., 12-h pseudoephedrine [120 mg] during the day) relieve pain, pressure, and rhinorrhea. Analgesics and antipyretics like acetaminophen or NSAIDs (e.g., ibuprofen), nasal saline spray, and nasal washes provide relief. Intranasal glucocorticoids may help, particularly for

TABLE 35-2 Indications for Antibiotic Treatment of Acute Sinusitis

INDICATION	DEFINITION
Persistent	Symptoms lasting ≥10 days
Severe	Fever of >102°F and either purulent nasal discharge or nasal pain for at least 3–4 consecutive days
Worsening	New fever, headache, or increase in nasal discharge following an upper respiratory tract infection that lasted for 5–6 days and was initially improving

Note: In typical populations, roughly 20% and no more than 50% of adults with sinusitis will meet the criteria for antibiotic prescribing.

patients with an allergic cause of sinusitis. Because patients may be accustomed to receiving antibiotics, provision of a clear explanation, symptom-based treatments, and reasons for reconsultation are important. Red flags for which patients should reconsult include recurrent fever of >102°F, sinus symptoms that worsen after initial improvement, and rapid worsening of facial pain that becomes persistent, as well as any other concerning symptoms.

Antibiotic prescribing criteria for sinusitis are based on symptoms (Table 35-2). Only patients with persistent, severe, or worsening symptoms, especially those who have already used decongestants and analgesics for 2–4 days, meet the criteria for antibiotic prescribing. The antibiotic of choice is amoxicillin/clavulanate (875 mg/125 mg bid for 7 days). Amoxicillin (875 mg PO bid for 7 days) is an alternative. For patients with mild penicillin allergies, cefuroxime is a reasonable choice. For those with severe penicillin allergies, doxycycline is a reasonable alternative. Macrolides are specifically not recommended for sinusitis because of high rates of macrolide-resistant *S. pneumoniae*.

Patients who meet the criteria for antibiotic prescribing should show signs of improvement after 3–5 days of therapy. If not, second-line regimens include amoxicillin/clavulanate (2000 mg/125 mg bid for 7 days) or levofloxacin, although fluoroquinolones are associated with dysglycemia, neuropathy, and tendon and aortic rupture. For patients whose condition still is not improving after 3–5 days of treatment with a second-line antibiotic or in whom a complication or an alternative diagnosis is suspected, clinicians should consider referral to an otorhinolaryngologist and/or the performance of imaging tests. The imaging modality of choice is noncontrast CT. Patients with recurrent acute sinusitis may benefit from nasal culture during episodes; imaging between episodes to identify predisposing anatomic abnormalities; and allergic or immunologic evaluation.

Patients with acute fungal sinusitis should be treated with IV antifungal agents and often require surgical debridement. Patients with nosocomial sinusitis should have precipitating factors (e.g., nasotracheal intubation) addressed and should be empirically treated with broad-spectrum antibiotics until culture and susceptibility results are available.

## CHRONIC SINUSITIS

**Definition and Etiology** Chronic sinusitis is defined as inflammation of the paranasal sinuses that lasts >12 weeks. Chronic sinusitis is primarily an inflammatory disease and can also be associated with acute or chronic infection or allergic, structural (e.g., deviated nasal septum or polyps), and immunologic etiologies. Repeated viral infections may lead to chronic sinusitis. Bacterial colonization or chronic infection plays a role in some cases of chronic sinusitis. *S. aureus* and gram-negative bacteria are commonly identified. Commonly involved allergens and irritants are dust mites, mold, tobacco smoke, occupational factors, and other airborne toxins. Functional or immunologic problems can include impaired mucociliary clearance (e.g., due to cystic fibrosis) or immunodeficiency due to acquired conditions or medications. Chronic sinusitis often coexists with allergic rhinitis and asthma.

**Symptoms and Signs** Cardinal symptoms of chronic sinusitis are facial pain or pressure, nasal discharge or postnasal drip, congestion, and hyposmia or anosmia. Associated symptoms may include fatigue, malaise, ear pressure, hoarseness, and cough. The diagnosis of sinus inflammation must be confirmed with anterior rhinoscopy, nasal endoscopy, or imaging because up to 40% of patients with chronic sinus symptoms do not have mucosal changes evidencing disease.

In practical terms, chronic sinusitis can be divided into three main types (in decreasing order of frequency): (1) chronic sinusitis without polyps, (2) chronic sinusitis with polyps, and (3) allergic fungal sinusitis. In general, chronic sinusitis without polyps is more common among women, develops in childhood and young adulthood, is characterized by presentations with facial pain, and is often due to T<sub>H</sub>1 lymphocyte predominance associated with bacterial infection or colonization. Chronic sinusitis with polyps is more common among men; develops in adulthood; is characterized by presentations with decrease or loss of smell, asthma, or aspirin sensitivity (Chap. 287); and is often due to T<sub>H</sub>2 lymphocyte predominance associated with eosinophilic inflammation, asthma, or aspirin sensitivity. Allergic fungal rhinosinusitis is also associated with polyp formation; typically occurs in patients in their 20s and 30s who are from warm, humid regions and who have other atopic diseases; and is associated with IgE-mediated allergy and eosinophils (Chap. 217). The mucus in allergic fungal rhinosinusitis is classically greenish-brown, has a peanut butter-like consistency, and includes viable hyphae from *Aspergillus* or other fungal species. Allergic fungal rhinosinusitis is resistant to medical treatments.

**Evaluation** On anterior rhinoscopy, polyps are seen as white, gray, tan, or yellow translucent growths in the middle meatus. The imaging modality of choice is noncontrast CT. Allergic fungal rhinosinusitis may be unilateral; however, unilateral symptoms or polyps on exam or imaging, especially if associated with bloody discharge, should raise concern about tumors.

## TREATMENT

### Chronic Sinusitis

Treatment includes avoidance of identifiable triggers such as allergens, smoke, and irritants. Saline sprays and washes provide symptom relief, and higher-volume saline washes are probably more effective. Intranasal glucocorticoids, including mometasone and fluticasone sprays or higher-potency and higher-volume budesonide rinses, are mainstays of treatment, especially for chronic sinusitis with polyps. Intranasal glucocorticoids reduce polyp size. Oral administration of glucocorticoids for 2–3 weeks is sometimes effective against chronic sinusitis that is unresponsive to intranasal steroids—again, especially for patients with polyps. Intranasal or systemic antihistamines may help patients whose illness has an allergic component. Likewise, leukotriene antagonists like montelukast may help.

Although antibiotics are frequently prescribed for 2–4 weeks to patients with chronic sinusitis, there is little evidence that these drugs are effective. Evidence of modest quality supports the use of 3 months of macrolide treatment for patients who have chronic sinusitis without polyps. Antifungal agents have not shown benefit against any subtype of chronic sinusitis. Decongestants should be used only sparingly and briefly.

Endoscopic sinus surgery improves quality of life in patients who have had inadequate responses to medical therapy. Patients with more limited, focal disease may more reliably have better results. The goals of surgery are to remove polyps from the nasal cavity and paranasal sinuses. For patients with allergic fungal rhinosinusitis, medical therapy is classically ineffective, surgery produces good results, and patients should be treated with perioperative glucocorticoids. In children, adenoidectomy may be effective in some cases. In the future, immune endotyping may allow selection of more individualized biological treatments.

**TABLE 35-3** Clinical Findings That Suggest Various Forms of Nonstreptococcal Pharyngitis

CLINICAL FINDING(S) OR BEHAVIORAL FACTOR	SUSPECTED DIAGNOSIS
Scarlatiniform rash	Group A $\beta$ -hemolytic streptococci or <i>Arcanobacterium haemolyticum</i>
Cough and otitis media	<i>Haemophilus influenzae</i>
Sex between men with associated urogenital symptoms, fellatio between a woman and a man who has current urogenital symptoms, persistent sore throat unresponsive to penicillin	<i>Neisseria gonorrhoeae</i>
Travel to endemic areas, pseudomembrane on examination	<i>Corynebacterium diphtheriae</i>
Persistent sore throat with bronchopulmonary symptoms	<i>Mycoplasma pneumoniae</i>
Marked adenopathy (especially that involving posterior cervical or auricular nodes), splenomegaly, palatine petechiae, gelatinous uvula	Acute infectious mononucleosis
New sexual partner in the previous month; fever, rash, myalgias, headache	Acute HIV infection

## SORE THROAT AND NECK PAIN

Sore throat is not synonymous with pharyngitis and can also be caused by submandibular space, retropharyngeal and peritonsillar abscesses, thyroiditis, gastroesophageal reflux, tumors, and postnasal drainage.

Acute pharyngitis, in which symptoms are generally present for days, is most often caused by respiratory viruses; is often caused by group A  $\beta$ -hemolytic streptococci (GAS); and can be caused by other bacteria (including *Neisseria gonorrhoeae*), Epstein-Barr virus (EBV), and HIV. On physical examination, pharyngeal erythema is associated most commonly with viral infections, including the common cold and influenza. Pharyngeal exudate should not be confused with *Candida* infection, which looks like cottage-cheese, can be scraped off, and leaves a bleeding surface, or leukoplakia, which cannot be scraped off. History and exam findings may help differentiate sore throat and pharyngitis of various etiologies (Table 35-3).

### ■ STREPTOCOCCAL PHARYNGITIS

GAS is the only common cause of sore throat that should be treated with antibiotics. The principal goal in the evaluation of adults with sore throat is to identify patients likely to have GAS pharyngitis, or “strep throat.” Prompt antibiotic treatment of adults likely to have strep throat has the potential to reduce symptoms, prevent the spread of disease, and reduce suppurative complications (e.g., peritonsillar abscess). Nonsuppurative complications are rare. In developed countries, the prevalence of rheumatic fever (Chap. 148) is extremely low, and antibiotic treatment does not prevent poststreptococcal glomerulonephritis (Chap. 148).

Most patients with non-GAS pharyngitis have various forms of viral pharyngitis and do not require antibiotics. Nevertheless, clinicians prescribe antibiotics to a majority of adults with sore throats. By using a simple clinical scoring algorithm, clinicians can predict the presence or absence of GAS with sufficient accuracy and avoid prescribing antibiotics to patients who are unlikely to have strep throat. Although there is a role for testing (see “Evaluation,” below), most adults with sore throat do not need to have a GAS test.

About 10% of adults with sore throat are infected with GAS. Among children with sore throat, the prevalence of GAS can be as high as 35%, with rates peaking from 5 to 15 years of age. The prevalence of GAS is higher in winter and early spring. The risk of streptococcal pharyngitis is elevated among health care and child care workers, teachers, parents of young children, and patients exposed to individuals with strep throat. Clinicians need to be aware of local outbreaks of GAS infection,

**TABLE 35-4** The Centor Criteria and the Probability of Streptococcal Pharyngitis for Adults<sup>a</sup>

NO. OF CRITERIA MET <sup>b</sup>	POSTEVALUATION PROBABILITY (%)	RECOMMENDATION
0	2	No test, no antibiotic
1	3	No test, no antibiotic
2	8	Rapid test
3	19	Rapid test
4	41	Empirical antibiotic treatment or rapid test

<sup>a</sup>Assuming a pretest probability of strep throat for adults of 10%. <sup>b</sup>The criteria are (1) a history of fever, (2) an absence of cough, (3) tender anterior cervical lymphadenopathy, and (4) tonsillar swelling or exudate. Each criterion gets 1 point. Roughly 40–60% of adults will meet no criteria or one criterion; ~20% will meet the criteria for antibiotic prescribing.

particularly in military and institutional settings, where the prevalence of GAS and the risk of acute rheumatic fever may be elevated.

**Evaluation** The Centor criteria consist of four findings, each of which is assigned 1 point: (1) history of fever, (2) absence of cough, (3) tender anterior cervical lymphadenopathy, and (4) tonsillar exudate or swelling. The Centor criteria are easy to assess and accurately stratify adult patients with suspected streptococcal pharyngitis. Patients with no points have a 2% probability of being infected with GAS, whereas those with 4 points have a probability of 41% (Table 35-4). The Centor criteria have an area under the curve of 0.79. Other clinical decision algorithms similar to the Centor criteria may not perform as well, are not as simple, or have not been as rigorously evaluated.

If the test/no treatment threshold is set at 5%, for a GAS prevalence of ~10%, adults meeting no criteria or only one Centor criterion have a probability of GAS pharyngitis so low that they should neither be tested nor be treated with an antibiotic. Adults meeting two or three Centor criteria have an intermediate probability of GAS pharyngitis; they should have a rapid antigen test performed, and the results should guide antibiotic treatment. For adults meeting four Centor criteria, it is reasonable either to perform a rapid test or to institute empirical antibiotic treatment. However, some guidelines recommend—and some ambulatory quality measures require—a GAS test to be associated with antibiotic prescribing in adults, regardless of the number of Centor criteria met.

In children, the Centor criteria are less specific, and streptococcal pharyngitis should be confirmed with testing. Children who have signs of pharyngitis without signs of viral infection (conjunctivitis, runny nose, cough, hoarseness, nonexudative oral lesions) should have testing performed.

Outside of the United States, because complications are rare and even streptococcal pharyngitis is self-limited in the vast majority of cases, some guidelines do not recommend use of rapid GAS testing or routine antibiotic treatment of sore throat.

Clinicians should have a lower threshold for diagnosing and treating GAS pharyngitis in patients with a history of acute rheumatic fever, patients with documented streptococcal exposure in the past week, patients who live in a community with a current strep throat epidemic, and patients who are diabetic or otherwise immunocompromised.

**RAPID STREP TESTS** Rapid GAS-specific antigen tests have a sensitivity of ~80% and a specificity of ~95%. Results are available within minutes and can be used to make therapeutic decisions before the patient leaves the office. Improper collection technique can adversely affect the sensitivity of rapid strep tests: clinicians should rub the tonsils and pharynx, touching any areas where exudate or ulceration are present.

**THROAT CULTURES** A single-swab throat culture has a sensitivity of ~85–90%, as defined by isolation of GAS on a second swab. A throat culture can also be falsely positive for true infection: some patients with a culture positive for GAS may be only uninfected carriers, as defined by their failure to exhibit a fourfold increase in antibodies to GAS—the gold standard test. Among adults and children seeking medical care for a sore throat, test specificity may be as low as 50–70% because of

CLINICAL FINDING(S) OR BEHAVIORAL FACTOR	SUSPECTED DIAGNOSIS
Scarlatiniform rash	Group A $\beta$ -hemolytic streptococci or <i>Arcanobacterium haemolyticum</i>
Cough and otitis media	<i>Haemophilus influenzae</i>
Sex between men with associated urogenital symptoms, fellatio between a woman and a man who has current urogenital symptoms, persistent sore throat unresponsive to penicillin	<i>Neisseria gonorrhoeae</i>
Travel to endemic areas, pseudomembrane on examination	<i>Corynebacterium diphtheriae</i>
Persistent sore throat with bronchopulmonary symptoms	<i>Mycoplasma pneumoniae</i>
Marked adenopathy (especially that involving posterior cervical or auricular nodes), splenomegaly, palatine petechiae, gelatinous uvula	Acute infectious mononucleosis
New sexual partner in the previous month; fever, rash, myalgias, headache	Acute HIV infection

patients who do not exhibit serologic evidence of infection. Throat cultures are not recommended for the routine evaluation of adults with sore throat. The modest gain in sensitivity over rapid testing is outweighed by the 24- to 48-h delay in test results, with a consequent delay in the symptomatic relief associated with antibiotic treatment.

Indiscriminate strep testing in adults with sore throat or respiratory symptoms should be discouraged. Rapid strep tests and culture do not differentiate between patients who have true infection and those who are carriers of GAS (with carriage rates as high as 20% among schoolchildren and ~5% among adolescents and young adults). In adults who meet no Centor criteria or only one criterion—40–60% of adults with pharyngitis—a positive test is highly likely to be falsely positive and/or to represent GAS carriage.

**Complications** Complications of streptococcal pharyngitis are rare but include acute rheumatic fever (Chap. 148), poststreptococcal glomerulonephritis (Chap. 148), scarlet fever (Chap. 148), sinusitis, peritonsillar abscess, and other invasive GAS infections.

## TREATMENT

### Streptococcal Pharyngitis

All patients with pharyngitis—nonstreptococcal and streptococcal—should receive analgesics (acetaminophen or NSAIDs). Saline gargles, humidification, soft foods, and tea with honey soothe a painful throat.

Penicillin is the antibiotic of choice for streptococcal pharyngitis (Table 35-5). Penicillin is a narrow-spectrum, low-cost, and well-tolerated drug to which no GAS isolate has been resistant. Amoxicillin is an acceptable alternative in children as it comes in a palatable liquid form. For patients with mild penicillin allergy, cephalexin and cefadroxil are good alternatives. For patients with severe penicillin allergies, clinicians should prescribe erythromycin, clarithromycin, or clindamycin. Unlike other infections for which emerging evidence supports progressively shorter antibiotic courses, streptococcal pharyngitis requires longer courses (7–10 days), which are more effective.

Glucocorticoids (e.g., dexamethasone, 10 mg as a single oral dose) have so far been poorly studied as an adjunctive treatment for sore throat and strep throat and are not recommended. These drugs may result in decreased pain within 24 h but do not decrease school or work absenteeism or relapse rates. Even short courses of steroids are associated with increased rates of sepsis, gastrointestinal bleeding, congestive heart failure, venous thromboembolism, and fracture within 30 days.

Streptococcal and nonstreptococcal pharyngitis should resolve in 3–5 days. Symptoms that should lead patients to seek further care include shaking chills (rigors), neck swelling (beyond lymphadenopathy), trouble swallowing, drooling, or symptoms that persist for >5 days without improvement.

**TABLE 35-5** Antibiotic Treatment of Group A Streptococcal Pharyngitis

ANTIBIOTIC	DOSING
<b>Antibiotic of Choice</b>	
Penicillin	500 mg PO qid or 1000 mg PO bid × 10 days
<b>Alternative for Non-Penicillin-Allergic Patients</b>	
Amoxicillin	500 mg PO bid or 1000 mg qd × 10 days
<b>Alternatives for Non-Anaphylactic Penicillin-Allergic Patients</b>	
Cephalexin	500 mg PO bid × 10 days
Cefadroxil	1 g PO qd × 10 days
<b>Alternatives for Patients with Severe Penicillin Allergy</b>	
Erythromycin	250–500 mg PO qid or 500–1000 mg PO bid × 5 days
Clarithromycin	500 mg PO bid × 5 days
Clindamycin	300 mg PO tid × 10 days

### NONSTREPTOCOCCAL PHARYNGITIS

**Acute Infectious Mononucleosis** New EBV infection may be the cause of pharyngitis in 1–6% of young adults (Chap. 194). EBV is rarely the cause of pharyngitis in adults >40 years of age. The full-blown acute syndrome, which is present in only about one-fourth of patients with infectious mononucleosis (“mono”), is characterized by a triad of clinical, hematologic, and serologic findings. The clinical presentation is typified by the development over several days of malaise, fever, sore throat, and marked adenopathy that is particularly evident in the cervical lymph nodes. On physical examination, marked adenopathy is virtually always documented and is most specific for mononucleosis when the posterior cervical or posterior auricular nodes are involved. Splenomegaly and exudative pharyngitis with prominent tonsillar swelling, palatine petechiae, and a gelatinous uvula are often noted. The classic hematologic findings are an absolute lymphocyte count of >4000/ $\mu$ L or a relative lymphocyte count of >50% with “atypical” morphologic features in >10% of the lymphocytes. The characteristic serologic finding is the heterophil antibody, which is detectable in only 40% of patients during the first week of illness but in 80–90% of patients by the third week.

**Other Bacterial Pharyngitis** Non-group A streptococci (especially group C and group G streptococci), *Mycoplasma pneumoniae*, *Chlamydia pneumoniae*, *N. gonorrhoeae*, and *H. influenzae* have all been associated with sore throat in some studies. Although antibacterial treatment has not been proven to speed the resolution of symptoms and signs of any of these types of nonstreptococcal pharyngitis, antibiotic treatment is indicated if throat cultures from a patient with persistent sore throat yield group C or group G streptococci.

**LEMIERRE'S SYNDROME** Lemierre's syndrome consists of septic thrombophlebitis of the internal jugular vein accompanied by metastatic infections, most commonly of the lung but with possible involvement of the joints, bones, liver, meninges, and brain. Lemierre's syndrome is most commonly caused by *Fusobacterium necrophorum*, although it can also be caused by species of *Bacteroides*, *Eikenella*, *Streptococcus*, *Peptostreptococcus*, or other bacterial genera. This syndrome probably occurs predominantly in male patients. Clinicians should consider Lemierre's syndrome in a teenage or young adult patient who has non-GAS pharyngitis that is not resolving, particularly if it is accompanied by rigors, neck pain or swelling, or other extrapharyngeal symptoms.

**GONOCOCCAL PHARYNGITIS** *N. gonorrhoeae* may be the cause of pharyngitis in 1% of adult patients seeking primary care for a sore throat, although gonococcal infection of the pharynx is more often asymptomatic. When symptomatic, pharyngeal gonorrhea may range from mild to severe, with protracted pharyngitis characterized by pain, fever, and pharyngeal exudate. Gonococcal pharyngitis should be suspected in men who have sex with men with associated symptoms of urogenital infection, women who have practiced fellatio with a man with genital gonorrhea, and anyone who has persistent sore throat that has been unresponsive to treatment for presumptive streptococcal pharyngitis.

**DIPHTHERIA** Diphtheria, caused by *Corynebacterium diphtheriae*, is endemic in developing countries (Chap. 150). Diphtheria produces only mild pharyngitis beneath its characteristic grayish pseudomembrane.

**ACUTE HIV INFECTION** Clinicians should consider acute HIV infection in patients with sore throat, particularly when it is associated with headache, fever, myalgias, lymphadenopathy, anorexia, and rash (Chap. 202). Of patients with acute HIV infection, roughly half have a sore throat. However, in most settings in the United States, only ~1% of patients with viral or mononucleosis-like symptoms have acute HIV infection.

### HEAD AND NECK ABSCESESSES

Head and neck abscesses are more common among patients with diabetes, who are immunocompromised, and among older adults. Such abscesses are often a complication of infections of the teeth and gums, throat,

or salivary ducts; lymphadenitis; ear infections; sinus infections; congenital cysts; and IV drug use. Prompt recognition is important, as head and neck abscesses can cause airway compromise due to edema or mass effect. Head and neck abscesses can follow fascial planes and spread to the mediastinum (where they can cause mediastinitis, pleural effusions, empyema, or pericarditis), the carotid sheath, the skull base, and the meninges. Head and neck abscesses have also been associated with aspiration pneumonia, necrotizing fasciitis, Lemierre's syndrome, and toxic shock syndrome.

*Submandibular abscesses* generally result from an infected or extracted tooth and can cause Ludwig angina, a swelling of the floor of the mouth that can enlarge and displace the tongue posteriorly.

*Peritonsillar abscesses*, which may occur predominantly in male patients, generally result from complicated bacterial pharyngitis and present with fever, dysphagia, profound throat pain (necessitating drooling to avoid swallowing saliva), trismus, and "hot potato voice" (inability to articulate, as if patients have hot food in their mouths). Patients are likely to have unilateral palate bulging, often with uvular deviation. Peritonsillar abscesses are caused by viridans group streptococci, β-hemolytic streptococci, *F. necrophorum*, *S. aureus*, *Prevotella*, and *Bacteroides*.

*Retropharyngeal abscesses* often present after an antecedent URI in children with sore throat, dysphagia, deep neck pain, neck stiffness, trismus, and drooling. The pharyngeal wall may be displaced, but swelling or abscess may not be apparent on examination. In severe cases, patients may have dyspnea and stridor.

Patients with suspected head and neck abscesses, with the possible exception of patients who have obvious peritonsillar abscesses, should undergo imaging by CT.

## TREATMENT

### Head and Neck Abscesses

The mainstays of treatment for head and neck abscesses are securing the airway, surgical drainage, and IV antibiotic administration. To secure the airway, mask ventilation or oral intubation may not be effective, and oral fiberoptic intubation or tracheotomy may be necessary. Peritonsillar abscess may be managed with needle aspiration and/or tonsillectomy. Other head and neck abscesses require incision and drainage. The selected IV antibiotics should cover streptococci, anaerobes, and possibly *S. aureus*. Frequently used antibiotics include ampicillin/sulbactam, clindamycin plus ceftriaxone, or meropenem. For some abscesses with adequate source control with incision and drainage, penicillin may be as effective as broader-spectrum agents.

## EPIGLOTTITIS

Along with associated dysphagia, odynophagia, hoarseness, and stridor or tachypnea, supraglottitis or epiglottitis must be considered in adults presenting with sore throat. The inflamed and enlarged epiglottis protrudes up into the oropharynx. Patients may extend their neck or lean forward and drool oral secretions to avoid swallowing. Epiglottitis can cause "hot potato voice." Attempts to examine or swab the posterior pharynx or obtain a culture can provoke laryngospasm and should only be done carefully in a controlled setting. Because obstruction of the airway may become acutely life-threatening, the patient with epiglottitis must be observed in a hospital setting, and examination in an operating room, where an airway can be established immediately by an experienced operator, should be strongly considered. Although not necessary for the diagnosis, a lateral neck radiograph can demonstrate epiglottal swelling referred to as the "thumb sign."

In adults, conservative therapy under observation is sufficient in most cases, but intubation by an experienced clinician or tracheostomy may become necessary. Treatments also include humidification with nebulized normal saline or humidified oxygen and administration of glucocorticoids, IV antibiotics, and nebulized epinephrine.

*H. influenzae*, the most common cause of supraglottitis in children, is less common in adults. Other responsible organisms in adults are *S. pneumoniae*, *S. pyogenes*, and *S. aureus*. The *H. influenzae* type b vaccine has led to a dramatic decrease in epiglottitis overall, with large reductions in young children; however, the incidence of supraglottitis and epiglottitis in adults may be increasing.

## LARYNGITIS

Laryngitis—*inflammation of the larynx and surrounding structures*—is most commonly caused by viral URIs. In children, parainfluenza virus can cause croup, or laryngotracheobronchitis, which is characterized by a "barking" cough but can also include laryngitis.

Beyond viruses, laryngitis can be caused in rare cases by bacteria and fungi. Bacterial laryngitis can be a complication of viral laryngitis, occurring about 7 days into the illness. The most common bacteria involved are *S. pneumoniae*, *H. influenzae*, and *M. catarrhalis*. Fungal laryngitis is probably rarer but should be considered in patients who are immunosuppressed or who have recently been treated with antibacterial drugs.

Noninfectious causes of laryngitis include vocal trauma (e.g., due to yelling, screaming, or loud singing), inhalation injuries, allergies, gastroesophageal reflux disease (laryngopharyngeal reflux), asthma, and pollution. Immunocompetent patients are at risk for infections with herpesvirus, HIV, and coxsackievirus. Smokers are at elevated risk for malignancy and other infections.

Laryngitis is characterized by a raspy, hoarse, or breathy voice, sometimes progressing to a complete loss of voice. Laryngitis can have associated dry cough and anterior throat pain; patients often feel a need to clear their throats. The physical examination in patients who may have laryngitis should focus on the head, neck, and lungs, but the diagnosis of laryngitis is generally based on history. If visualization of the vocal cords is necessary, indirect examination with a mirror or flexible laryngoscopy usually shows erythema and edema of the vocal cords and surrounding structures.

## TREATMENT

### Laryngitis

Laryngitis is generally self-limited, usually lasting 3–7 days, but may last up to 14 days. Vocal rest is crucial. Airway humidification and hydration should help. Patients likely to have laryngopharyngeal reflux should avoid gastroesophageal reflux-inducing foods and behaviors and should take antireflux medications. In randomized controlled trials, antibiotics were not effective in decreasing objective symptoms of laryngitis.

Red flags for emergency evaluation and monitoring include shortness of breath, stridor, dysphagia, odynophagia, drooling, and posturing that could indicate epiglottitis. Referral to an otolaryngologist should be considered for patients who rely on their voice for work, such as singers and teachers. A history of smoking or weight loss should raise suspicion of malignancy. Symptoms lasting >3 weeks should prompt referral to an otolaryngologist or speech specialist.

## FURTHER READING

- C RM, L JA: Web exclusive. Annals on call—*Fusobacterium* pharyngitis debate. Ann Intern Med 171:OC1, 2019.
- C KP et al: Appropriateness of outpatient antibiotic prescribing among privately insured US patients: ICD-10-CM based cross sectional study. BMJ 364:k5092, 2019.
- L AS et al: Clinical practice guideline: The diagnosis and management of acute otitis media. Pediatrics 131:e964, 2013.
- R TA, L JA: Novel approaches to decrease inappropriate ambulatory antibiotic use. Expert Rev Anti Infect Ther 17:511, 2019.
- S GV et al: Core elements of outpatient antibiotic stewardship. MMWR Recomm Rep 65:1, 2016.

As primary care physicians and consultants, internists are often asked to evaluate patients with disease of the oral soft tissues, teeth, and pharynx. Knowledge of the oral milieu and its unique structures is necessary to guide preventive services and recognize oral manifestations of local or systemic disease (Chap. A3). Furthermore, internists frequently collaborate with dentists in the care of patients who have a variety of medical conditions that affect oral health or who undergo dental procedures that increase their risk of medical complications.

### DISEASES OF THE TEETH AND PERIODONTAL STRUCTURES

Tooth formation begins during the sixth week of embryonic life and continues through 17 years of age. Teeth start to develop in utero and continue to develop until after the tooth erupts. Normally, all 20 deciduous teeth have erupted by age 3 and have been shed by age 13. Permanent teeth, eventually totaling 32, begin to erupt by age 6 and have completely erupted by age 14, though third molars ("wisdom teeth") may erupt later.

The erupted tooth consists of the visible *crown* covered with enamel and the root submerged below the gum line and covered with bonelike *cementum*. *Dentin*, a material that is denser than bone and exquisitely sensitive to pain, forms the majority of the tooth substance, surrounding a core of myxomatous *pulp* containing the vascular and nerve supply. The tooth is held firmly in the alveolar socket by the *periodontium*, supporting structures that consist of the gingivae, alveolar bone, cementum, and periodontal ligament. The periodontal ligament tenaciously binds the tooth's cementum to the alveolar bone. Above this ligament is a collar of attached gingiva just below the crown. A few millimeters of unattached or free gingiva (1–3 mm) overlap the base of the crown, forming a shallow sulcus along the gum-tooth margin.

**Dental Caries, Pulpal and Periapical Disease, and Complications** Dental caries usually begin asymptotically as a destructive infectious process of the enamel. Bacteria—principally *Streptococcus mutans*—colonize the organic buffering biofilm (*plaque*) on the tooth surface. If not removed by brushing or by the natural cleansing and antibacterial action of saliva, bacterial acids can demineralize the enamel. Fissures and pits on the occlusal surfaces are the most frequent sites of early decay. Surfaces between the teeth, adjacent to tooth restorations and exposed roots, are also vulnerable, particularly as individuals age. Over time, dental caries extend to the underlying dentin, leading to cavitation of the enamel. Without management, the caries will penetrate to the tooth pulp, producing *acute pulpitis*. At this stage, when the pulp infection is limited, the tooth may become sensitive to percussion and to hot or cold, and pain resolves immediately when the irritating stimulus is removed. Should the infection spread throughout the pulp, *irreversible pulpitis* occurs, leading to *pulp necrosis*. At this later stage, pain can be severe and has a sharp or throbbing visceral quality that may be worse when the patient lies down. Once pulp necrosis is complete, pain may be constant or intermittent, but cold sensitivity is lost.

Treatment of caries involves removal of the softened and infected hard tissue and restoration of the tooth structure with silver amalgam, glass ionomer, composite resin, or gold. Once irreversible pulpitis occurs, root canal therapy becomes necessary; removal of the contents of the pulp chamber and root canal is followed by thorough cleaning and filling with an inert material. Alternatively, the tooth may be extracted.

Pulpal infection leads to *periapical abscess* formation, which can produce pain on chewing. If the infection is mild and chronic, a *periapical granuloma* or eventually a *periapical cyst* forms, either of which

produces radiolucency at the root apex. When unchecked, a periapical abscess can erode into the alveolar bone, producing osteomyelitis; penetrate and drain through the gingivae, producing a parulis (gumboil); or track along deep fascial planes, producing virulent cellulitis (Ludwig's angina) involving the submandibular space and floor of the mouth (Chap. 177). Elderly patients, patients with diabetes mellitus, and patients taking glucocorticoids may experience little or no pain or fever as these complications develop.

**Periodontal Disease** Periodontal disease and dental caries are the primary causes of tooth loss. Like dental caries, chronic infection of the gingiva and anchoring structures of the tooth begins with formation of bacterial plaque. The process begins at the gum line. Plaque and *calculus* (calcified plaque) are preventable by appropriate daily oral hygiene, including periodic professional cleaning. Left undisturbed, chronic inflammation can ensue and produce hyperemia of the free and attached gingivae (*gingivitis*), which then typically bleed with brushing. If this issue is ignored, severe *periodontitis* can develop, leading to deepening of the physiologic sulcus and destruction of the periodontal ligament. Gingival pockets develop around the teeth. As the periodontium (including the supporting bone) is destroyed, the teeth loosen. A role for chronic inflammation due to chronic periodontal disease in promoting coronary heart disease and stroke has been proposed. Epidemiologic studies have demonstrated a moderate but significant association between chronic periodontal inflammation and atherosclerosis, though a causal role remains unproven.

Acute and aggressive forms of periodontal disease are less common than the chronic forms described above. However, if the host is stressed or exposed to a new pathogen, rapidly progressive and destructive disease of the periodontal tissue can occur. A virulent example is *acute necrotizing ulcerative gingivitis*. The presentation includes sudden gingival inflammation, ulceration, bleeding, interdental gingival necrosis, and fetid halitosis. *Localized juvenile periodontitis*, which is seen in adolescents, is particularly destructive and appears to be associated with impaired neutrophil chemotaxis. *AIDS-related periodontitis* resembles acute necrotizing ulcerative gingivitis in some patients and a more destructive form of adult chronic periodontitis in others. It may also produce a gangrene-like destructive process of the oral soft tissues and bone that resembles *noma*, an infectious condition seen in severely malnourished children in developing nations.

**Prevention of Tooth Decay and Periodontal Infection** Despite the reduced prevalences of dental caries and periodontal disease in the United States (due in large part to water fluoridation and improved dental care, respectively), both diseases constitute a major public health problem worldwide, particularly in certain groups. The internist should promote preventive dental care and hygiene as part of health maintenance. Populations at high risk for dental caries and periodontal disease include those with hyposalivation and/or xerostomia, diabetics, alcoholics, tobacco users, persons with Down syndrome, and those with gingival hyperplasia. Furthermore, patients lacking access to dental care (e.g., as a result of low socioeconomic status) and patients with a reduced ability to provide self-care (e.g., individuals with disabilities, nursing home residents, and persons with dementia or upper-extremity disability) suffer at a disproportionate rate. It is important to provide counseling regarding regular dental hygiene and professional cleaning, use of fluoride-containing toothpaste, professional fluoride treatments, and (for patients with limited dexterity) use of electric toothbrushes and also to instruct persons caring for those who are not capable of self-care. Cost, fear of dental care, and differences in language and culture create barriers that prevent some people from seeking preventive dental services.

**Developmental and Systemic Disease Affecting the Teeth and Periodontium** In addition to posing cosmetic issues, *malocclusion*, the most common developmental oral problem, can interfere with mastication unless corrected through orthodontic and surgical techniques. Impacted third molars are common and can become infected or erupt into an insufficient space. Acquired prognathism due to *acromegaly* may also lead to malocclusion, as may deformity of the maxilla and

mandible due to *Paget's disease* of the bone. Delayed tooth eruption, a receding chin, and a protruding tongue are occasional features of *cretinism* and *hypopituitarism*. Congenital syphilis produces tapering, notched (*Hutchinson's*) incisors and finely nodular (*mulberry*) molar crowns. *Enamel hypoplasia* results in crown defects ranging from pits to deep fissures of primary or permanent teeth. Intrauterine infection (syphilis, rubella), vitamin deficiency (A, C, or D), disorders of calcium metabolism (malabsorption, vitamin D-resistant rickets, hypoparathyroidism), prematurity, high fever, and rare inherited defects (*amelogenesis imperfecta*) are all causes. Tetracycline, given in sufficiently high doses during the first 8 years of life, may produce enamel hypoplasia and discoloration. Doxycycline does not cause permanent tooth staining in children despite warnings included for all tetracycline-class antibiotics. Exposure to endogenous pigments can discolor developing teeth; etiologies include *erythroblastosis fetalis* (green or bluish-black), congenital liver disease (green or yellow-brown), and porphyria (red or brown that fluoresces with ultraviolet light). *Mottled enamel* occurs if excessive fluoride is ingested during development. Worn enamel is seen with age, bruxism, or excessive acid exposure (e.g., chronic gastric reflux or bulimia). Celiac disease is associated with nonspecific enamel defects in children but not in adults.

Total or partial tooth loss resulting from periodontitis is seen with cyclic neutropenia, Papillon-Lefèvre syndrome, Chédiak-Higashi syndrome, and leukemia. Rapid focal tooth loosening is most often due to infection, but rarer causes include Langerhans cell histiocytosis, Ewing's sarcoma, osteosarcoma, and Burkitt's lymphoma. Early loss of primary teeth is a feature of *hypophosphatasia*, a rare congenital error of metabolism.

Pregnancy may produce gingivitis and localized *pyogenic granulomas*. Severe periodontal disease occurs in uncontrolled diabetes mellitus. *Drug-induced gingival overgrowth* may be caused by anti-convulsants, calcium channel blockers, and immunosuppressants, although excellent daily oral care can prevent or reduce its occurrence. *Idiopathic familial gingival fibromatosis* and several syndrome-related disorders cause similar conditions. Discontinuation of the medication may reverse the drug-induced form, although surgery may be needed to control both of the latter entities. *Linear gingival erythema* is variably seen in patients with advanced HIV infection and probably represents immune deficiency and decreased neutrophil activity. Diffuse or focal gingival swelling may be a feature of early or late acute myelomonocytic leukemia as well as of other lymphoproliferative disorders. A rare but pathognomonic sign of granulomatosis with polyangiitis is a red-purplish, granular gingivitis (*strawberry gums*).

## DISEASES OF THE ORAL MUCOSA

**Infections** Most oral mucosal diseases involve microorganisms (Table 36-1).

**Pigmented Lesions** See Table 36-2.

**Dermatologic Diseases** See Tables 36-1, 36-2, and 36-3 and Chaps. 56–61.

**Diseases of the Tongue** See Table 36-4.

**HIV Disease and AIDS** See Tables 36-1, 36-2, 36-3, and 36-5; Chap. 202.

**Ulcers** Ulceration is the most common oral mucosal lesion. Although there are many causes, the host and the pattern of lesions, including the presence of organ system features, narrow the differential diagnosis (Table 36-1). Most acute ulcers are painful and self-limited. Recurrent aphthous ulcers and herpes simplex account for the majority. Persistent and deep aphthous ulcers can be idiopathic or can accompany HIV/AIDS. Aphthous lesions are often the presenting symptom in *Behcet's syndrome* (Chap. 364). Similar-appearing, though less painful, lesions may occur in reactive arthritis, and aphthous ulcers are occasionally present during phases of *discoid* or *systemic lupus erythematosus* (Chap. 360). Aphthous-like ulcers are seen in *Crohn's disease* (Chap. 326), but, unlike the common aphthous variety, they

may exhibit granulomatous inflammation on histologic examination. Recurrent aphthous are more prevalent in patients with *celiac disease* and have been reported to remit with elimination of gluten.

Of major concern are chronic, relatively painless ulcers and mixed red/white patches (erythroplakia and leukoplakia) of >2 weeks' duration. Squamous cell carcinoma and premalignant dysplasia should be considered early and a diagnostic biopsy performed. This awareness and this procedure are critically important because early-stage malignancy is vastly more treatable than late-stage disease. High-risk sites include the lower lip, floor of the mouth, ventral and lateral tongue, and soft palate-tonsillar pillar complex. Significant risk factors for oral cancer in Western countries include sun exposure (lower lip), tobacco and alcohol use, and human papillomavirus infection. In India and some other Asian countries, smokeless tobacco mixed with betel nut, slaked lime, and spices is a common cause of oral cancer. Rarer causes of chronic oral ulcer, such as tuberculosis, fungal infection, granulomatosis with polyangiitis, and midline granuloma, may look identical to carcinoma. Making the correct diagnosis depends on recognizing other clinical features and performing a biopsy of the lesion. The syphilitic chancre is typically painless and therefore easily missed. Regional lymphadenopathy is invariably present. The syphilitic etiology is confirmed with appropriate bacterial and serologic tests.

Disorders of mucosal fragility often produce painful oral ulcers that fail to heal within 2 weeks. *Mucous membrane pemphigoid* and *pemphigus vulgaris* are the major acquired disorders. While their clinical features are often distinctive, a biopsy or immunohistochemical examination should be performed to diagnose these entities and to distinguish them from *lichen planus* and drug reactions.

**Hematologic and Nutritional Disease** Internists are more likely to encounter patients with acquired, rather than congenital, bleeding disorders. Bleeding should stop 15 min after minor trauma and within an hour after tooth extraction if local pressure is applied. More prolonged bleeding, if not due to continued injury or rupture of a large vessel, should lead to investigation for a clotting abnormality. In addition to bleeding, petechiae and ecchymoses are prone to occur at the vibrating line between the soft and hard palates in patients with platelet dysfunction or thrombocytopenia.

All forms of leukemia, but particularly *acute myelomonocytic leukemia*, can produce gingival bleeding, ulcers, and gingival enlargement. Oral ulcers are a feature of agranulocytosis, and ulcers and mucositis are often severe complications of chemotherapy and radiation therapy for hematologic and other malignancies. *Plummer-Vinson syndrome* (iron deficiency, angular stomatitis, glossitis, and dysphagia) raises the risk of oral squamous cell cancer and esophageal cancer at the posteriocranial tissue web. Atrophic papillae and a red, burning tongue may occur with pernicious anemia. Deficiencies in B-group vitamins produce many of these same symptoms as well as oral ulceration and cheilosis. Consequences of *scurvy* include swollen, bleeding gums; ulcers; and loosening of the teeth.

## NONDENTAL CAUSES OF ORAL PAIN

Most, but not all, oral pain emanates from inflamed or injured tooth pulp or periodontal tissues. Nonodontogenic causes are often overlooked. In most instances, toothache is predictable and proportional to the stimulus applied, and an identifiable condition (e.g., caries, abscess) is found. Local anesthesia eliminates pain originating from dental or periodontal structures, but not referred pains. The most common nondental source of pain is myofascial pain referred from muscles of mastication, which become tender and ache with increased use. Many sufferers exhibit *bruxism* (grinding of the teeth) secondary to stress and anxiety. *Temporomandibular joint disorder* is closely related. It affects both sexes, with a higher prevalence among women. Features include pain, limited mandibular movement, and temporomandibular joint sounds. The etiologies are complex; malocclusion does not play the primary role once attributed to it. *Osteoarthritis* is a common cause of masticatory pain. Anti-inflammatory medication, jaw rest, soft foods, and heat provide relief. The temporomandibular joint is involved in 50% of patients with *rheumatoid arthritis*, and its involvement is

TABLE 36-1 Vesicular, Bullous, or Ulcerative Lesions of the Oral Mucosa

CONDITION	USUAL LOCATION	CLINICAL FEATURES	COURSE
<b>Viral Diseases</b>			
Primary acute herpetic gingivostomatitis (HSV type 1; rarely type 2)	Lip and oral mucosa (buccal, gingival, lingual mucosa)	Labial vesicles that rupture and crust, and intraoral vesicles that quickly ulcerate; extremely painful; acute gingivitis, fever, malaise, foul odor, and cervical lymphadenopathy; occurs primarily in infants, children, and young adults	Heals spontaneously in 10–14 days; unless secondarily infected, lesions lasting >3 weeks are not due to primary HSV infection
Recurrent herpes labialis	Mucocutaneous junction of lip, perioral skin	Eruption of groups of vesicles that may coalesce, then rupture and crust; painful to pressure or spicy foods	Lasts 1 week, but condition may be prolonged if secondarily infected; if severe, topical or oral antiviral treatment may reduce healing time
Recurrent intraoral herpes simplex	Palate and gingiva	Small vesicles on keratinized epithelium that rupture and coalesce; painful	Heals spontaneously in 1 week; if severe, topical or oral antiviral treatment may reduce healing time
Chickenpox (VZV)	Gingiva and oral mucosa	Skin lesions may be accompanied by small vesicles on oral mucosa that rupture to form shallow ulcers; may coalesce to form large bullous lesions that ulcerate; mucosa may have generalized erythema	Lesions heal spontaneously within 2 weeks
Herpes zoster (VZV reactivation)	Cheek, tongue, gingiva, or palate	Unilateral vesicular eruptions and ulceration in linear pattern following sensory distribution of trigeminal nerve or one of its branches	Gradual healing without scarring unless secondarily infected; postherpetic neuralgia is common; oral acyclovir, famciclovir, or valacyclovir reduces healing time and postherpetic neuralgia
Infectious mononucleosis (Epstein-Barr virus)	Oral mucosa	Fatigue, sore throat, malaise, fever, and cervical lymphadenopathy; numerous small ulcers usually appear several days before lymphadenopathy; gingival bleeding and multiple petechiae at junction of hard and soft palates	Oral lesions disappear during convalescence; no treatment is given, though glucocorticoids are indicated if tonsillar swelling compromises the airway
Herpangina (coxsackievirus A; also possibly coxsackievirus B and echovirus)	Oral mucosa, pharynx, tongue	Sudden onset of fever, sore throat, and oropharyngeal vesicles, usually in children <4 years old, during summer months; diffuse pharyngeal congestion and vesicles (1–2 mm), grayish-white surrounded by red areola; vesicles enlarge and ulcerate	Incubation period of 2–9 days; fever for 1–4 days; recovery uneventful
Hand-foot-and-mouth disease (most commonly coxsackievirus A16)	Oral mucosa, pharynx, palms, and soles	Fever, malaise, headache with oropharyngeal vesicles that become painful, shallow ulcers; highly infectious; usually affects children under age 10	Incubation period 2–18 days; lesions heal spontaneously in 2–4 weeks
Primary HIV infection	Gingiva, palate, and pharynx	Acute gingivitis and oropharyngeal ulceration, associated with febrile illness resembling mononucleosis and including lymphadenopathy	Followed by HIV seroconversion, asymptomatic HIV infection, and usually ultimately by HIV disease

**Bacterial or Fungal Diseases**

Acute necrotizing ulcerative gingivitis ("trench mouth")	Gingiva	Painful, bleeding gingiva characterized by necrosis and ulceration of gingival papillae and margins plus lymphadenopathy and foul breath	Debridement and diluted (1:3) peroxide lavage provide relief within 24 h; antibiotics in acutely ill patients; relapse may occur
Prenatal (congenital) syphilis	Palate, jaws, tongue, and teeth	Gummatus involvement of palate, jaws, and facial bones; Hutchinson's incisors, mulberry molars, glossitis, mucous patches, and fissures at corner of mouth	Tooth deformities in permanent dentition irreversible
Primary syphilis (chancre)	Lesion appearing where organism enters body; may occur on lips, tongue, or tonsillar area	Small papule developing rapidly into a large, painless ulcer with indurated border; unilateral lymphadenopathy; chancre and lymph nodes containing spirochetes; serologic tests positive by third to fourth weeks	Healing of chancre in 1–2 months, followed by secondary syphilis in 6–8 weeks
Secondary syphilis	Oral mucosa frequently involved with mucous patches, which occur primarily on palate and also at commissures of mouth	Maculopapular lesions of oral mucosa, 5–10 mm in diameter with central ulceration covered by grayish membrane; eruptions occurring on various mucosal surfaces and skin, accompanied by fever, malaise, and sore throat	Lesions may persist from several weeks to a year
Tertiary syphilis	Palate and tongue	Gummatus infiltration of palate or tongue followed by ulceration and fibrosis; atrophy of tongue papillae produces characteristic bald tongue and glossitis	Gumma may destroy palate, causing complete perforation
Gonorrhea	Lesions may occur in mouth at site of inoculation or secondarily by hematogenous spread from a primary focus	Most pharyngeal infection is asymptomatic; may produce burning or itching sensation; oropharynx and tonsils may be ulcerated and erythematous; saliva viscous and fetid	More difficult to eradicate than urogenital infection, though pharyngitis usually resolves with appropriate antimicrobial treatment
Tuberculosis	Tongue, tonsillar area, soft palate	Painless, solitary, 1- to 5-cm, irregular ulcer covered with persistent exudate; ulcer has firm undermined border	Autoinoculation from pulmonary infection is usual; lesions resolve with appropriate antimicrobial therapy
Cervicofacial actinomycosis	Swellings in region of face, neck, and floor of mouth	Infection may be associated with extraction, jaw fracture, or eruption of molar tooth; in acute form, resembles acute pyogenic abscess, but contains yellow "sulfur granules" (gram-positive mycelia and their hyphae)	Typically, swelling is hard and grows painlessly; multiple abscesses with draining tracts develop; penicillin first choice; surgery usually necessary

(Continued)

TABLE 36-1 Vesicular, Bullous, or Ulcerative Lesions of the Oral Mucosa (Continued)

CONDITION	USUAL LOCATION	CLINICAL FEATURES	COURSE
<b>Bacterial or Fungal Diseases (Continued)</b>			
Histoplasmosis	Any area of the mouth, particularly tongue, gingiva, or palate	Nodular, verrucous, or granulomatous lesions; ulcers are indurated and painful; usual source hematogenous or pulmonary, but may be primary	Systemic antifungal therapy necessary
<b>Candidiasis<sup>a</sup></b>			
<b>Dermatologic Diseases</b>			
Mucous membrane pemphigoid	Typically produces marked gingival erythema and ulceration; other areas of oral cavity, esophagus, and vagina may be affected	Painful, grayish-white collapsed vesicles or bullae of full-thickness epithelium with peripheral erythematous zone; gingival lesions desquamate, leaving ulcerated area	Protracted course with remissions and exacerbations; involvement of different sites develops slowly; glucocorticoids may temporarily reduce symptoms but do not control disease
EM minor and EM major (Stevens-Johnson syndrome)	Primarily oral mucosa and skin of hands and feet	Intraoral ruptured bullae surrounded by inflammatory area; lips may show hemorrhagic crusts; "iris" or "target" lesion on skin is pathognomonic; patient may have severe signs of toxicity	Onset very rapid; usually idiopathic, but may be associated with trigger such as drug reaction; condition may last 3–6 weeks; mortality rate for untreated EM major is 5–15%
Pemphigus vulgaris	Oral mucosa and skin; sites of mechanical trauma (soft/hard palate, frenulum, lips, buccal mucosa)	Usually (>70%) presents with oral lesions; fragile, ruptured bullae and ulcerated oral areas; mostly in older adults	With repeated occurrence of bullae, toxicity may lead to cachexia, infection, and death within 2 years; often controllable with oral glucocorticoids
Lichen planus	Oral mucosa and skin	White striae in mouth; purplish nodules on skin at sites of friction; occasionally causes oral mucosal ulcers and erosive gingivitis	White striae alone usually asymptomatic; erosive lesions often difficult to treat, but may respond to glucocorticoids
<b>Other Conditions</b>			
Recurrent aphthous ulcers	Usually on nonkeratinized oral mucosa (buccal and labial mucosa, floor of mouth, soft palate, lateral and ventral tongue)	Single or clustered painful ulcers with surrounding erythematous border; lesions may be 1–2 mm in diameter in crops (herpetiform), 1–5 mm (minor), or 5–15 mm (major)	Lesions heal in 1–2 weeks but may recur monthly or several times a year; protective barrier with benzocaine and topical glucocorticoids relieve symptoms; systemic glucocorticoids may be needed in severe cases
Behcet's syndrome	Oral mucosa, eyes, genitalia, gut, and CNS	Multiple aphthous ulcers in mouth; inflammatory ocular changes, ulcerative lesions on genitalia; inflammatory bowel disease and CNS disease	Oral lesions often first manifestation; persist several weeks and heal without scarring
Traumatic ulcers	Anywhere on oral mucosa; dentures frequently responsible for ulcers in vestibule	Localized, discrete ulcerated lesions with red border; produced by accidental biting of mucosa, penetration by foreign object, or chronic irritation by dentures	Lesions usually heal in 7–10 days when irritant is removed, unless secondarily infected
Squamous cell carcinoma	Any area of mouth, most commonly on lower lip, lateral borders of tongue, and floor of mouth	Red, white, or red and white ulcer with elevated or indurated border; failure to heal; pain not prominent in early lesions	Invades and destroys underlying tissues; frequently metastasizes to regional lymph nodes
Acute myeloid leukemia (usually monocytic)	Gingiva	Gingival swelling and superficial ulceration followed by hyperplasia of gingiva with extensive necrosis and hemorrhage; deep ulcers may occur elsewhere on mucosa, complicated by secondary infection	Usually responds to systemic treatment of leukemia; occasionally requires local irradiation
Lymphoma	Gingiva, tongue, palate, and tonsillar area	Elevated, ulcerated area that may proliferate rapidly, giving appearance of traumatic inflammation	Fatal if untreated; may indicate underlying HIV infection
Chemical or thermal burns	Any area in mouth	White slough due to contact with corrosive agents (e.g., aspirin, hot cheese) applied locally; removal of slough leaves raw, painful surface	Lesion heals in several weeks if not secondarily infected

<sup>a</sup>See Table 36-3.

Abbreviations: CNS, central nervous system; EM, erythema multiforme; HSV, herpes simplex virus; VZV, varicella-zoster virus.

usually a late feature of severe disease. Bilateral preauricular pain, particularly in the morning, limits range of motion.

*Migrainous neuralgia* may be localized to the mouth. Episodes of pain and remission without an identifiable cause and a lack of relief with local anesthesia are important clues. *Trigeminal neuralgia (tic dououreux)* can involve the entire branch or part of the mandibular or maxillary branch of the fifth cranial nerve and can produce pain in one or a few teeth. Pain may occur spontaneously or may be triggered by touching the lip or gingiva, brushing the teeth, or chewing. *Glossopharyngeal neuralgia* produces similar acute neuropathic symptoms

in the distribution of the ninth cranial nerve. Swallowing, sneezing, coughing, or pressure on the tragus of the ear triggers pain that is felt in the base of the tongue, pharynx, and soft palate and may be referred to the temporomandibular joint. *Neuritis* involving the maxillary and mandibular divisions of the trigeminal nerve (e.g., maxillary sinusitis, neuroma, and leukemic infiltrate) is distinguished from ordinary toothache by the neuropathic quality of the pain. Occasionally, *phantom pain* follows tooth extraction. Pain and hyperalgesia behind the ear and on the side of the face in the day or so before facial weakness develops often constitute the earliest symptom of *Bell's palsy*. Likewise,

TABLE 36-2 Pigmented Lesions of the Oral Mucosa

CONDITION	USUAL LOCATION	CLINICAL FEATURES	COURSE
Oral melanotic macule	Any area of mouth	Discrete or diffuse, localized, brown to black macule	Remains indefinitely; no growth
Diffuse melanin pigmentation	Any area of mouth	Diffuse pale to dark-brown pigmentation; may be physiologic ("racial") or due to smoking	Remains indefinitely
Nevi	Any area of mouth	Discrete, localized, brown to black pigmentation	Remains indefinitely
Malignant melanoma	Any area of mouth	Can be flat and diffuse, painless, brown to black; or can be raised and nodular	Expands and invades early; metastasis leads to death
Addison's disease	Any area of mouth, but mostly buccal mucosa	Blotches or spots of bluish-black to dark-brown pigmentation occurring early in disease, accompanied by diffuse pigmentation of skin; other symptoms of adrenal insufficiency	Condition controlled by adrenal steroid replacement
Peutz-Jeghers syndrome	Any area of mouth	Dark-brown spots on lips, buccal mucosa, with characteristic distribution of pigment around lips, nose, and eyes and on hands; concomitant intestinal polyposis	Oral pigmented lesions remain indefinitely; gastrointestinal polyps may become malignant
Drug ingestion (neuroleptics, oral contraceptives, minocycline, zidovudine, quinine derivatives)	Any area of mouth	Brown, black, or gray areas of pigmentation	Gradually disappears following cessation of drug intake
Amalgam tattoo	Gingiva and alveolar mucosa	Small blue-black pigmented areas associated with embedded amalgam particles in soft tissues; may show up on radiographs as radiopaque particles in some cases	Remains indefinitely
Heavy metal pigmentation (bismuth, mercury, lead)	Gingival margin	Thin blue-black pigmented line along gingival margin; rarely seen except in children exposed to lead-based paint	Indicative of systemic absorption; no significance for oral health
Black hairy tongue	Dorsum of tongue	Elongation of filiform papillae of tongue, which become stained by coffee, tea, tobacco, or pigmented bacteria	Improves within 1–2 weeks with gentle brushing of tongue or (if due to bacterial overgrowth) discontinuation of antibiotic
Fordyce spots	Buccal and labial mucosa	Numerous small yellowish spots just beneath mucosal surface; no symptoms; due to hyperplasia of sebaceous glands	Benign; remains without apparent change
Kaposi's sarcoma	Palate most common, but may occur at any other site	Red or blue plaques of variable size and shape; often enlarge, become nodular, and may ulcerate	Usually indicative of HIV infection or non-Hodgkin's lymphoma; rarely fatal, but may require treatment for comfort or cosmesis
Mucous retention cysts	Buccal and labial mucosa	Bluish, clear fluid-filled cyst due to extravasated mucus from injured minor salivary gland	Benign; painless unless traumatized; may be removed surgically

TABLE 36-3 White Lesions of Oral Mucosa

CONDITION	USUAL LOCATION	CLINICAL FEATURES	COURSE
Lichen planus	Buccal mucosa, tongue, gingiva, and lips; skin	Striae, white plaques, red areas, ulcers in mouth; purplish papules on skin; may be asymptomatic, sore, or painful; lichenoid drug reactions may look similar	Protracted; responds to topical glucocorticoids
White sponge nevus	Oral mucosa, vagina, anal mucosa	Painless white thickening of epithelium; adolescence/early adulthood onset; familial	Benign and permanent
Smoker's leukoplakia and smokeless tobacco lesions	Any area of oral mucosa, sometimes related to location of habit	White patch that may become firm, rough, or red-fissured and ulcerated; may become sore and painful but is usually painless	May or may not resolve with cessation of habit; 2% of patients develop squamous cell carcinoma; early biopsy essential
Erythroplakia with or without white patches	Floor of mouth commonly affected in men; tongue and buccal mucosa in women	Velvety, reddish plaque; occasionally mixed with white patches or smooth red areas	High risk of squamous cell cancer; early biopsy essential
Candidiasis	Any area in mouth	<i>Pseudomembranous type</i> ("thrush"): creamy white curdlike patches that reveal a raw, bleeding surface when scraped; found in sick infants, debilitated elderly patients receiving high-dose glucocorticoids or broad-spectrum antibiotics, and patients with AIDS	Responds favorably to antifungal therapy and correction of predisposing causes where possible
		<i>Erythematous type</i> : flat, red, sometimes sore areas in same groups of patients	Course same as for pseudomembranous type
		<i>Candidal leukoplakia</i> : nonremovable white thickening of epithelium due to <i>Candida</i>	Responds to prolonged antifungal therapy
		<i>Angular cheilitis</i> : sore fissures at corner of mouth	Responds to topical antifungal therapy
Hairy leukoplakia	Usually on lateral tongue, rarely elsewhere on oral mucosa	White areas ranging from small and flat to extensive accentuation of vertical folds; found in HIV carriers (all risk groups for AIDS)	Due to Epstein-Barr virus; responds to high-dose acyclovir but recurs; rarely causes discomfort unless secondarily infected with <i>Candida</i>
Warts (human papillomavirus)	Anywhere on skin and oral mucosa	Single or multiple papillary lesions with thick, white, keratinized surfaces containing many pointed projections; cauliflower lesions covered with normal-colored mucosa or multiple pink or pale bumps (focal epithelial hyperplasia)	Lesions grow rapidly and spread; squamous cell carcinoma must be ruled out with biopsy; excision or laser therapy; may regress in HIV-infected patients receiving antiretroviral therapy

TABLE 36-4 Alterations of the Tongue

TYPE OF CHANGE	CLINICAL FEATURES
<b>Size or Morphology</b>	
Macroglossia	Enlarged tongue that may be part of a syndrome found in developmental conditions such as Down syndrome, Simpson-Golabi-Behmel syndrome, or Beckwith-Wiedemann syndrome; may be due to tumor (hemangioma or lymphangioma), metabolic disease (e.g., primary amyloidosis), or endocrine disturbance (e.g., acromegaly or cretinism); may occur when all teeth are removed
Fissured ("scrotal") tongue	Dorsal surface and sides of tongue covered by painless shallow or deep fissures that may collect debris and become irritated
Median rhomboid glossitis	Congenital abnormality with ovoid, denuded area in median posterior portion of tongue; may be associated with candidiasis and may respond to antifungal treatment
<b>Color</b>	
"Geographic" tongue (benign migratory glossitis)	Asymptomatic inflammatory condition of tongue, with rapid loss and regrowth of filiform papillae leading to appearance of denuded red patches "wandering" across surface
Hairy tongue	Elongation of filiform papillae of medial dorsal surface area due to failure of keratin layer of papillae to desquamate normally; brownish-black coloration may be due to staining by tobacco, food, or chromogenic organisms
"Strawberry" and "raspberry" tongue	Appearance of tongue during scarlet fever due to hypertrophy of fungiform papillae as well as changes in filiform papillae
"Bald" tongue	Atrophy may be associated with xerostomia, pernicious anemia, iron-deficiency anemia, pellagra, or syphilis; may be accompanied by painful burning sensation; may be an expression of erythematous candidiasis and respond to antifungal treatment

similar symptoms may precede visible lesions of herpes zoster infecting the seventh nerve (*Ramsey-Hunt syndrome*) or trigeminal nerve. *Postherpetic neuralgia* may follow either condition. *Coronary ischemia* may produce pain exclusively in the face and jaw; as in typical angina pectoris, this pain is usually reproducible with increased myocardial demand. Aching in several upper molar or premolar teeth that is unrelieved by anesthetizing the teeth may point to *maxillary sinusitis*.

*Giant cell arteritis* is notorious for producing headache, but it may also produce facial pain or sore throat without headache. Jaw and tongue claudication with chewing or talking is relatively common. Tongue infarction is rare. Patients with subacute thyroiditis often experience pain referred to the face or jaw before the tenderness of the thyroid gland and transient hyperthyroidism are appreciated.

"Burning mouth syndrome" (*glossodynia*) occurs in the absence of an identifiable cause (e.g., vitamin B<sub>12</sub> deficiency, iron deficiency, diabetes mellitus, low-grade *Candida* infection, food sensitivity, or subtle xerostomia) and predominantly affects postmenopausal women. The etiology may be neuropathic. Clonazepam, α-lipoic acid, and cognitive-behavioral therapy have benefited some patients. Some cases associated with an angiotensin-converting enzyme inhibitor have remitted when treatment with the drug was discontinued.

### DISEASES OF THE SALIVARY GLANDS

Saliva is essential to oral health. Its absence leads to dental caries, periodontal disease, and difficulties in wearing dental prostheses, masticating, and speaking. Its major components, water and mucin, serve as a cleansing solvent and lubricating fluid. In addition, saliva contains antimicrobial factors (e.g., lysozyme, lactoperoxidase, secretory IgA), epidermal growth factor, minerals, and buffering systems. The major salivary glands secrete intermittently in response to autonomic stimulation, which is high during a meal but low otherwise. Hundreds

TABLE 36-5 Oral Lesions Associated with HIV Infection

LESION MORPHOLOGY	ETOIOLOGIES
Papules, nodules, plaques	Candidiasis (hyperplastic and pseudomembranous) <sup>a</sup> Condyloma acuminatum (human papillomavirus infection) Squamous cell carcinoma (preinvasive and invasive) Non-Hodgkin's lymphoma <sup>a</sup> Hairy leukoplakia <sup>a</sup>
Ulcers	Recurrent aphthous ulcers <sup>a</sup> Angular cheilitis Squamous cell carcinoma Acute necrotizing ulcerative gingivitis <sup>a</sup> Necrotizing ulcerative periodontitis <sup>a</sup> Necrotizing ulcerative stomatitis Non-Hodgkin's lymphoma <sup>a</sup> Viral infection (herpes simplex, herpes zoster, cytomegalovirus infection) Infection caused by <i>Mycobacterium tuberculosis</i> or <i>Mycobacterium avium-intracellulare</i> Fungal infection (histoplasmosis, cryptococcosis, candidiasis, geotrichosis, aspergillosis) Bacterial infection ( <i>Escherichia coli</i> , <i>Enterobacter cloacae</i> , <i>Klebsiella pneumoniae</i> , <i>Pseudomonas aeruginosa</i> ) Drug reactions (single or multiple ulcers)
Pigmented lesions	Kaposi's sarcoma <sup>a</sup> Bacillary angiomatosis (skin and visceral lesions more common than oral) Zidovudine pigmentation (skin, nails, and occasionally oral mucosa) Addison's disease
Miscellaneous	Linear gingival erythema <sup>a</sup>

<sup>a</sup>Strongly associated with HIV infection.

of minor glands in the lips and cheeks secrete mucus continuously throughout the day and night. Consequently, oral function becomes impaired when salivary function is reduced. The sensation of a dry mouth (*xerostomia*) is perceived when salivary flow is reduced by 50%. The most common etiology is medication, especially drugs with anticholinergic properties but also alpha and beta blockers, calcium channel blockers, and diuretics. Other causes include Sjögren's syndrome, chronic parotitis, salivary duct obstruction, diabetes mellitus, HIV/AIDS, and radiation therapy that includes the salivary glands in the field (e.g., for Hodgkin's lymphoma and for head and neck cancer). Management involves the elimination or limitation of drying medications, preventive dental care, and supplementation with oral liquid or salivary substitutes. Sugarless mints or chewing gum may stimulate salivary secretion if dysfunction is mild. When sufficient exocrine tissue remains, pilocarpine or cevimeline has been shown to increase secretions. Commercial saliva substitutes or gels relieve dryness. Fluoride supplementation is critical to prevent caries.

*Sialolithiasis* presents most often as painful swelling but in some instances as only swelling or only pain. Conservative therapy consists of local heat, massage, and hydration. Promotion of salivary secretion with mints or lemon drops may flush out small stones. Antibiotic treatment is necessary when bacterial infection is suspected. In adults, *acute bacterial parotitis* is typically unilateral and most commonly affects postoperative, dehydrated, and debilitated patients. *Staphylococcus aureus* (including methicillin-resistant strains) and anaerobic bacteria are the most common pathogens. Chronic bacterial *sialadenitis* results from lowered salivary secretion and recurrent bacterial infection. When suspected bacterial infection is not responsive to therapy, the differential diagnosis should be expanded to include benign and malignant neoplasms, lymphoproliferative disorders, Sjögren's syndrome, sarcoidosis, tuberculosis, lymphadenitis, actinomycosis, and

granulomatosis with polyangiitis. Bilateral nontender parotid enlargement occurs with diabetes mellitus, cirrhosis, bulimia, HIV/AIDS, and drugs (e.g., iodide, propylthiouracil).

*Pleomorphic adenoma* composes two-thirds of all salivary neoplasms. The parotid is the principal salivary gland affected, and the tumor presents as a firm, slow-growing mass. Although this tumor is benign, its recurrence is common if resection is incomplete. Malignant tumors such as mucoepidermoid carcinoma, adenoid cystic carcinoma, and adenocarcinoma tend to grow relatively fast, depending upon grade. They may ulcerate and invade nerves, producing numbness and facial paralysis. Surgical resection is the primary treatment. Radiation therapy (particularly neutron-beam therapy) is used when surgery is not feasible and after resection for certain histologic types with a high risk of recurrence. Malignant salivary gland tumors have a 5-year survival rate of 94% when the stage is local and 35% when distant.

**Dental Care for Medically Complex Patients** Routine dental care (e.g., uncomplicated extraction, scaling and cleaning, tooth restoration, and root canal) is remarkably safe. The most common concerns regarding care of dental patients with medical disease are excessive bleeding for patients taking anticoagulants, infection of the heart valves and prosthetic devices from hematogenous seeding by the oral flora, and cardiovascular complications resulting from vasopressors used with local anesthetics during dental treatment. Experience confirms that the risk of any of these complications is very low.

Patients undergoing tooth extraction or alveolar and gingival surgery rarely experience uncontrolled bleeding when warfarin anticoagulation is maintained within the therapeutic range currently recommended for prevention of venous thrombosis, atrial fibrillation, or mechanical heart valve. Embolic complications and death, however, have been reported during subtherapeutic anticoagulation. Therapeutic anticoagulation should be confirmed before and continued through the procedure. Likewise, low-dose aspirin (e.g., 81–325 mg) can safely be continued. For patients taking aspirin and another antiplatelet medication (e.g., clopidogrel), the decision to continue the second antiplatelet medication should be based on individual consideration of the risks of thrombosis and bleeding. The newer target-specific oral anticoagulants (dabigatran, apixaban, rivaroxaban, and edoxaban) are in increasingly common use. Simple extractions of one to three teeth, periodontal surgery, abscess drainage, and implant positioning do not typically require interruption of therapy. More extensive surgery may necessitate delaying or holding a dose of the anticoagulant or more elaborate measures to manage the risk of thrombosis and bleeding.

Patients at risk for bacterial endocarditis (*Chap. 128*) should maintain optimal oral hygiene, including flossing, and have regular professional cleanings. Currently, guidelines recommend that prophylactic antibiotics be restricted to those patients at high risk for bacterial endocarditis who undergo dental and oral procedures involving significant manipulation of gingival or periapical tissue or penetration of the oral mucosa. If unexpected bleeding occurs, antibiotics given within 2 h after the procedure provide effective prophylaxis.

Hematogenous bacterial seeding from oral infection can undoubtedly produce late prosthetic-joint infection and therefore requires removal of the infected tissue (e.g., drainage, extraction, root canal) and appropriate antibiotic therapy. However, evidence that late prosthetic-joint infection follows routine dental procedures is lacking. For this reason, antibiotic prophylaxis is generally not recommended before oral surgery or oral mucosal manipulation for patients who have undergone joint replacement surgery. Exceptions to this may be considered for patients who have experienced joint replacement complications.

Concern often arises regarding the use of vasoconstrictors to treat patients with hypertension and heart disease. Vasoconstrictors enhance the depth and duration of local anesthesia, thus reducing the anesthetic dose and potential toxicity. If intravascular injection is avoided, 2% lidocaine with 1:100,000 epinephrine (limited to a total of 0.036 mg of epinephrine) can be used safely in patients with controlled hypertension and stable coronary heart disease, arrhythmia,

or congestive heart failure. Precautions should be taken with patients taking tricyclic antidepressants and nonselective beta blockers because these drugs may potentiate the effect of epinephrine.

Elective dental treatments should be postponed for at least 1 month and preferably for 6 months after myocardial infarction, after which the risk of reinfarction is low provided the patient is medically stable (e.g., stable rhythm, stable angina, and no heart failure). Patients who have suffered a stroke should have elective dental care deferred for 9 months. In both situations, effective stress reduction requires good pain control, including the use of the minimal amount of vasoconstrictor necessary to provide good hemostasis and local anesthesia.

Bisphosphonate therapy is associated with *osteonecrosis* of the jaw. However, the risk with oral bisphosphonate therapy is very low. Most patients affected have received high-dose aminobisphosphonate therapy for multiple myeloma or metastatic breast cancer and have undergone tooth extraction or dental surgery. Intraoral lesions, of which two-thirds are painful, appear as exposed yellow-white hard bone involving the mandible or maxilla. Screening tests for determining risk of osteonecrosis are unreliable. Patients slated for aminobisphosphonate therapy should receive preventive dental care that reduces the risk of infection and the need for future dentoalveolar surgery.

**Halitosis** Halitosis typically emanates from the oral cavity or nasal passages. Volatile sulfur compounds resulting from bacterial decay of food and cellular debris account for the malodor. Periodontal disease, caries, acute forms of gingivitis, poorly fitting dentures, oral abscess, and tongue coating are common causes. Treatment includes correcting poor hygiene, treating infection, and tongue brushing. Hyposalivation can produce and exacerbate halitosis. Pockets of decay in the tonsillar crypts, esophageal diverticulum, esophageal stasis (e.g., achalasia, stricture), sinusitis, and lung abscess account for some instances. A few systemic diseases produce distinctive odors: renal failure (ammoniacal), hepatic (fishy), and ketoacidosis (fruity). *Helicobacter pylori* gastritis can also produce ammoniacal breath. If a patient presents because of concern about halitosis but no odor is detectable, then pseudohalitosis or halitophobia must be considered.

**Aging and Oral Health** While tooth loss and dental disease are not normal consequences of aging, a complex array of structural and functional changes that occur with age can affect oral health. Subtle changes in tooth structure (e.g., diminished pulp space and volume, sclerosis of dentinal tubules, and altered proportions of nerve and vascular pulp content) result in the elimination or diminution of pain sensitivity and a reduction in the reparative capacity of the teeth. In addition, age-associated fatty replacement of salivary acini may reduce physiologic reserve, thus increasing the risk of hyposalivation. In healthy older adults, there is minimal, if any, reduction in salivary flow.

Poor oral hygiene often results when general health fails or when patients lose manual dexterity and upper-extremity flexibility. This situation is particularly common among frail older adults and nursing home residents and must be emphasized because regular oral cleaning and dental care reduce the incidence of pneumonia and oral disease as well as the mortality risk in this population. Other risks for dental decay include limited lifetime fluoride exposure. Without assiduous care, decay can become quite advanced yet remain asymptomatic. Consequently, much of a tooth—or the entire tooth—can be destroyed before the patient is aware of the process.

Periodontal disease, a leading cause of tooth loss, is indicated by loss of alveolar bone height. More than 90% of the U.S. population has some degree of periodontal disease by age 50. Healthy adults who have not had significant alveolar bone loss by the sixth decade of life do not typically experience significant worsening with advancing age.

With the passing of those born in the first half of the twentieth century, complete edentulousness in the United States is becoming increasingly restricted to impoverished populations. When it is present, speech, mastication, and facial contours are dramatically affected. Edentulousness may also exacerbate obstructive sleep apnea, particularly in asymptomatic individuals who wear dentures. Dentures can

improve verbal articulation and restore diminished facial contours. Mastication can also be restored; however, patients expecting dentures to facilitate oral intake are often disappointed. Accommodation to dentures requires a period of adjustment. Pain can result from friction or traumatic lesions produced by loose dentures. Poor fit and poor oral hygiene may permit the development of candidiasis. This fungal infection may be either asymptomatic or painful and is suggested by erythematous smooth or granular tissue conforming to an area covered by the appliance. Individuals with dentures and no natural teeth need regular (annual) professional oral examinations.

### FURTHER READING

- D SC: Interaction with other health team members in caring for elderly patients. *Dent Clin North Am* 49:377, 2005.
- K E, D V: Treatment in the dental practice of the patient receiving anticoagulant therapy. *J Am Dent Assoc* 150:602, 2019.
- W JA et al: Improving nursing home residents' oral hygiene: Results of a cluster randomized intervention trial. *J Am Med Dir Assoc* 19:1086, 2018.

### MECHANISMS UNDERLYING DYSPNEA

The mechanisms underlying dyspnea are complex, as it can arise from different contributory respiratory sensations. Although a large body of research has increased our understanding of mechanisms underlying particular respiratory sensations such as "chest tightness" or "air hunger," it is likely that a given disease state might produce the sensation of dyspnea via more than one underlying mechanism. Dyspnea can arise from a variety of pathways, including generation of *afferent* signals from the respiratory system to the central nervous system (CNS), *efferent* signals from the CNS to the respiratory muscles, and particularly when there is a mismatch in the integrative signaling between these two pathways, termed *efferent-reafferent mismatch* (Fig. 37-1).

*Afferent signals* trigger the CNS (brainstem and/or cortex) and include primarily: (1) peripheral chemoreceptors in the carotid body and aortic arch and central chemoreceptors in the medulla that are activated by hypoxemia, hypercapnia, or acidemia, and might produce a sense of "air hunger"; and (2) mechanoreceptors in the upper airways, lungs (including stretch receptors, irritant receptors, and J receptors), and chest wall (including muscle spindles as stretch receptors and tendon organs that monitor force generation) that are activated in the setting of an increased work load from a disease state producing an increase in airway resistance that may be associated with symptoms of chest tightness (e.g., asthma or COPD) or decreased lung or chest wall compliance (e.g., pulmonary fibrosis). Other afferent signals that trigger dyspnea within the respiratory system can arise from pulmonary vascular receptor responses to changes in pulmonary artery pressure and skeletal muscle (termed metaboreceptors) that are believed to sense changes in the biochemical environment.

*Efferent signals* are sent from the CNS (motor cortex and brainstem) to the respiratory muscles and are also transmitted by corollary discharge to the sensory cortex; they are believed to underlie sensations of respiratory effort (or "work of breathing") and perhaps contribute to sensations of "air hunger," especially in response to an increased ventilatory load in a disease state such as COPD. In addition, fear or anxiety may heighten the sense of dyspnea by exacerbating the underlying physiologic disturbance in response to an increased respiratory rate or disordered breathing pattern.

### ASSESSING DYSPNEA

While it is well appreciated that dyspnea is a difficult quality to reliably measure due to multiple relevant possible domains that can be measured (e.g., sensory-perceptual experience, affective distress, and symptom impact or burden), and there exist no uniformly agreed upon tools for dyspnea assessment, consensus opinion is that dyspnea should be formally assessed in a context most relevant and beneficial for patient management and, furthermore, that the specific domains being measured are adequately described. There are a number of emerging tools that have been developed for formal dyspnea assessment. As an example, the GOLD criteria advocate use of a dyspnea assessment tool such as the Modified Medical Research Council Dyspnea Scale (Table 37-1) to assess symptom/impact burden in COPD.

### DIFFERENTIAL DIAGNOSIS

This chapter focuses largely on chronic dyspnea, which is defined as symptoms lasting longer than 1 month and can arise from a broad array of different underlying conditions, most commonly attributable to pulmonary or cardiac conditions that account for as many as 85% of the underlying causes of dyspnea. However, as many as one-third of patients may have multifactorial reasons underlying dyspnea. Examples of a wide array of conditions that underlie dyspnea with possible mechanisms underlying the presenting symptoms are described in Table 37-2.

Respiratory system causes include diseases of the airways (e.g., asthma and COPD), diseases of the parenchyma (more commonly, interstitial lung diseases are seen in the setting of chronic dyspnea, but alveolar filling processes, such as hypersensitivity pneumonitis or bronchiolitis obliterans organizing pneumonia [BOOP], can also

## Section 5 Alterations in Circulatory and Respiratory Functions

### 37

### Dyspnea

Rebecca M. Baron



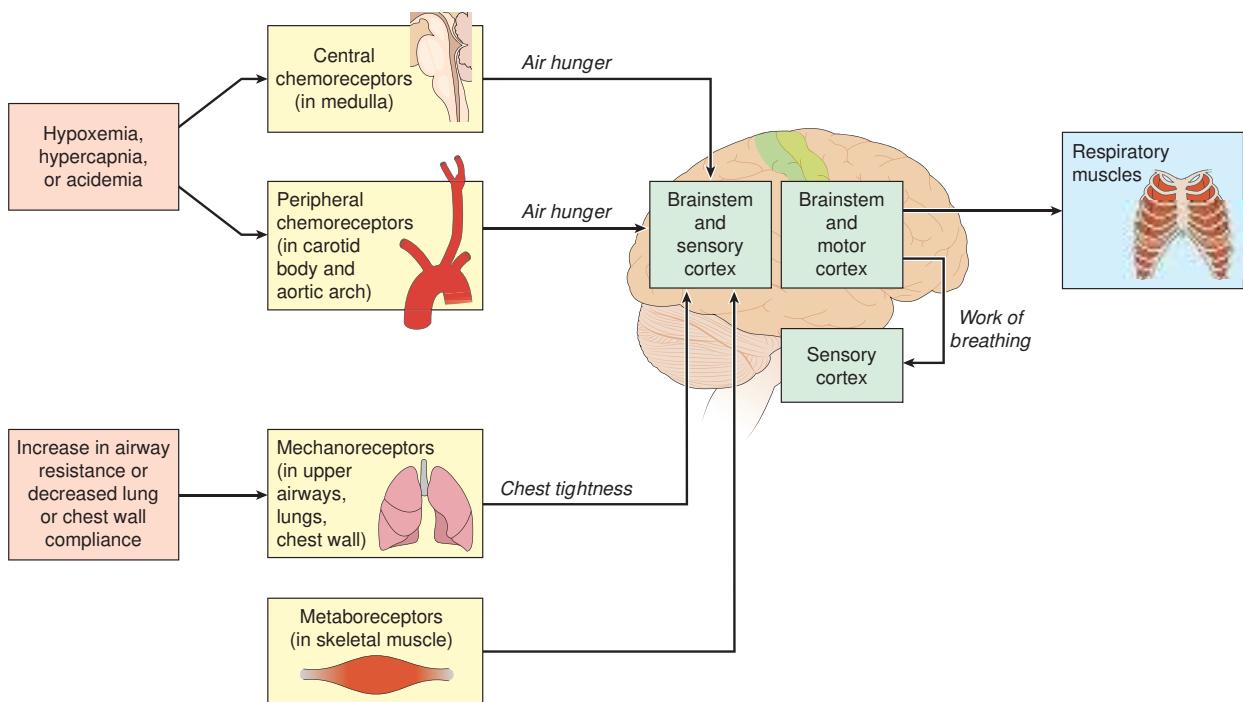
## DYSPNEA

### DEFINITION

The American Thoracic Society consensus statement defines *dyspnea* as a "subjective experience of breathing discomfort that consists of qualitatively distinct sensations that vary in intensity. The experience derives from interactions among multiple physiological, psychological, social, and environmental factors and may induce secondary physiological and behavioral responses." Dyspnea, a symptom, can be perceived only by the person experiencing it and, therefore, must be self-reported. In contrast, signs of increased work of breathing, such as tachypnea, accessory muscle use, and intercostal retraction, can be measured and reported by clinicians.

### EPIDEMIOLOGY

Dyspnea is common. It has been reported that up to one-half of inpatients and one-quarter of ambulatory patients experience dyspnea, with a prevalence of 9–13% in the community that increases to as high as 37% for adults aged ≥70 years. Dyspnea is a frequent cause for emergency room visits, accounting for as many as 3–4 million visits per year. Furthermore, it is increasingly appreciated that the degree of dyspnea may better predict outcomes in chronic obstructive pulmonary disease (COPD) than does the forced expiratory volume in 1 s (FEV<sub>1</sub>), and formal measures of dyspnea have been incorporated into the Global Initiative for Chronic Obstructive Lung Disease (GOLD) COPD severity assessment guidelines. Dyspnea may also predict outcomes in other chronic heart and lung diseases as well. Dyspnea can arise from a diverse array of pulmonary, cardiac, and neurologic underlying causes, and elucidation of particular symptoms may point toward a specific etiology and/or mechanism driving dyspnea (although additional diagnostic testing is often required, as will be further discussed below).



**FIGURE 37-1** Signaling pathways underlying dyspnea. Dyspnea arises from a range of sensory inputs, many of which lead to distinct descriptive phrases used by patients (shown in italics in the figure). The sensation of respiratory effort (or work of breathing) likely arises from signals transmitted from the motor cortex to the sensory cortex when outgoing motor commands are sent to the respiratory muscles. Motor output from the brain stem may also be accompanied by signals transmitted to the sensory cortex and contribute to the sensation of work of breathing. The sensation of air hunger likely derives from stimuli that increase the drive to breathe (e.g., hypoxemia, hypercapnia, acidemia; mediated by signals from central and peripheral chemoreceptors), as well as airway and interstitial inflammation (mediated by pulmonary afferent signals) and pulmonary vascular receptors. Dyspnea arises, in part, from a perceived mismatch between the outgoing efferent messages to the respiratory muscles and incoming afferent signals from the lungs and chest wall. Chest tightness, often associated with bronchospasm, is largely mediated by stimulation of vagal-irritant receptors. Afferent signals from airway, lung, and chest wall mechanoreceptors most likely pass through the brain stem before being transmitted to the sensory cortex, although it is possible that some afferent information bypasses the brain stem and goes directly to the sensory cortex. (Adapted from RM Schwartzstein: Approach to the patient with dyspnea. In: UpToDate, TW Post (Ed), UpToDate, Waltham, MA. (Accessed on 7 December 2021) 2018 UpToDate, Inc. For more information visit [www.uptodate.com](http://www.uptodate.com).)

present with similar symptoms), diseases affecting the chest wall (e.g., bony abnormalities such as kyphoscoliosis, or neuromuscular weakness conditions such as amyotrophic lateral sclerosis), and diseases affecting the pulmonary vasculature (e.g., pulmonary hypertension that can

arise from a variety of underlying causes, or chronic thromboembolic disease). Diseases affecting the cardiovascular system that can present with dyspnea include processes affecting left heart function, such as coronary artery disease and cardiomyopathy, as well as disease processes affecting the pericardium, including constrictive pericarditis and cardiac tamponade. Other conditions underlying dyspnea that might not directly emanate from the pulmonary or cardiovascular systems include anemia (thereby potentially affecting oxygen-carrying capacity), deconditioning, and psychological processes such as anxiety. Distinguishing between the myriad of underlying processes that might present with dyspnea can be challenging. A graded approach that begins with a history and physical examination, followed by selected laboratory testing that might then advance to additional diagnostics and potentially subspecialty referral, may help elucidate the underlying cause of dyspnea. However, a substantial proportion of patients may have persistent dyspnea despite treatment for an underlying process or may not have a specific underlying process identified that is driving the dyspnea.

**TABLE 37-1** An Example of a Clinical Method for Rating Dyspnea: The Modified Medical Research Council Dyspnea Scale<sup>a</sup>

GRADE OF DYSPNEA	DESCRIPTION
0	Not troubled by breathlessness, except with strenuous exercise
1	Shortness of breath walking on level ground or with walking up a slight hill
2	Walks slower than people of similar age on level ground due to breathlessness, or has to stop to rest when walking at own pace on level ground
3	Stops to rest after walking 100 m or after walking a few minutes on level ground
4	Too breathless to leave the house, or breathless with activities of daily living (e.g., dressing/undressing)

<sup>a</sup>Which has been incorporated into the Global Initiative for Chronic Obstructive Lung Disease (GOLD) guidelines as a possible tool for rating dyspnea in chronic obstructive pulmonary disease.

Source: Reproduced with permission from DA Mahler, CK Wells: Evaluation of clinical methods for rating dyspnea. *Chest* 93:580, 1988.

## APPROACH TO THE PATIENT

### Dyspnea (See Fig. 37-2)

#### OVERALL

For patients with a known prior pulmonary, cardiac, or neuromuscular condition and worsening dyspnea, the initial focus of the

TABLE 37-2 Differential Diagnosis of Disease Processes Underlying Dyspnea

SYSTEM	TYPE OF PROCESS	EXAMPLE OF DISEASE PROCESS	POSSIBLE PRESENTING DYSPNEA SYMPTOMS	POSSIBLE PHYSICAL FINDINGS	POSSIBLE MECHANISMS UNDERLYING DYSPNEA	INITIAL DIAGNOSTIC STUDIES (AND POSSIBLE FINDINGS)
Pulmonary	Airways disease	Asthma, COPD, upper airway obstruction	Chest tightness, tachypnea, increased WOB, air hunger, inability to get a deep breath	Wheezing, accessory muscle use, exertional hypoxemia (especially with COPD)	Increased WOB, hypoxemia, hypercapnia, stimulation of pulmonary receptors	Peak flow (reduced); spirometry (OVD); CXR (hyperinflation; loss of lung parenchyma in COPD), chest CT and airway examination for upper airway obstruction
	Parenchymal disease	Interstitial lung disease <sup>a</sup>	Air hunger, inability to get a deep breath	Dry end-inspiratory crackles, clubbing, exertional hypoxemia	Increased WOB, increased respiratory drive, hypoxemia, hypercapnia, stimulation of pulmonary receptors	Spirometry and lung volumes (RVD); CXR and chest CT (interstitial lung disease)
	Chest wall disease	Kyphoscoliosis, neuromuscular (NM) weakness	Increased WOB, inability to get a deep breath	Decreased diaphragm excursion; atelectasis	Increased WOB; stimulation of pulmonary receptors (if atelectasis is present)	Spirometry and lung volumes (RVD); MIP and MEPs (reduced in NM weakness)
Pulmonary and cardiac	Pulmonary vasculature	Pulmonary hypertension	Tachypnea	Elevated right heart pressures, exertional hypoxemia	Increased respiratory drive, hypoxemia, stimulation of vascular receptors	Diffusion capacity (reduced); ECG; ECHO (to evaluate pulmonary artery pressures) <sup>b</sup>
Cardiac	Left heart failure	Coronary artery disease, cardiomyopathy <sup>c</sup>	Chest tightness, air hunger	Elevated left heart pressures; wet crackles on lung examination; pulsus paradoxus (pericardial disease)	Increased WOB and drive, hypoxemia, stimulation of vascular and pulmonary receptors <sup>d</sup>	Consider BNP testing, especially in the acute setting; ECG, ECHO, may need stress testing and/or LHC
Other	Variable	Anemia Deconditioning Psychological Metabolic disturbances Gastrointestinal (e.g., gastroesophageal reflux disease [GERD], aspiration pneumonitis)	Exertional breathlessness Poor fitness Anxiety	Variable	Metaboreceptors (anemia, poor fitness); chemoreceptors (anaerobic metabolism from poor fitness); some subjects may have increased sensitivity to hypercapnia	Hematocrit for anemia; laboratory studies (e.g., metabolic panel, thyroid hormone testing for metabolic disturbances); consider upper gastrointestinal endoscopy and/or esophageal pH probe testing for GERD and concerns for aspiration; exclude other causes

<sup>a</sup>Differential diagnosis of interstitial lung disease includes idiopathic pulmonary fibrosis, collagen vascular disease, drug- or occupation-induced pneumonitis, lymphangitic spread of malignancy; processes that are more alveolar rather than interstitial in nature can also less commonly contribute to parenchymal lung disease underlying chronic dyspnea and include entities such as hypersensitivity pneumonitis, bronchiolitis obliterans organizing pneumonia, etc. <sup>b</sup>Would additionally consider these patients for CT angiography to evaluate for presence of thromboemboli, ventilation/perfusion scanning to evaluate for the presence of chronic thromboembolic disease, and right heart catheterization to further evaluate for pulmonary hypertension. <sup>c</sup>Diastolic dysfunction in the setting of a stiff left ventricle is often seen and contributes significantly to insidious dyspnea that can be difficult to treat. <sup>d</sup>May stimulate metaboreceptors if cardiac output is sufficiently reduced to result in a lactic acidosis.

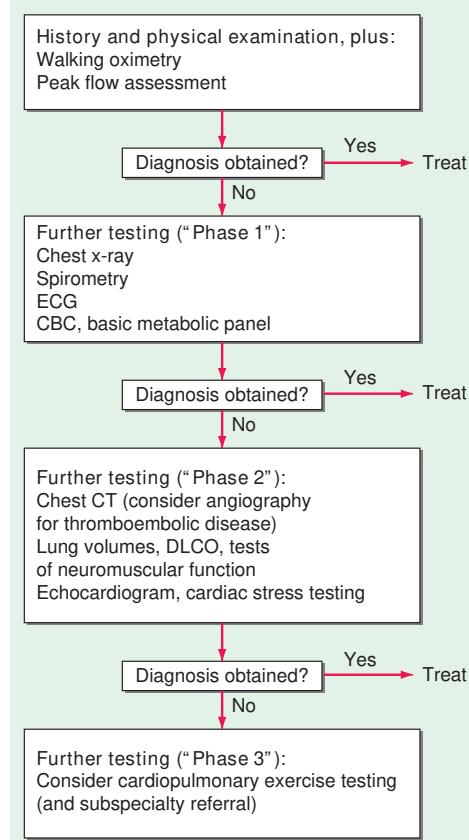
**Abbreviations:** BNP, brain natriuretic peptide; COPD, chronic obstructive pulmonary disease; CT, computed tomography; CXR, chest x-ray; ECG, electrocardiogram; ECHO, echocardiogram; GERD, gastroesophageal reflux disease; LHC, left heart catheterization; MIP/MEP, maximal inspiratory and maximal expiratory pressures (obtained in the pulmonary function testing laboratory); OVD, obstructive ventilatory defect; RVD, restrictive ventilatory defect; WOB, work of breathing.

evaluation will usually address determining whether the known condition has progressed or whether a new process has developed that is causing dyspnea. For patients without a prior known potential cause of dyspnea, the initial evaluation will focus on determining an underlying etiology. Determining the underlying cause, if possible, is extremely important, as the treatment may vary dramatically based on the predisposing condition. An initial history and physical examination remain fundamental to the evaluation followed by initial diagnostic testing as indicated that might prompt subspecialty referral (e.g., pulmonary, cardiology, neurology, sleep, and/or specialized dyspnea clinic) if the cause of dyspnea remains elusive (Fig. 37-2). As many as two-thirds of patients will require diagnostic testing beyond the initial clinical presentation.

#### HISTORY

The patient should be asked to describe in his or her own words what the discomfort feels like as well as the effect of position,

infections, and environmental stimuli on the dyspnea, as descriptors may be helpful in pointing toward an etiology. For example, symptoms of chest tightness might suggest the possibility of bronchoconstriction, and the sensation of inability to take a deep breath may correlate with dynamic hyperinflation from COPD. Orthopnea is a common indicator of congestive heart failure (CHF), mechanical impairment of the diaphragm associated with obesity, or asthma triggered by esophageal reflux. Nocturnal dyspnea suggests CHF or asthma. Acute, intermittent episodes of dyspnea are more likely to reflect episodes of myocardial ischemia, bronchospasm, or pulmonary embolism, while chronic persistent dyspnea is more typical of COPD, interstitial lung disease, and chronic thromboembolic disease. Information on risk factors for drug-induced or occupational lung disease and for coronary artery disease should be elicited. Left atrial myxoma or hepatopulmonary syndrome should be considered when the patient complains of *platypnea*—i.e., dyspnea in the upright position with relief in the supine position.



**FIGURE 37-2** Possible algorithm for the evaluation of the patient with dyspnea. As described in the text, the approach should begin with a detailed history and physical examination, followed by progressive testing and ultimately more invasive testing and subspecialty referral as is indicated to determine the underlying cause of dyspnea. CBC, complete blood count; DLCO, diffusing capacity of the lungs for carbon monoxide; ECG, electrocardiogram. (Adapted from NG Kurnani et al: Am Fam Physician 71:1529, 2005.)

### PHYSICAL EXAMINATION

Initial vital signs might be helpful in pointing toward an underlying etiology in the context of the remainder of the evaluation. For example, the presence of fever might point toward an underlying infectious or inflammatory process; the presence of hypertension in the setting of a heart failure might point toward diastolic dysfunction; the presence of tachycardia might be associated with many different underlying processes including fever, cardiac dysfunction, and deconditioning; and the presence of resting hypoxemia suggests processes involving hypercapnia, ventilation-perfusion mismatch, shunt, or impairment in diffusion capacity might be involved. An exertional oxygen saturation should also be obtained as described below. The physical examination should begin during the interview of the patient. Inability of the patient to speak in full sentences before stopping to get a deep breath suggests a condition that leads to stimulation of the controller or impairment of the ventilatory pump with reduced vital capacity. Evidence of increased work of breathing (suprACLAVICULAR retractions; use of accessory muscles of ventilation; and the tripod position, characterized by sitting with the hands braced on the knees) is indicative of increased airway resistance or stiffness of the lungs and the chest wall. When measuring the vital signs, the physician should accurately assess the respiratory rate and measure the pulsus paradoxus (Chap. 270); if the systolic pressure decreases by >10 mmHg on inspiration, the

presence of COPD, acute asthma, or pericardial disease should be considered. During the general examination, signs of anemia (pale conjunctivae), cyanosis, and cirrhosis (spider angiomas, gynecomastia) should be sought. Examination of the chest should focus on symmetry of movement; percussion (dullness is indicative of pleural effusion; hyperresonance is a sign of pneumothorax and emphysema); and auscultation (wheezes, rhonchi, prolonged expiratory phase, and diminished breath sounds are clues to disorders of the airways; rales suggest interstitial edema or fibrosis). The cardiac examination should focus on signs of elevated right heart pressures (jugular venous distention, edema, accentuated pulmonic component to the second heart sound); left ventricular dysfunction (S3 and S4 gallops); and valvular disease (murmurs). When examining the abdomen with the patient in the supine position, the physician should note whether there is paradoxical movement of the abdomen as well as the presence of increased respiratory distress in the supine position: inward motion during inspiration is a sign of diaphragmatic weakness, and rounding of the abdomen during exhalation is suggestive of pulmonary edema. Clubbing of the digits may be an indication of interstitial pulmonary fibrosis or bronchiectasis, and joint swelling or deformation as well as changes consistent with Raynaud's disease may be indicative of a collagen-vascular process that can be associated with pulmonary disease.

Patients should be asked to walk under observation with oximetry in order to reproduce the symptoms. The patient should be examined during and at the end of exercise for new findings that were not present at rest (e.g., presence of wheezing) and for changes in oxygen saturation.

### CHEST IMAGING

After the history elicitation and the physical examination, a chest radiograph should be obtained if the diagnosis remains elusive. The lung volumes should be assessed: hyperinflation is consistent with obstructive lung disease, whereas low lung volumes suggest interstitial edema or fibrosis, diaphragmatic dysfunction, or impaired chest wall motion. The pulmonary parenchyma should be examined for evidence of interstitial disease, infiltrates, and emphysema. Prominent pulmonary vasculature in the upper zones indicates pulmonary venous hypertension, while enlarged central pulmonary arteries may suggest pulmonary arterial hypertension. An enlarged cardiac silhouette can point toward dilated cardiomyopathy or valvular disease. Bilateral pleural effusions are typical of CHF and some forms of collagen-vascular disease. Unilateral effusions raise the specter of carcinoma and pulmonary embolism but may also occur in heart failure or in the case of a parapneumonic effusion. CT of the chest is generally reserved for further evaluation of the lung parenchyma (interstitial lung disease) and possible pulmonary embolism if there remains diagnostic uncertainty.

### LABORATORY STUDIES

Initial laboratory testing should include a hematocrit to exclude occult anemia as an underlying cause of reduced oxygen-carrying capacity contributing to dyspnea, and a basic metabolic panel may be helpful to exclude a significant underlying metabolic acidosis (and conversely, an elevated bicarbonate might point toward the possibility of carbon dioxide retention that might be seen in chronic respiratory failure—in such a setting, an arterial blood gas may provide useful additional information). Additional laboratory studies should include electrocardiography to seek evidence of ventricular hypertrophy and prior myocardial infarction and spirometry, which can be diagnostic of the presence of an obstructive ventilatory defect and suggest the possibility of a restrictive ventilatory defect (that then might prompt additional pulmonary function laboratory testing, including lung volumes, diffusion capacity, and possible tests of neuromuscular function). Echocardiography is indicated when systolic dysfunction, pulmonary hypertension, or

valvular heart disease is suspected. Bronchoprovocation testing and/or home peak-flow monitoring may be useful in patients with intermittent symptoms suggestive of asthma who have a normal physical examination and spirometry; up to one-third of patients with the clinical diagnosis of asthma do not have reactive airways disease when formally tested. Measurement of brain natriuretic peptide levels in serum is increasingly used to assess for CHF in patients presenting with acute dyspnea but may be elevated in the presence of right ventricular strain as well.

#### DISTINGUISHING CARDIOVASCULAR FROM RESPIRATORY SYSTEM DYSPNEA

If a patient has evidence of both pulmonary and cardiac disease that is not responsive to treatment or it remains unclear what factors are primarily driving the dyspnea, a cardiopulmonary exercise test (CPET) can be carried out to determine which system is responsible for the exercise limitation. CPET includes incremental symptom-limited exercise (cycling or treadmill) with measurements of ventilation and pulmonary gas exchange and, in some cases, includes noninvasive and invasive measures of pulmonary vascular pressures and cardiac output. If, at peak exercise, the patient achieves predicted maximal ventilation, demonstrates an increase in dead space or hypoxemia, or develops bronchospasm, the respiratory system may be the cause of the problem. Alternatively, if the heart rate is >85% of the predicted maximum, if the anaerobic threshold occurs early, if the blood pressure becomes excessively high or decreases during exercise, if the O<sub>2</sub> pulse (O<sub>2</sub> consumption/heart rate, an indicator of stroke volume) falls, or if there are ischemic changes on the electrocardiogram, an abnormality of the cardiovascular system is likely the explanation for the breathing discomfort. Additionally, a CPET may also help point toward a peripheral extraction deficit or metabolic/neuromuscular disease as potential underlying processes driving dyspnea.

### TREATMENT

#### Dyspnea

The first goal is to correct the underlying condition(s) driving dyspnea and address potentially reversible causes with appropriate treatment for the particular condition. Multiple different interventions may be necessary, given that dyspnea often arises from multifactorial causes. If relief of dyspnea with treatment of the underlying condition(s) is not fully possible, an effort is made to lessen the intensity of the symptom and its effect on the patient's quality of life. More recent work at the consensus conference level has sought to define an identifiable entity of persistent dyspnea in order to develop an approach to improving efforts to address symptom management for this condition. In 2017, an international group of experts defined "chronic breathlessness syndrome" as "the experience of breathlessness that persists despite optimal treatment of the underlying pathophysiology and results in disability for the patient." Despite an increased understanding of the mechanisms underlying dyspnea, there has been limited progress in treatment strategies for dyspnea. Supplemental O<sub>2</sub> should be administered if the resting O<sub>2</sub> saturation is ≤88% or if the patient's saturation drops to these levels with activity or sleep. In particular, for patients with COPD, supplemental oxygen for those with hypoxemia has been shown to improve mortality, and pulmonary rehabilitation programs (including some community-based exercise programs such as yoga and Tai Chi) have demonstrated positive effects on dyspnea, exercise capacity, and rates of hospitalization. Opioids have been shown to reduce symptoms of dyspnea, largely through reducing air hunger, thus likely suppressing respiratory drive and influencing cortical activity. However, opioids should be considered for each patient individually based on the risk-benefit profile in regard to the effects of respiratory depression. Studies of anxiolytics for dyspnea

have not demonstrated consistent benefit. Additional approaches are under study for dyspnea, including inhaled furosemide that might alter afferent sensory information.

#### FURTHER READING

- B RB et al: Multidimensional dyspnea profile: An instrument for clinical and laboratory research. *Eur Respir J* 45:1681, 2015.
- F OR et al: Diagnostic approach to chronic dyspnea in adults. *J Thorac Dis* 11(Suppl 17):S2117, 2019.
- J M et al: Toward an expert consensus to delineate a clinical syndrome of chronic breathlessness: Chronic breathlessness syndrome. *Eur Respir J* 49:1602277, 2017.
- L L P ERS R
- S F : Dyspnoea: A multidimensional and multidisciplinary approach. *Eur Respir J* 43:1750, 2014.
- O'D DE et al: Unraveling the causes of unexplained dyspnea. *Clin Chest Med* 40:471, 2019.
- P MB et al: An Official American Thoracic Society Statement: Update on the mechanisms, assessment, and management of dyspnea. *Am J Respir Crit Care Med* 185:435, 2012.
- R K et al: Yoga and Tai Chi: A mind-body approach in managing respiratory symptoms in obstructive lung diseases. *Curr Opin Pulm Med* 26:186, 2020.

## 38

## Cough

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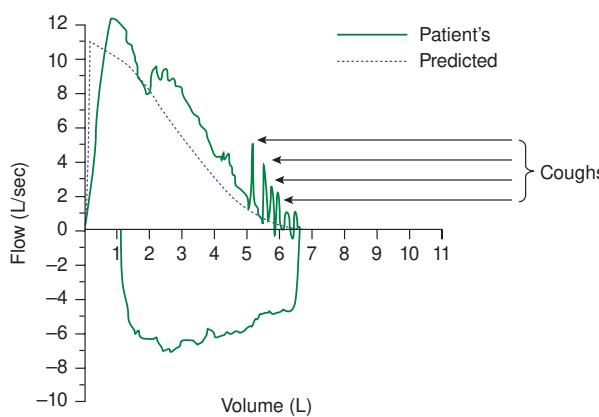


### COUGH

Cough performs an essential protective function for human airways and lungs. Without an effective cough reflex, we are at risk for retained airway secretions and aspirated material predisposing to infection, atelectasis, and respiratory compromise. At the other extreme, excessive coughing can be exhausting; can be complicated by emesis, syncope, muscular pain, or rib fractures; can aggravate low back pain, abdominal or inguinal hernias, and urinary incontinence; and can be a major impediment to social interactions. Cough is often a clue to the presence of respiratory disease. In many instances, cough is an expected and accepted manifestation of disease, as in acute respiratory tract infection. However, persistent cough in the absence of other respiratory symptoms commonly causes patients to seek medical attention.

#### COUGH MECHANISM

Both chemical (e.g., capsaicin) and mechanical (e.g., mucus, particulates in air pollution) stimuli can initiate the cough reflex. Cationic channels (e.g., transient receptor potential channels) and adenosine triphosphate-activated ion channels (P2X3) function as sensory neuronal receptors, with signals transmitted centrally via A<sub>δ</sub> (mechanosensory) and C fibers (chemosensory). Afferent nerve endings richly innervate the pharynx, larynx, and airways to the level of the terminal bronchioles and extend into the lung parenchyma. They are also located in the external auditory canal (the auricular branch of the vagus nerve, or Arnold's nerve) and in the esophagus. Sensory signals travel via the vagus and superior laryngeal nerves to a region of the brainstem in the nucleus tractus solitarius. Integrated neural networks process this input into a conscious sensation referred to as the "urge to cough." The efferent limb of the cough reflex involves a highly orchestrated series of involuntary muscular actions, with the potential for input from cortical pathways as well, making possible voluntary cough. The vocal



**FIGURE 38-1** Flow-volume curve shows spikes of high expiratory flow achieved with cough.

cords adduct, leading to transient upper-airway occlusion. Expiratory muscles contract, generating positive intrathoracic pressures as high as 300 mmHg. With sudden release of the laryngeal contraction, rapid expiratory flows are generated, exceeding the normal “envelope” of maximal expiratory flow seen on the flow-volume curve (Fig. 38-1). Bronchial smooth-muscle contraction together with dynamic compression of airways narrows airway lumens and maximizes the velocity of exhalation. The kinetic energy available to dislodge mucus from the inside of airway walls is directly proportional to the square of the velocity of expiratory airflow. A deep breath preceding a cough optimizes the function of the expiratory muscles; a series of repetitive coughs at successively lower lung volumes sweeps the point of maximal expiratory velocity progressively further into the lung periphery.

### ■ IMPAIRED COUGH

Weak or ineffective cough compromises the ability to clear lower respiratory tract secretions, predisposing to more serious infections and their sequelae. Weakness or paralysis of the expiratory (abdominal and intercostal) muscles and pain in the chest wall or abdomen are foremost on the list of causes of impaired cough (Table 38-1). Cough strength is generally assessed qualitatively; peak expiratory flow or maximal expiratory pressure at the mouth can be used as a surrogate marker for cough strength. A variety of assistive devices and techniques have been developed to improve cough efficacy, running the gamut from simple (splinting of the abdominal muscles with a tightly held pillow to reduce postoperative pain while coughing) to complex (a mechanical cough-assist device supplied via face mask or tracheal tube that applies a cycle of positive pressure followed rapidly by negative pressure). Cough may fail to clear secretions completely despite a preserved ability to generate normal expiratory velocities; such failure may be due to abnormal airway secretions (e.g., abnormally viscous secretions of cystic fibrosis), ciliary dysfunction (e.g., primary ciliary dyskinesia), or structural abnormalities of the airways (e.g., tracheomalacia with excessive expiratory collapse of the trachea during cough).

**TABLE 38-1** Causes of Impaired Cough and Airway Clearance

Respiratory muscle weakness
Chest wall or abdominal pain
Chest wall deformity (e.g., severe kyphoscoliosis)
Impaired glottic closure or tracheostomy
Central respiratory depression (e.g., anesthesia, sedation, or neurologic disease)
Abnormal airway secretions
Ciliary dysfunction
Tracheobronchomalacia
Bronchiectasis
Tracheal or bronchial stenoses

### ■ SYMPTOMATIC COUGH

Cough may occur in the context of other respiratory symptoms that together point to a diagnosis; for example, cough accompanied by wheezing, shortness of breath, and chest tightness after exposure to a cat or other sources of allergens suggests asthma. At times, however, cough is the dominant or sole symptom of disease, and it may be of sufficient duration and severity that relief is sought. The duration of cough is a clue to its etiology, at least retrospectively. Acute cough (<3 weeks) is most commonly due to a respiratory tract infection, aspiration, or inhalation of noxious chemicals or smoke. Subacute cough (3–8 weeks in duration) is a common residuum of tracheobronchitis, as in pertussis or “postviral tussive syndrome.” Chronic cough (>8 weeks) may be caused by a wide variety of cardiopulmonary diseases, including those of inflammatory, infectious, neoplastic, and cardiovascular etiologies. When initial assessment with chest examination and radiography is normal, cough-variant asthma, gastroesophageal reflux, rhinosinusitis with excessive nasopharyngeal drainage, and medications (angiotensin-converting enzyme [ACE] inhibitors) are the most common identifiable causes of chronic cough. In a long-time cigarette smoker, an early-morning, productive cough suggests chronic bronchitis. A dry, irritative cough that lingers for >2 months following one or more respiratory tract infections (“postbronchitic cough”) is a very common cause of chronic cough, especially in the winter months. Chronic cough in the absence of identifiable etiology has been recognized with increasing frequency, is thought to be due to exaggerated neurologic signaling via sensory cough-reflex pathways, and is referred to as “chronic cough hypersensitivity syndrome.”

### ■ ASSESSMENT OF CHRONIC COUGH

Except for our ability to detect the sound of excess airway secretions, details as to the resonance of the cough, its time of occurrence during the day, and the pattern of coughing (e.g., occurring in paroxysms) infrequently provide useful etiologic clues. Regardless of cause, cough often worsens upon first lying down at night, with talking, or with the hyperpnea of exercise; it frequently improves with sleep. An exception may involve the cough that occurs only with certain allergic exposures or exercise in cold air, as in asthma. Useful historical questions include what circumstances surrounded the onset of cough, what makes the cough better or worse, and whether the cough produces sputum.

The physical examination seeks clues suggesting the presence of cardiopulmonary disease, including findings such as wheezing or crackles on chest examination. Examination of the auditory canals and tympanic membranes (for irritation of the latter resulting in stimulation of Arnold’s nerve), the nasal passageways (for rhinitis or polyps), and the nails (for clubbing) may also provide etiologic clues. Because cough can be a manifestation of a systemic disease such as sarcoidosis or vasculitis, a thorough general examination is likewise important.

In virtually all instances, evaluation of chronic cough merits a chest radiograph. The list of diseases that can cause persistent cough without other symptoms and without detectable abnormalities on physical examination is long. It includes serious illnesses such as sarcoidosis or Hodgkin’s disease in young adults, lung cancer in older patients, and (worldwide) pulmonary tuberculosis. An abnormal chest film prompts an evaluation aimed at explaining the radiographic abnormality. In a patient with chronic productive cough, examination of expectorated sputum is warranted, because determining the cause of mucus hypersecretion is a crucial clue to etiology. Purulent-appearing sputum should be sent for routine bacterial culture and, in certain circumstances, mycobacterial culture as well. Cytologic examination of mucoid sputum may be useful to assess for malignancy and oropharyngeal aspiration and to distinguish neutrophilic from eosinophilic bronchitis. Expectoration of blood—whether streaks of blood, blood mixed with airway secretions, or pure blood—deserves a special approach to assessment and management (Chap. 39).

### ■ CHRONIC COUGH WITH A NORMAL CHEST RADIOGRAPH

It is commonly held that (alone or in combination) the use of an ACE inhibitor; postnasal drainage; gastroesophageal reflux; and asthma

account for >90% of cases of chronic cough with a normal or noncontributory chest radiograph. However, clinical experience does not support this contention, and strict adherence to this concept discourages the search for alternative explanations by both clinicians and researchers. In recent years, the concept of a distinct “cough hypersensitivity syndrome” has emerged, emphasizing the putative role of sensitized sensory nerve endings and afferent neural pathways in causing chronic refractory cough, akin to chronic neuropathic pain. It presents with a dry or minimally productive cough and a tickle or sensitivity in the throat, made worse with talking, laughing, or exertion. It is more common in women than men and can last for years. Specific diagnostic criteria are lacking; the diagnosis is suspected when alternative etiologies are excluded by diagnostic testing or failed therapeutic trials. It is uncertain whether persistent daily coughing elicits an inflammatory response and is thereby self-perpetuating.

ACE inhibitor-induced cough occurs in 5–30% of patients taking these agents and is not dose-dependent. ACE metabolizes bradykinin and other tachykinins, such as substance P. The mechanism of ACE inhibitor-associated cough may involve sensitization of sensory nerve endings due to accumulation of bradykinin. Any patient with chronic unexplained cough who is taking an ACE inhibitor should have a trial period off the medication, regardless of the timing of the onset of cough relative to the initiation of ACE inhibitor therapy. In most instances, a safe alternative is available; angiotensin receptor blockers do not cause cough. Failure to observe a decrease in cough after 1 month off medication argues strongly against this etiology.

Postnasal drainage of any etiology can cause cough as a response to stimulation of sensory receptors of the cough-reflex pathway in the hypopharynx or aspiration of draining secretions into the trachea. The term *upper airway cough syndrome* has been coined to encompass the concept that chronic inflammation in the nose and sinuses can cause cough even in the absence of physical drainage into the pharynx. Historical clues suggesting this etiology include a sensation of postnasal drip, frequent throat clearing, and sneezing and rhinorrhea. On speculum examination of the nose, excess mucoid or purulent secretions, inflamed and edematous nasal mucosa, and/or polyps may be seen; in addition, secretions or a cobblestoned appearance of the mucosa along the posterior pharyngeal wall may be noted. Unfortunately, there is no means by which to quantitate postnasal drainage. In many instances, this diagnosis must rely on subjective information provided by the patient. Furthermore, this assessment must also be counterbalanced by the fact that many people who have chronic postnasal drainage do not experience cough.

Linking gastroesophageal reflux to chronic cough poses similar challenges. It is thought that reflux of gastric contents into the lower esophagus may trigger cough via reflex pathways initiated in the esophageal mucosa. Reflux to the level of the pharynx (laryngopharyngeal reflux), with consequent aspiration of gastric contents, causes a chemical bronchitis and possibly pneumonitis that can elicit cough for days afterward, but it is a rare finding among persons with chronic cough. Retrosternal burning after meals or on recumbency, frequent eructation, hoarseness, and throat pain may be indicative of gastroesophageal reflux. Nevertheless, reflux may also elicit minimal or no symptoms. Glottic inflammation detected on laryngoscopy may be a manifestation of recurrent reflux to the level of the throat, but it is a nonspecific finding. Quantification of the frequency and level of reflux requires a somewhat invasive procedure to measure esophageal pH (either nasopharyngeal placement of a catheter with a pH probe into the esophagus for 24 h or endoscopic placement of a radiotransmitter capsule into the esophagus) and, with newer techniques, esophageal pressures (manometry) and nonacid reflux. The precise interpretation of test results that permits an etiologic linking of reflux events and cough remains debated. Again, assigning the cause of cough to gastroesophageal reflux must be weighed against the observation that many people with symptomatic reflux do not experience chronic cough.

Cough alone as a manifestation of asthma is common among children but not among adults. Cough due to asthma in the absence of wheezing, shortness of breath, and chest tightness is referred to as “cough-variant asthma.” A history suggestive of cough-variant asthma

ties the onset of cough to exposure to typical triggers for asthma and the resolution of cough to discontinuation of exposure. Objective testing can establish the diagnosis of asthma (airflow obstruction on spirometry that varies over time or reverses in response to a bronchodilator) or exclude it with certainty (a negative response to a bronchoprovocation challenge—e.g., with methacholine). In a patient capable of taking reliable measurements, home expiratory peak flow monitoring can be a cost-effective method to support or discount a diagnosis of asthma.

Eosinophilic bronchitis causes chronic cough with a normal chest radiograph. This uncommon condition is characterized by sputum eosinophilia in excess of 3% without airflow obstruction or bronchial hyperresponsiveness and is successfully treated with inhaled glucocorticoids. Measurement of an elevated concentration of nitric oxide in exhaled breath has the potential to detect eosinophilic airway inflammation (in asthma or eosinophilic bronchitis) and predict a favorable response to inhaled steroids in persons with chronic cough.

Treatment of chronic cough in a patient with a normal chest radiograph is often empirical and is targeted at the most likely cause(s) of cough as determined by history, physical examination, and possibly pulmonary function testing. Therapy for postnasal drainage depends on the presumed etiology (infection, allergy, or vasomotor rhinitis) and may include systemic antihistamines; decongestants; antibiotics; nasal saline irrigation; and nasal pump sprays with glucocorticoids, antihistamines, or anticholinergics. Antacids histamine type 2 ( $H_2$ ) receptor antagonists, and proton pump inhibitors are used to neutralize or decrease the production of gastric acid in gastroesophageal reflux disease; dietary changes, elevation of the head and torso during sleep, and medications to improve gastric emptying or impede the flow of refluxate (e.g., alginates) are additional therapeutic measures. Cough-variant asthma typically responds well to inhaled glucocorticoids and intermittent use of inhaled  $\beta$ -agonist bronchodilators.

Patients who fail to respond to treatment targeting the common causes of chronic cough or who have had these causes excluded by appropriate diagnostic testing should, in the opinion of the author, undergo chest CT. Diseases causing cough that may be missed on chest x-ray include tumors, early interstitial lung disease, bronchiectasis, and atypical mycobacterial pulmonary infection. On the other hand, patients with chronic cough who have normal findings on chest examination, lung function testing, oxygenation assessment, and chest CT can be reassured as to the absence of serious pulmonary pathology.

## ■ GLOBAL CONSIDERATIONS

Regular exposure to air pollution can cause chronic cough and throat clearing, as well as lower respiratory tract disease. Smoke from cooking and heating fuels in poorly ventilated homes; toxic exposures in work settings lacking implementation of occupational safety standards; and ambient chemicals and particulates in highly polluted outdoor air are all forms of air pollution causing cough. Limited therapeutic options are available; treatment focuses on improving environmental air quality (e.g., use of a stove chimney in the home), removal from the exposure, and use of an appropriate face mask.

In areas of the world where tuberculosis is endemic, chronic cough conjures the possibility of active pulmonary tuberculosis and mandates appropriate evaluation, including chest imaging and sputum analysis.

## ■ SYMPTOM BASED TREATMENT OF COUGH

Empiric treatment of chronic idiopathic cough with inhaled corticosteroids, inhaled anticholinergic bronchodilators, and macrolide antibiotics has been tried without consistent success. Currently available cough suppressants are only modestly effective. Most potent are narcotic cough suppressants, such as codeine, hydrocodone, or morphine, which are thought to act in the “cough center” in the brainstem. The tendency of narcotic cough suppressants to cause drowsiness and constipation and their potential for addictive dependence limit their appeal for long-term use. Dextromethorphan is an over-the-counter, centrally acting cough suppressant with fewer side effects and less efficacy than the narcotic cough suppressants. Dextromethorphan is thought to have a different site of action than narcotic cough suppressants and can be used in combination with them if necessary. Benzonatate is thought to

inhibit neural activity of sensory nerves in the cough-reflex pathway. It is generally free of side effects; however, its effectiveness in suppressing cough is variable and unpredictable. Inhaled lidocaine, an inhibitor of voltage-gated sodium channels, provides transient cough suppression, but because of associated oropharyngeal anesthesia, it poses the risk of aspiration.

Attempts to treat cough hypersensitivity syndrome have focused on inhibition of neural pathways. Small case series and randomized clinical trials have indicated benefit from off-label use of gabapentin, pregabalin, or amitriptyline. Recent studies suggest a role for behavioral modification using specialized speech therapy techniques, but widespread application of this modality is currently not practical. Novel cough suppressants without the limitations of currently available agents are greatly needed. Approaches that are being explored include the development of neurokinin-1 receptor antagonists, transient receptor protein vanilloid-1 (TRPV1) channel antagonists, a promising P2X3 channel antagonist (gefapixant), and novel opioid and opioid-like receptor agonists.

### FURTHER READING

- B CE et al: Eosinophilic bronchitis as an important cause of chronic cough. *Am J Respir Crit Care Med* 160:406, 1999.
- C TL (ed): *Chronic Cough*. San Diego, Plural Publishing, Inc., 2019.
- G P et al: Treatment of unexplained chronic cough: CHEST guideline and expert panel report. *Chest* 149:27, 2016.
- K PJ et al: Chronic cough due to gastroesophageal reflux in adults: CHEST Guideline and Expert Panel Report. *Chest* 150:1381, 2016.
- M AH et al: ERS guidelines on the diagnosis and treatment of chronic cough in adults and children. *Eur Respir J* 55: 1901136, 2020.
- R LE et al: Double-blind comparison of losartan, lisinopril and hydrochlorothiazide in hypertensive patients with previous angiotensin converting enzyme inhibitor-associated cough. *J Hypertens Suppl* 13:S73, 1995.
- R NM et al: Gabapentin for refractory chronic cough: A randomized, double-blind, placebo-controlled trial. *Lancet* 380:1583, 2012.
- S JA, W A: Chronic cough. *N Engl J Med* 375:1544, 2016.

The dual blood supply of the lungs makes it unique. The lungs have both the pulmonary and bronchial circulations. The pulmonary circulation is a low-pressure system that is essential for gas exchange at the alveolar level; in contrast, the bronchial circulation originates from the aorta and, therefore, is a higher-pressure system. The bronchial arteries supply the airways and can neovascularize tumors, dilated airways of bronchiectasis, and cavitary lesions. Most hemoptysis originates from the bronchial circulation, and bleeding from the higher-pressure system makes it more difficult to stop.

### ETIOLOGY

Hemoptysis commonly results from infection, malignancy, or vascular disease; however, the differential for bleeding from the respiratory tree is varied and broad. In the United States, the most common causes are viral bronchitis, bronchiectasis, or malignancy. In other parts of the world, infections such as tuberculosis are the most common causes.

**Infections** Most blood-tinged sputum and small-volume hemoptysis are due to viral bronchitis. Patients with chronic bronchitis are at risk for bacterial superinfection with organisms such as *Streptococcus pneumoniae*, *Haemophilus influenzae*, or *Moraxella catarrhalis*, increasing airway inflammation and potential for bleeding. Similarly, patients with bronchiectasis are prone to hemoptysis during exacerbations. Due to recurrent bacterial infection, bronchiectatic airways are dilated, inflamed, and highly vascular, supplied by the bronchial circulation. In several case series, bronchiectasis is the leading cause of massive hemoptysis and subsequent death.

Tuberculosis had long been the most common cause of hemoptysis worldwide, but it is now surpassed in industrialized countries by bronchitis and bronchiectasis. In patients with tuberculosis, development of cavitary disease is frequently the source of bleeding, but rarer complications such as the erosion of a pulmonary artery aneurysm into a preexisting cavity (i.e., Rasmussen's aneurysm) can also be the source.

Other infectious agents such as endemic fungi, *Nocardia*, and non-tuberculous mycobacteria can present as cavitary lung disease complicated by hemoptysis. In addition, *Aspergillus* species can develop into mycetomas within preexisting cavities, with neovascularization to these inflamed spaces leading to bleeding. Pulmonary abscesses and necrotizing pneumonia can cause bleeding by devitalizing lung parenchyma. Common responsible organisms include *Staphylococcus aureus*, *Klebsiella pneumoniae*, and oral anaerobes.

Paragonimiasis can mimic tuberculosis and is another significant cause of hemoptysis seen globally; it is common in Southeast Asia and China, although cases have been reported in North America from raw crayfish ingestion. It should be considered as a cause of hemoptysis in recent immigrants from endemic areas.

**Vascular** Hemoptysis from a vascular cause can be associated with cardiac disease, pulmonary embolism, arteriovenous malformation, or diffuse alveolar hemorrhage (DAH). While the classic description of the sputum expectorated in pulmonary edema (from elevated left end-diastolic pressure) is "pink and frothy," a spectrum of hemoptysis including frank blood can be seen. This observation is particularly true now with the more widespread use of anticoagulants and antiplatelet medications.

Pulmonary embolism with parenchymal infarction can present with hemoptysis, but pulmonary emboli do not commonly cause hemoptysis. An ectatic vessel in an airway or a pulmonary arteriovenous malformation can be a source of bleeding. A rare vascular cause of hemoptysis is the rupture of an aortobronchial fistula; these fistulae arise in the setting of aortic pathology such as aneurysm or pseudoaneurysm and can cause small bleeding episodes that herald massive hemoptysis.

DAH causes significant bleeding into the lung parenchyma but, interestingly, is not often associated with hemoptysis. DAH typically presents with diffuse ground glass opacities on chest imaging. A range of insults cause DAH, including immune-mediated capillaritis from diseases such as systemic lupus erythematosus, toxicity from cocaine and other inhalants, and stem cell transplantation. The

## 39

## Hemoptysis

Carolyn M. D'Ambrosio



**Hemoptysis** is the expectoration of blood from the respiratory tract. Bleeding from the gastrointestinal tract (hematemesis) or nasal cavities (epistaxis) can mimic hemoptysis. Once established as hemoptysis, the degree of blood that is being expectorated (volume and frequency) is the next step as massive or life-threatening hemoptysis (>400 mL of blood in 24 h or >150 mL at one time) requires emergent intervention. This chapter will focus predominantly on non-life-threatening hemoptysis. The source of the bleeding as well as the cause are the next steps when approaching a patient with hemoptysis.

### ANATOMY AND PHYSIOLOGY OF HEMOPTYSIS

Hemoptysis can arise from anywhere in the respiratory tract, from the glottis to the alveolus. Most commonly, bleeding arises from the bronchi or medium-sized airways, but a thorough evaluation of the entire respiratory tree is important.

so-called “pulmonary-renal” syndromes, including granulomatosis with polyangiitis and anti-glomerular basement membrane disease, may lead to both hemoptysis and hematuria (though one manifestation may be present without the other). A recently identified cause of hemoptysis and DAH is vaping-induced lung injury.

**Malignancy** Bronchogenic carcinoma of any histology is a common cause of hemoptysis (both massive and nonmassive). Hemoptysis can indicate airway involvement of the tumor and can be a presenting symptom of carcinoid tumors, vascular lesions that frequently arise in the proximal airways. Small cell and squamous cell carcinomas are frequently central in nature and more likely to erode into major pulmonary vessels, resulting in massive hemoptysis. Pulmonary metastases from distant tumors (e.g., melanoma, sarcoma, adenocarcinomas of the breast and colon) can also cause bleeding. Kaposi’s sarcoma, seen in advanced acquired immunodeficiency syndrome, is very vascular and can develop anywhere along the respiratory tract, from the bronchi to the oral cavity.

**Mechanical and Other Causes** In addition to infection, vascular disease, and malignancy, other insults to the pulmonary system can cause hemoptysis. Pulmonary endometriosis causes cyclical bleeding known as catamenial hemoptysis. Foreign body aspiration can lead to airway irritation and bleeding. Diagnostic and therapeutic procedures are also potential offenders: pulmonary vein stenosis can result from left atrial procedures, such as pulmonary vein isolation, and pulmonary artery catheters can lead to rupture of the pulmonary artery if the distal balloon is kept inflated. Finally, in the setting of thrombocytopenia, coagulopathy, anticoagulation, or antiplatelet therapy, even minor insults can cause hemoptysis.

## EVALUATION AND MANAGEMENT

**History** The amount or severity of bleeding is the first step in assessing a patient with hemoptysis. A patient’s description of the sputum (e.g., flecks of blood, pink-tinged, or frank blood or clot) is helpful if you cannot examine it. An approach to management of hemoptysis is outlined in Fig. 39-1.

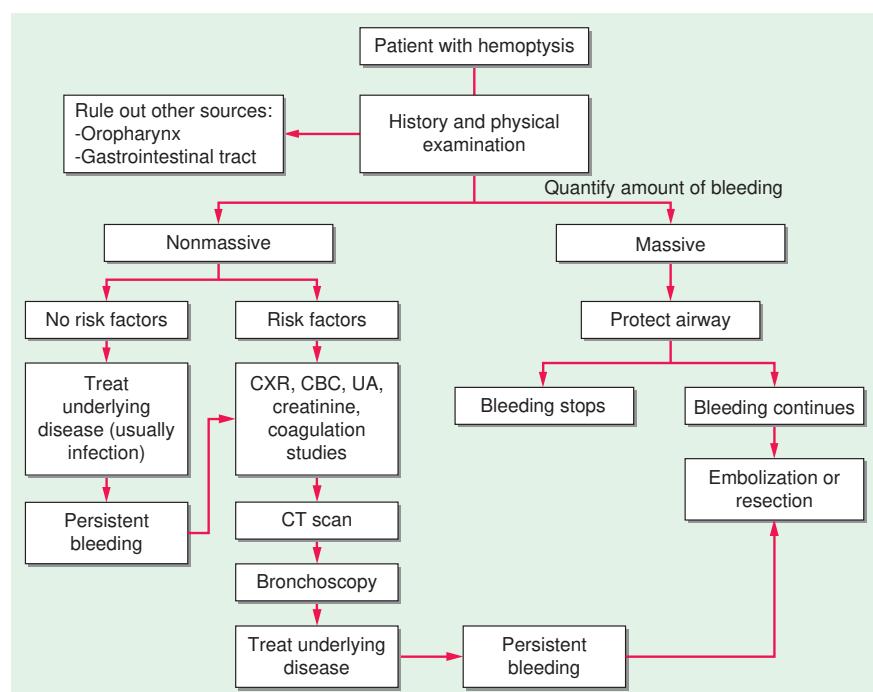


FIGURE 39-1 Approach to the management of hemoptysis. CBC, complete blood count; CT, computed tomography; CXR, chest x-ray; UA, urinalysis.

While there is no agreed-upon volume, blood loss of 400 mL in 24 h or 100–150 mL expectorated at one time should be considered life-threatening hemoptysis. These numbers derive from the blood volume of the tracheobronchial tree (generally 100–200 mL). Patients rarely die of exsanguination but, rather, are at risk of death due to asphyxiation from blood filling the airways and airspaces. Most patients cannot describe the volume of their hemoptysis in milliliters, so using referents like cups (one U.S. cup is 236 mL) can be helpful. Fortunately, life-threatening hemoptysis only accounts for 5–15% of cases of hemoptysis.

The history may point to the cause of hemoptysis. Fever, chills, or antecedent cough may suggest infection. A history of smoking or unintentional weight loss makes malignancy more likely. Patients should be asked about inhalational exposures, including vaping. A thorough medical history with careful attention to chronic pulmonary disease should be obtained, with evaluation of risk factors for malignancy and bronchiectatic lung disease (e.g., cystic fibrosis, sarcoidosis).

**Physical Examination** Reviewing the vital signs is an important first step. Patients who have life-threatening hemoptysis can have hypoxemia, tachycardia, and hemodynamic instability. As the site of bleeding is important, evaluation of the nasal and oral cavities is imperative. In addition, auscultation of the lungs and seeking other relevant physical findings such as clubbing can point to a cause of the hemoptysis. A focal area of wheezing could suggest a foreign body aspiration. Other signs of a bleeding diathesis (e.g., skin or mucosal ecchymoses and petechiae) or telangiectasias may suggest other etiologies of the hemoptysis.

**Diagnostic Studies** Initial studies should include measurement of a complete blood count to assess for infection, anemia, or thrombocytopenia; coagulation parameters; measurement of electrolytes and renal function; and urinalysis to exclude pulmonary-renal disease. Chest imaging is necessary for every patient.

A chest radiograph is usually obtained first, although it frequently does not localize bleeding and can appear normal. In patients without risk factors for malignancy or other abnormalities in the initial evaluation and with a normal chest radiograph, treating for bronchitis and ensuring close follow-up is a reasonable strategy, with further diagnostic workup.

In contrast, patients with risk factors for malignancy (i.e., age >40 or a smoking history) should undergo additional testing. First, chest computed tomography (CT) with contrast should be obtained to better identify masses, bronchiectasis, and parenchymal lesions. A CT looking for pulmonary embolism should be considered if the history and physical examination are consistent with that diagnosis. Following a CT, a flexible bronchoscopy should be performed to exclude bronchogenic carcinoma unless imaging reveals a lesion that can be sampled without bronchoscopy. Small case series show that patients with hemoptysis and unrevealing bronchoscopies have good outcomes.

**Interventions** When the amount of hemoptysis is massive or life-threatening, there are three simultaneous goals: first, protect the nonbleeding lung; second, locate the site of bleeding; and third, control the bleeding.

Protecting the airway and nonbleeding lung is paramount in the management of massive hemoptysis because asphyxiation can happen quickly. If the side of bleeding is known, the patient should be positioned with the bleeding side down to use gravitational advantage to keep blood out of the nonbleeding lung. Endotracheal intubation should be avoided unless truly necessary, since suctioning through an endotracheal tube is a less effective means of removing blood and clot than the cough reflex. If intubation is required, take steps to protect the nonbleeding lung either by selective intubation of one lung (i.e., the nonbleeding lung) or insertion of a double-lumen endotracheal tube.

Locating the bleeding site is sometimes obvious, but frequently, it can be difficult to determine. A chest radiograph, if it shows new opacities, can be helpful in localizing the side or site of bleeding, although this test is not adequate by itself. CT angiography helps by localizing active extravasation. Flexible bronchoscopy may be useful to identify the side of bleeding (although it has only a 50% chance of locating the site). Experts do not agree on the timing of bronchoscopy, although in some cases—cystic fibrosis, for instance—bronchoscopy is *not* recommended because it may delay definitive management. Finally, proceeding directly to angiography is also a reasonable strategy given that it has both diagnostic and therapeutic capabilities.

Controlling the bleeding during an episode of life-threatening hemoptysis can be accomplished in one of three ways: from the airway lumen, from the involved blood vessel, or by surgical resection of both airway and vessel involved. Bronchoscopic measures are generally only temporizing: a flexible bronchoscope can be used to suction clot and insert a balloon catheter or bronchial blocker that occludes the involved airway. Rigid bronchoscopy, done by an interventional pulmonologist or thoracic surgeon, may allow therapeutic interventions of bleeding airway lesions such as photoagulation and cautery. Because most life-threatening cases of hemoptysis arise from the bronchial circulation, bronchial artery embolization is the procedure of choice for control of the bleeding. However, bronchial artery embolization can have significant complications such as embolization of the anterior spinal artery. However, it is generally successful in the short term, with >80% success rate at controlling bleeding immediately, although bleeding can recur if the underlying disease (e.g., a mycetoma) is not treated. Surgical resection has a high mortality rate (up to 15–40%) and should not be pursued unless initial measures have failed and bleeding is ongoing. Ideal candidates for surgery have localized disease but otherwise normal lung parenchyma.

## A

*Anna K. Brady and Patricia A. Kritek contributed to this chapter in the 20th edition, and some material from that chapter has been retained here.*

### FURTHER READING

- A      Met al: Cryptogenic hemoptysis: Clinical features, bronchoscopic findings, and natural history in 67 patients. *Ann Intern Med* 102:829, 1985.
- F      PA et al: CF pulmonary guidelines. Pulmonary complications: Hemoptysis and pneumothorax. *Am J Respir Crit Care Med* 182:298, 2010.
- H      B et al: Hemoptysis: Etiology, evaluation, and outcome in a tertiary care hospital. *Chest* 112:440, 1997.
- J      -      E: Clinical assessment and management of massive hemoptysis. *Crit Care Med* 28:1642, 2000.
- J      JL: Manifestations of hemoptysis: How to manage minor, moderate, and massive bleeding. *Postgrad Med* 112:4:101, 2002.
- L      JE et al: Pulmonary illness related to e-cigarette, reply. *N Engl J Med* 382:903, 2020.
- L      JL et al: The pulmonary physician in critical care: Illustrative case 7. Assessment and management of massive hemoptysis. *Thorax* 58:814, 2003.
- S      DR, S      TP: Bronchial artery embolization for massive hemoptysis. *Semin Intervent Radiol* 28:48, 2011.



## HYPOXIA

The fundamental purpose of the cardiorespiratory system is to deliver O<sub>2</sub> and nutrients to cells and to remove CO<sub>2</sub> and other metabolic products from them. Proper maintenance of this function depends not only on intact cardiovascular and respiratory systems, but also on an adequate number of red blood cells and hemoglobin and a supply of inspired gas containing adequate O<sub>2</sub>.

### ■ RESPONSES TO HYPOXIA

Decreased O<sub>2</sub> availability to cells typically results in an inhibition of oxidative phosphorylation and increased anaerobic glycolysis. This switch from aerobic to anaerobic metabolism, the Pasteur effect, reduces the rate of adenosine 5'-triphosphate (ATP) production. In severe hypoxia, when ATP production is inadequate to meet the energy requirements of ionic and osmotic equilibrium, cell membrane depolarization leads to uncontrolled Ca<sup>2+</sup> influx and activation of Ca<sup>2+</sup>-dependent phospholipases and proteases. These events, in turn, cause cell swelling, activation of apoptotic pathways, and, ultimately, cell death.

The adaptations to hypoxia are mediated, in part, by the upregulation of genes encoding a variety of proteins, including glycolytic enzymes, such as phosphoglycerate kinase and phosphofructokinase, as well as the glucose transporters Glut-1 and Glut-2; and by growth factors, such as vascular endothelial growth factor (VEGF) and erythropoietin, which enhance erythrocyte production. The hypoxia-induced increase in expression of these and other key proteins is governed by the hypoxia-sensitive transcription factor, hypoxia-inducible factor-1 (HIF-1).

During hypoxia, systemic arterioles dilate, at least in part, by opening of K<sub>ATP</sub> channels in vascular smooth-muscle cells due to the hypoxia-induced reduction in ATP concentration. By contrast, in pulmonary vascular smooth-muscle cells, inhibition of K<sup>+</sup> channels causes depolarization, which, in turn, activates voltage-gated Ca<sup>2+</sup> channels, raising the cytosolic [Ca<sup>2+</sup>] and causing smooth-muscle cell contraction. Hypoxia-induced pulmonary arterial constriction shunts blood away from poorly ventilated portions toward better ventilated portions of the lung (i.e., improves ventilation-perfusion mismatch); however, it also increases pulmonary vascular resistance and right ventricular afterload.

**Effects on the Central Nervous System** Changes in the central nervous system (CNS), particularly the higher centers, are especially important consequences of hypoxia. Acute hypoxia causes impaired judgment, motor incoordination, and a clinical picture resembling acute alcohol intoxication. High-altitude illness is characterized by headache secondary to cerebral vasodilation, gastrointestinal symptoms, dizziness, insomnia, fatigue, or somnolence. Pulmonary arterial and sometimes venous constriction causes capillary leakage and high-altitude pulmonary edema (HAPE) (*Chap. 37*), which intensifies hypoxia, further promoting vasoconstriction. Rarely, high-altitude cerebral edema (HACE) develops, which is manifest by severe headache and papilledema and can cause coma. As hypoxia becomes more severe, the regulatory centers of the brainstem are affected, and death usually results from respiratory failure.

**Effects on the Cardiovascular System** Acute hypoxia stimulates the chemoreceptor reflex arc to induce vasoconstriction and systemic arterial vasodilation. These acute changes are accompanied by transiently increased myocardial contractility, which is followed by depressed myocardial contractility with prolonged hypoxia.

### ■ CAUSES OF HYPOXIA

**Respiratory Hypoxia** When hypoxia occurs from respiratory failure, Pa<sub>O<sub>2</sub></sub> declines, and when respiratory failure is persistent, the

hemoglobin-oxygen ( $\text{Hb-O}_2$ ) dissociation curve (see Fig. 98-2) is displaced to the right, with greater quantities of  $\text{O}_2$  released at any level of tissue  $\text{P}_{\text{O}_2}$ . Arterial hypoxemia, that is, a reduction of  $\text{O}_2$  saturation of arterial blood ( $\text{Sa}_{\text{O}_2}$ ), and consequent cyanosis are likely to be more marked when such depression of  $\text{Pa}_{\text{O}_2}$  results from pulmonary disease than when the depression occurs as the result of a decline in the fraction of oxygen in inspired air ( $\text{F}_{\text{O}_2}$ ). In this latter situation,  $\text{Pa}_{\text{O}_2}$  falls secondary to anoxia-induced hyperventilation and the  $\text{Hb-O}_2$  dissociation curve is displaced to the left, limiting the decline in  $\text{Sa}_{\text{O}_2}$  at any level of  $\text{Pa}_{\text{O}_2}$ .

The most common cause of respiratory hypoxia is *ventilation-perfusion mismatch* resulting from perfusion of poorly ventilated alveoli. Respiratory hypoxemia may also be caused by *hypoventilation*, in which case it is associated with an elevation of  $\text{PaCO}_2$  (Chap. 285). These two forms of respiratory hypoxia are usually correctable by inspiring 100%  $\text{O}_2$  for several minutes. A third cause of respiratory hypoxia is shunting of blood across the lung from the pulmonary arterial to the venous bed (*intrapulmonary right-to-left shunting*) by perfusion of nonventilated portions of the lung, as in pulmonary atelectasis or through pulmonary arteriovenous connections. The low  $\text{Pa}_{\text{O}_2}$  in this situation is only partially corrected by an  $\text{F}_{\text{O}_2}$  of 100%.

**Hypoxia Secondary to High Altitude** As one ascends rapidly to 3000 m (~10,000 ft), the reduction of the  $\text{O}_2$  content of inspired air ( $\text{F}_{\text{O}_2}$ ) leads to a decrease in alveolar  $\text{P}_{\text{O}_2}$  to 60 mmHg, and a condition termed *high-altitude illness* develops (see above). At higher altitudes, arterial saturation declines rapidly and symptoms become more serious; and at 5000 m, unacclimated individuals usually cease to be able to function normally owing to the changes in CNS function described above.

**Hypoxia Secondary to Right-to-Left Extrapulmonary Shunting** From a physiologic viewpoint, this cause of hypoxia resembles intrapulmonary right-to-left shunting but is caused by congenital cardiac malformations, such as tetralogy of Fallot, transposition of the great arteries, atrial or ventricular septal defect, patent ductus arteriosus, and Eisenmenger's syndrome (Chap. 269). As in pulmonary right-to-left shunting, the  $\text{Pa}_{\text{O}_2}$  cannot be restored to normal with inspiration of 100%  $\text{O}_2$ .

**Anemic Hypoxia** A reduction in hemoglobin concentration of the blood is accompanied by a corresponding decline in the  $\text{O}_2$ -carrying capacity of the blood. Although the  $\text{Pa}_{\text{O}_2}$  is normal in anemic hypoxia, the absolute quantity of  $\text{O}_2$  transported per unit volume of blood is diminished. As the anemic blood passes through the capillaries and the usual quantity of  $\text{O}_2$  is removed from it, the  $\text{P}_{\text{O}_2}$  and saturation in the venous blood decline to a greater extent than normal.

**Carbon Monoxide (CO) Intoxication** (See also Chap. 463) Hemoglobin that binds with CO (carboxy-hemoglobin [COHb]) is unavailable for  $\text{O}_2$  transport. In addition, the presence of COHb shifts the  $\text{Hb-O}_2$  dissociation curve to the left (see Fig. 98-2) so that  $\text{O}_2$  is unloaded only at lower tensions, further contributing to tissue hypoxia.

**Circulatory Hypoxia** As in anemic hypoxia, the  $\text{Pa}_{\text{O}_2}$  is usually normal, but venous and tissue  $\text{P}_{\text{O}_2}$  values are reduced as a consequence of reduced tissue perfusion and greater tissue  $\text{O}_2$  extraction. This pathophysiology leads to an increased arterial-mixed venous  $\text{O}_2$  difference (a-v- $\text{O}_2$  difference), or gradient. Generalized circulatory hypoxia occurs in heart failure (Chap. 257) and in most forms of shock (Chap. 303).

**Specific Organ Hypoxia** Localized circulatory hypoxia may occur as a result of decreased perfusion secondary to arterial obstruction, as in localized atherosclerosis in any vascular bed, or as a consequence of vasoconstriction, as observed in Raynaud's phenomenon (Chap. 281). Localized hypoxia may also result from venous obstruction and the resultant expansion of interstitial fluid causing arteriolar compression and, thereby, reduction of arterial inflow. Edema, which increases the distance through which  $\text{O}_2$  must diffuse before it reaches cells, can also cause localized hypoxia. In an attempt to maintain adequate perfusion to more vital organs in patients with reduced cardiac output secondary

to heart failure or hypovolemic shock, vasoconstriction may reduce perfusion in the limbs and skin, causing hypoxia of these regions.

**Increased  $\text{O}_2$  Requirements** If the  $\text{O}_2$  consumption of tissues is elevated without a corresponding increase in perfusion, tissue hypoxia ensues and the  $\text{P}_{\text{O}_2}$  in venous blood declines. Ordinarily, the clinical picture of patients with hypoxia due to an elevated metabolic rate, as in fever or thyrotoxicosis, is quite different from that in other types of hypoxia: the skin is warm and flushed owing to increased cutaneous blood flow that dissipates the excessive heat produced, and cyanosis is usually absent.

Exercise is a classic example of increased tissue  $\text{O}_2$  requirements. These increased demands are normally met by several mechanisms operating simultaneously: (1) increase in the cardiac output and ventilation and, thus,  $\text{O}_2$  delivery to the tissues; (2) a preferential shift in blood flow to the exercising muscles by changing vascular resistances in the circulatory beds of exercising tissues, directly and/or reflexly; (3) an increase in  $\text{O}_2$  extraction from the delivered blood and a widening of the arteriovenous  $\text{O}_2$  difference; and (4) a reduction in the pH of the tissues and capillary blood, shifting the  $\text{Hb-O}_2$  curve to the right (see Fig. 98-2), and unloading more  $\text{O}_2$  from hemoglobin. If the capacity of these mechanisms is exceeded, then hypoxia, especially of the exercising muscles, will result.

**Improper Oxygen Utilization** Cyanide (Chap. 459) and several other similarly acting poisons cause cellular hypoxia by impairing electron transport in mitochondria, thereby limiting oxidative phosphorylation and ATP production. The tissues are unable to use  $\text{O}_2$ , and as a consequence, the venous blood tends to have a high  $\text{O}_2$  tension. This condition has been termed *histotoxic hypoxia*.

## ■ ADAPTATION TO HYPOXIA

An important component of the respiratory response to hypoxia originates in special chemosensitive cells in the carotid and aortic bodies and in the respiratory center in the brainstem. The stimulation of these cells by hypoxia increases ventilation, with a loss of  $\text{CO}_2$ , and can lead to respiratory alkalosis. When combined with the metabolic acidosis resulting from the production of lactic acid, the serum bicarbonate level declines (Chap. 55).

With the reduction of  $\text{Pa}_{\text{O}_2}$ , cerebrovascular resistance decreases and cerebral blood flow increases in an attempt to maintain  $\text{O}_2$  delivery to the brain. However, when the reduction of  $\text{Pa}_{\text{O}_2}$  is accompanied by hyperventilation and a reduction of  $\text{PaCO}_2$ , cerebrovascular resistance rises, cerebral blood flow falls, and tissue hypoxia intensifies.

The diffuse, systemic vasodilation that occurs in generalized hypoxia increases the cardiac output. In patients with underlying heart disease, the requirements of peripheral tissues for an increase of cardiac output with hypoxia may precipitate congestive heart failure. In patients with ischemic heart disease, a reduced  $\text{Pa}_{\text{O}_2}$  may intensify myocardial ischemia and further impair left ventricular function.

One of the important compensatory mechanisms for chronic hypoxia is an increase in the hemoglobin concentration and in the number of red blood cells in the circulating blood, that is, the development of polycythemia induced by erythropoietin production (Chap. 103). In persons with chronic hypoxemia secondary to prolonged residence at a high altitude (>13,000 ft, 4200 m), a condition termed *chronic mountain sickness* develops. This disorder is characterized by a blunted respiratory drive, reduced ventilation, erythrocytosis, cyanosis, weakness, right ventricular enlargement secondary to pulmonary hypertension, and even stupor.

## CYANOSIS

*Cyanosis* refers to a bluish color of the skin and mucous membranes resulting from an increased quantity of reduced hemoglobin (i.e., deoxygenated hemoglobin) or of hemoglobin derivatives (e.g., methemoglobin or sulfhemoglobin) in the small blood vessels of those tissues. It is usually most marked in the lips, nail beds, ears, and malar eminences. Cyanosis, especially if developed recently, is more commonly detected by a family member than the patient. The florid skin characteristic of polycythemia vera (Chap. 103) must be distinguished from the true cyanosis discussed here. A cherry-colored flush, rather than cyanosis, is caused by COHb (Chap. 459).

The degree of cyanosis is modified by the color of the cutaneous pigment and the thickness of the skin, as well as by the state of the cutaneous capillaries. The accurate clinical detection of the presence and degree of cyanosis is difficult, as proved by oximetric studies. In some instances, central cyanosis can be detected reliably when the  $\text{Sa}_\text{O}_2$  has fallen to 85%; in others, particularly in dark-skinned persons, it may not be detected until it has declined to 75%. In the latter case, examination of the mucous membranes in the oral cavity and the conjunctivae rather than examination of the skin is more helpful in the detection of cyanosis.

The increase in the quantity of reduced hemoglobin in the mucocutaneous vessels that produces cyanosis may be brought about either by an increase in the quantity of venous blood as a result of dilation of the venules (including precapillary venules) or by a reduction in the  $\text{Sa}_\text{O}_2$  in the capillary blood. In general, cyanosis becomes apparent when the concentration of reduced hemoglobin in capillary blood exceeds 40 g/L (4 g/dL).

It is the *absolute*, rather than the *relative*, quantity of reduced hemoglobin that is important in producing cyanosis. Thus, in a patient with severe anemia, the *relative* quantity of reduced hemoglobin in the venous blood may be very large when considered in relation to the total quantity of hemoglobin in the blood. However, since the concentration of the latter is markedly reduced, the *absolute* quantity of reduced hemoglobin may still be low, and, therefore, patients with severe anemia and even *marked* arterial desaturation may not display cyanosis. Conversely, the higher the total hemoglobin content, the greater is the tendency toward cyanosis; thus, patients with marked polycythemia tend to be cyanotic at higher levels of  $\text{Sa}_\text{O}_2$  than patients with normal hematocrit values. Likewise, local passive congestion, which causes an increase in the total quantity of reduced hemoglobin in the vessels in a given area, may cause cyanosis. Cyanosis is also observed when nonfunctional hemoglobin, such as methemoglobin (consequential or acquired) or sulfhemoglobin (Chap. 98), is present in blood.

Cyanosis may be subdivided into central and peripheral types. In *central cyanosis*, the  $\text{Sa}_\text{O}_2$  is reduced or an abnormal hemoglobin derivative is present, and the mucous membranes and skin are both affected. *Peripheral cyanosis* is due to a slowing of blood flow and abnormally great extraction of  $\text{O}_2$  from normally saturated arterial blood; it results from vasoconstriction and diminished peripheral blood flow, such as occurs in cold exposure, shock, congestive failure, and peripheral vascular disease. Often in these conditions, the mucous membranes of the oral cavity, including the sublingual mucosa, may be spared. Clinical differentiation between central and peripheral cyanosis may not always be straightforward, and in conditions such as cardiogenic shock with pulmonary edema, there may be a mixture of both types.

## ■ DIFFERENTIAL DIAGNOSIS

**Central Cyanosis (Table 40-1)** Decreased  $\text{Sa}_\text{O}_2$  results from a marked reduction in the  $\text{Pa}_\text{O}_2$ . This reduction may be brought about by a decline in the  $\text{F}_\text{O}_2$  without sufficient compensatory alveolar hyperventilation to maintain alveolar  $\text{P}_\text{O}_2$ . Cyanosis usually becomes manifest in an ascent to an altitude of 4000 m (13,000 ft).

Seriously *impaired pulmonary function*, through perfusion of unventilated or poorly ventilated areas of the lung or alveolar hypoventilation, is a common cause of central cyanosis (Chap. 285). This condition may occur acutely, as in extensive pneumonia or pulmonary edema, or chronically, with chronic pulmonary diseases (e.g., emphysema). In the latter situation, secondary polycythemia is generally present and clubbing of the fingers (see below) may occur. Another cause of reduced  $\text{Sa}_\text{O}_2$  is *shunting of systemic venous blood into the arterial circuit*. Certain forms of congenital heart disease are associated with cyanosis on this basis (see above and Chap. 269).

*Pulmonary arteriovenous fistulae* may be congenital or acquired, solitary or multiple, and microscopic or massive. The severity of cyanosis produced by these fistulae depends on their size and number. They occur with some frequency in hereditary hemorrhagic telangiectasia.  $\text{Sa}_\text{O}_2$  reduction and cyanosis may also occur in some patients with cirrhosis, presumably as a consequence of pulmonary arteriovenous fistulae or portal vein–pulmonary vein anastomoses.

TABLE 40-1 Causes of Cyanosis

### Central Cyanosis

#### Decreased arterial oxygen saturation

Decreased atmospheric pressure—high altitude

#### Impaired pulmonary function

Alveolar hypoventilation

Inhomogeneity in pulmonary ventilation and perfusion (perfusion of hypoxic alveoli)

Impaired oxygen diffusion

#### Anatomic shunts

Certain types of congenital heart disease

Pulmonary arteriovenous fistulas

Multiple small intrapulmonary shunts

#### Hemoglobin with low affinity for oxygen

### Hemoglobin abnormalities

Methemoglobinemia—hereditary, acquired

Sulfhemoglobinemia—acquired

Carboxyhemoglobinemia (not true cyanosis)

### Peripheral Cyanosis

Reduced cardiac output

Cold exposure

Redistribution of blood flow from extremities

Arterial obstruction

Venous obstruction

In patients with cardiac or pulmonary right-to-left shunts, the presence and severity of cyanosis depend on the size of the shunt relative to the systemic flow and on the  $\text{Hb-O}_2$  saturation of the venous blood. With increased extraction of  $\text{O}_2$  from the blood by the exercising muscles, the venous blood returning to the right side of the heart is more unsaturated than at rest, and shunting of this blood intensifies the cyanosis. Secondary polycythemia occurs frequently in patients in this setting and contributes to the cyanosis.

Cyanosis can be caused by small quantities of circulating methemoglobin ( $\text{Hb Fe}^{3+}$ ) and by even smaller quantities of sulfhemoglobin (Chap. 98); both of these hemoglobin derivatives impair oxygen delivery to the tissues. Although they are uncommon causes of cyanosis, these abnormal hemoglobin species should be sought by spectroscopy when cyanosis is not readily explained by malfunction of the circulatory or respiratory systems. Generally, digital clubbing does not occur with them.

**Peripheral Cyanosis** Probably the most common cause of peripheral cyanosis is the normal vasoconstriction resulting from exposure to cold air or water. When cardiac output is reduced, cutaneous vasoconstriction occurs as a compensatory mechanism so that blood is diverted from the skin to more vital areas such as the CNS and heart, and cyanosis of the extremities may result even though the arterial blood is normally saturated.

Arterial obstruction to an extremity, as with an embolus, or arteriolar constriction, as in cold-induced vasospasm (Raynaud's phenomenon) (Chap. 281), generally results in pallor and coldness, and there may be associated cyanosis. Venous obstruction, as in thrombophlebitis or deep venous thrombosis, dilates the subpapillary venous plexuses and thereby intensifies cyanosis.

## APPROACH TO THE PATIENT

### Cyanosis

Certain features are important in arriving at the cause of cyanosis:

1. It is important to ascertain the time of onset of cyanosis. Cyanosis present since birth or infancy is usually due to congenital heart disease.

- Central and peripheral cyanosis must be differentiated. Evidence of disorders of the respiratory or cardiovascular systems is helpful. Massage or gentle warming of a cyanotic extremity will increase peripheral blood flow and abolish peripheral, but not central, cyanosis.
- The presence or absence of clubbing of the digits (see below) should be ascertained. The combination of cyanosis and clubbing is frequent in patients with congenital heart disease and right-to-left shunting and is seen occasionally in patients with pulmonary disease, such as lung abscess or pulmonary arteriovenous fistulae. In contrast, peripheral cyanosis or acutely developing central cyanosis is *not* associated with clubbed digits.
- $\text{PaO}_2$  and  $\text{SaO}_2$  should be determined, and in patients with cyanosis in whom the mechanism is obscure, spectroscopic examination of the blood should be performed to look for abnormal types of hemoglobin (critical in the differential diagnosis of cyanosis).

## CLUBBING

The selective bulbous enlargement of the distal segments of the fingers and toes due to proliferation of connective tissue, particularly on the dorsal surface, is termed *clubbing*; there is also increased sponginess of the soft tissue at the base of the clubbed nail. Clubbing may be hereditary, idiopathic, or acquired and associated with a variety of disorders, including cyanotic congenital heart disease (see above), infective endocarditis, and a variety of pulmonary conditions (among them primary and metastatic lung cancer, bronchiectasis, asbestos, sarcoidosis, lung abscess, cystic fibrosis, tuberculosis, and mesothelioma), as well as with some gastrointestinal diseases (including inflammatory bowel disease and hepatic cirrhosis). In some instances, it is occupational, for example, in jackhammer operators.

Clubbing in patients with primary and metastatic lung cancer, mesothelioma, bronchiectasis, or hepatic cirrhosis may be associated with *hypertrophic osteoarthropathy*. In this condition, the subperiosteal formation of new bone in the distal diaphyses of the long bones of the extremities causes pain and symmetric arthritis-like changes in the shoulders, knees, ankles, wrists, and elbows. The diagnosis of hypertrophic osteoarthropathy may be confirmed by bone radiograph or magnetic resonance imaging (MRI). Although the mechanism of clubbing is unclear, it appears to be secondary to humoral substances that cause dilation of the vessels of the distal digits as well as growth factors released from platelet precursors in the digital circulation. In certain circumstances, clubbing is reversible, such as following lung transplantation for cystic fibrosis.

## FURTHER READING

- C J et al: Clubbing and hypertrophic osteoarthropathy: Insights into diagnosis, pathophysiology, and clinical significance. *Acta Clin Belg* 22:1, 2016.  
 M I NR: Tissue hypoxia: Implications for the respiratory clinician. *Respir Care* 59:1590, 2014.

There is constant interchange of fluid between the two compartments of the extracellular fluid. The hydrostatic pressure within the capillaries and the colloid oncotic pressure in the interstitial fluid promote the movement of water and diffusible solutes from plasma to the interstitium. This movement is most prominent at the arterial origin of the capillary and falls progressively with the decline in intracapillary pressure and the rise in oncotic pressure toward the venular end. Fluid is returned from the interstitial space into the vascular system largely through the lymphatic system. These interchanges of fluids are normally balanced so that the volumes of the intravascular and interstitial compartments remain constant. However, a net movement of fluid from the intravascular to the interstitial spaces takes place and may be responsible for the development of edema under the following conditions: (1) an increase in intracapillary hydrostatic pressure; (2) inadequate lymphatic drainage; (3) reductions in the oncotic pressure in the plasma; (4) damage to the capillary endothelial barrier; and (5) increases in the oncotic pressure in the interstitial space.

## REDUCTION OF EFFECTIVE ARTERIAL VOLUME

In many forms of edema, the effective arterial blood volume, a parameter that represents the filling of the arterial tree and that effectively perfuses the tissues, is reduced. Underfilling of the arterial tree may be caused by a reduction of cardiac output and/or systemic vascular resistance, by the pooling of blood in the splanchnic veins (as in cirrhosis), and by hypoalbuminemia (Fig. 41-1A). As a consequence of this underfilling, a series of physiologic responses designed to restore the effective arterial volume to normal are set into motion. A key element of these responses is the renal retention of sodium and, therefore, water, thereby restoring effective arterial volume, but sometimes also leading to the development or intensification of edema.

## RENAL FACTORS AND THE RENIN ANGIOTENSIN ALDOSTERONE SYSTEM

The diminished renal blood flow characteristic of states in which the effective arterial blood volume is reduced is translated by the renal juxtaglomerular cells (specialized myoepithelial cells surrounding the afferent arteriole) into a signal for increased renin release. Renin is an enzyme with a molecular mass of about 40,000 Da that acts on its substrate, angiotensinogen, an  $\alpha_2$ -globulin synthesized by the liver, to release angiotensin I, a decapeptide, which in turn is converted to angiotensin II (AII), an octapeptide. AII has generalized vasoconstrictor properties, particularly on the renal efferent arterioles. This action reduces the hydrostatic pressure in the peritubular capillaries, whereas the increased filtration fraction raises the colloid oncotic pressure in these vessels, thereby enhancing salt and water reabsorption in the proximal tubule as well as in the ascending limb of the loop of Henle.

The renin-angiotensin-aldosterone system (RAAS) operates as both a hormonal and paracrine system. Its activation causes sodium and water retention and thereby contributes to edema formation. Blockade of the conversion of angiotensin I to AII and blockade of the AII receptors enhance sodium and water excretion and reduce many forms of edema. AII that enters the systemic circulation stimulates the production of aldosterone by the zona glomerulosa of the adrenal cortex. Aldosterone in turn enhances sodium reabsorption (and potassium excretion) by the collecting tubule, further favoring edema formation. Blockade of the action of aldosterone by spironolactone or eplerenone (aldosterone antagonists) or by amiloride (a blocker of epithelial sodium channels) often induces a moderate diuresis in edematous states.

## ARGININE VASOPRESSIN

(See also Chap. 381) The secretion of arginine vasopressin (AVP) by the posterior pituitary gland occurs in response to increased intracellular osmolar concentration; by stimulating  $V_2$  receptors, AVP increases the reabsorption of free water in the distal tubules and collecting ducts of the kidneys, thereby increasing total-body water. Circulating AVP is elevated in many patients with heart failure secondary to a nonosmotic stimulus associated with decreased effective arterial volume and reduced compliance of the left atrium. Such patients fail to show the normal reduction of AVP with a reduction of osmolality, contributing to edema formation and hyponatremia.

# 41

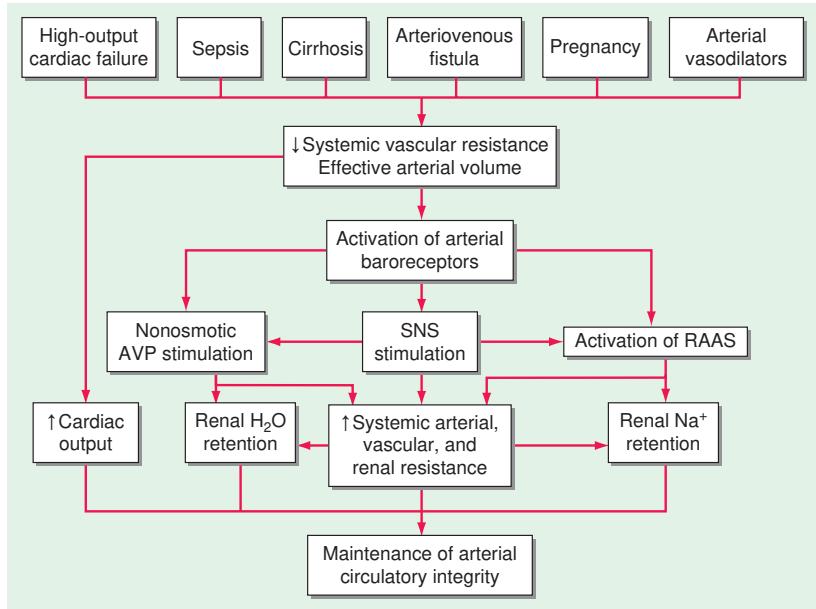
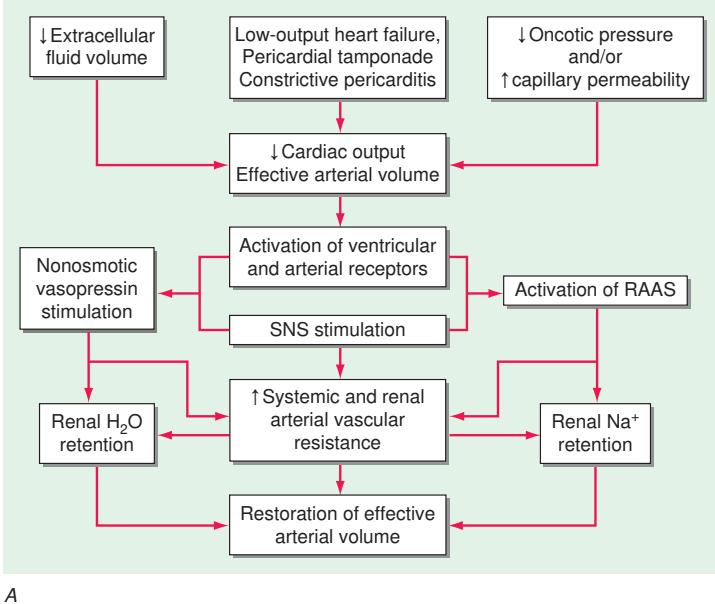
## Edema

Joseph Loscalzo



## PLASMA AND INTERSTITIAL FLUID EXCHANGE

Approximately two-thirds of total body water is intracellular and one-third is extracellular. One-fourth of the latter is in the plasma, and the remainder comprises the interstitial fluid. Edema represents an excess of interstitial fluid that has become evident clinically.



**FIGURE 41-1** Clinical conditions in which a decrease in cardiac output (**A**) and systemic vascular resistance (**B**) cause arterial underfilling with resulting neurohumoral activation and renal sodium and water retention. In addition to activating the neurohumoral axis, adrenergic stimulation causes renal vasoconstriction and enhances sodium and fluid transport by the proximal tubule epithelium. AVP, arginine vasopressin; RAAS, renin-angiotensin aldosterone system; SNS, sympathetic nervous system. (From Annals of Internal Medicine, RW Schrier: Body fluid volume regulation in health and disease: A unifying hypothesis. 113(2):155-159, 1990. Copyright © 1990, American College of Physicians. All Rights Reserved. Reprinted with the permission of American College of Physicians, Inc.)

### ■ ENDOTHELIN 1

This potent peptide vasoconstrictor is released by endothelial cells. Its concentration in the plasma is elevated in patients with severe heart failure and contributes to renal vasoconstriction, sodium retention, and edema.

### ■ Natriuretic Peptides

Atrial distention causes release into the circulation of atrial natriuretic peptide (ANP), a polypeptide. A high-molecular-weight precursor of ANP is stored in secretory granules within atrial myocytes. A

closely related natriuretic peptide (pre-pro-hormone brain natriuretic peptide [BNP]) is stored primarily in ventricular myocytes and is released when ventricular diastolic pressure rises. Released ANP and BNP (which is derived from its precursor) bind to the natriuretic receptor-A, which causes (1) excretion of sodium and water by augmenting glomerular filtration rate, inhibiting sodium reabsorption in the proximal tubule, and inhibiting release of renin and aldosterone; and (2) dilation of arterioles and venules by antagonizing the vasoconstrictor actions of AII, AVP, and sympathetic stimulation. Thus, elevated levels of natriuretic peptides have the capacity to oppose sodium retention in hypervolemic and edematous states.

Although circulating levels of ANP and BNP are elevated in heart failure and in cirrhosis with ascites, these natriuretic peptides are not sufficiently potent to prevent edema formation. Indeed, in edematous states, resistance to the actions of natriuretic peptides may be increased, further reducing their effectiveness.

Further discussion of the control of sodium and water balance is found in [Chap. 51](#).

### ■ CLINICAL CAUSES OF EDEMA

A weight gain of several kilograms usually precedes overt manifestations of generalized edema. *Anasarca* refers to gross, generalized edema. *Ascites* ([Chap. 50](#)) and *hydrothorax* refer to accumulation of excess fluid in the peritoneal and pleural cavities, respectively, and are considered special forms of edema.

Edema is recognized by the persistence of an indentation of the skin after pressure known as “pitting” edema. In its more subtle form, edema may be detected by noting that after the stethoscope is removed from the chest wall, the rim of the bell leaves an indentation on the skin of the chest for a few minutes. Edema may be present when the ring on a finger fits more snugly than in the past or when a patient complains of difficulty putting on shoes, particularly in the evening. Edema may also be recognized by puffiness of the face, which is most readily apparent in the periorbital areas owing to relative tissue laxity.

### ■ GENERALIZED EDEMA

The differences among the major causes of generalized edema are shown in [Table 41-1](#). Cardiac, renal, hepatic, or nutritional disorders are responsible for a large majority of patients with generalized edema. Consequently, the differential diagnosis of generalized edema should be directed toward identifying or excluding these several conditions.

**Heart Failure** (See also [Chap. 257](#)) In heart failure, the impaired systolic emptying of the ventricle(s) and/or the impairment of ventricular relaxation promotes an accumulation of blood in the venous circulation at the expense of the effective arterial volume. In addition, the activation of the sympathetic nervous system and the RAAS (see above) acts in concert to cause renal vasoconstriction and reduction of glomerular filtration and salt and water retention. Sodium and water retention continue, and the increment in blood volume accumulates in

TABLE 41-1 Principal Causes of Generalized Edema: History, Physical Examination, and Laboratory Findings

ORGAN SYSTEM	HISTORY	PHYSICAL EXAMINATION	LABORATORY FINDINGS
Cardiac	Dyspnea with exertion prominent—often associated with orthopnea—or paroxysmal nocturnal dyspnea	Elevated jugular venous pressure, ventricular ( $S_3$ ) gallop; occasionally with displaced or dyskinetic apical pulse; peripheral cyanosis, cool extremities, small pulse pressure when severe	Elevated urea nitrogen-to-creatinine ratio common; serum sodium often diminished; elevated natriuretic peptides
Hepatic	Dyspnea uncommon, except if associated with significant degree of ascites; most often a history of ethanol abuse	Frequently associated with ascites; jugular venous pressure normal or low; blood pressure lower than in renal or cardiac disease; one or more additional signs of chronic liver disease (jaundice, palmar erythema, Dupuytren's contracture, spider angioma, male gynecomastia; asterixis and other signs of encephalopathy) may be present	If severe, reductions in serum albumin, cholesterol, other hepatic proteins (transferrin, fibrinogen); liver enzymes elevated, depending on the cause and acuity of liver injury; tendency toward hypokalemia, respiratory alkalosis; macrocytosis from folate deficiency
Renal (CRF)	Usually chronic: may be associated with uremic signs and symptoms, including decreased appetite, altered (metallic or fishy) taste, altered sleep pattern, difficulty concentrating, restless legs, or myoclonus; dyspnea can be present, but generally less prominent than in heart failure	Elevated blood pressure; hypertensive retinopathy; nitrogenous fetor; pericardial friction rub in advanced cases with uremia	Elevation of serum creatinine and cystatin C; albuminuria; hyperkalemia, metabolic acidosis, hyperphosphatemia, hypocalcemia, anemia (usually normocytic)
Renal (NS)	Childhood diabetes mellitus; plasma cell dyscrasias	Periorbital edema; hypertension	Proteinuria ( $\geq 3.5 \text{ g/d}$ ); hypoalbuminemia; hypercholesterolemia; microscopic hematuria

Abbreviations: CRF, chronic renal failure; NS, nephrotic syndrome.

Source: Reproduced with permission from GM Chertow, in E Braunwald, L Goldman (eds): Approach to the patient with edema, in Primary Cardiology, 2nd ed. Philadelphia, Saunders, 2003.

the venous circulation, raising venous and intracapillary pressure and resulting in edema (Fig. 41-1).

The presence of overt cardiac disease, as manifested by cardiac enlargement and/or ventricular hypertrophy, together with clinical evidence of cardiac failure, such as dyspnea, basilar rales, venous distension, and hepatomegaly, usually indicates that edema results from heart failure. Noninvasive tests such as electrocardiography, echocardiography, and measurements of BNP (or N-terminal proBNP [NT-proBNP]) are helpful in establishing the diagnosis of heart disease. The edema of heart failure typically occurs in the dependent portions of the body.

**Edema of Renal Disease** (See also Chap. 314) The edema that occurs during the acute phase of glomerulonephritis is characteristically associated with hematuria, proteinuria, and hypertension. In most instances, the edema results from primary retention of sodium and water by the kidneys owing to renal dysfunction. This state differs from most forms of heart failure in that it is characterized by a normal (or sometimes even increased) cardiac output. Patients with *chronic* renal failure may also develop edema due to primary renal retention of sodium and water.

**Nephrotic Syndrome and Other Hypoalbuminemic States** The primary alteration in the nephrotic syndrome is a diminished colloid oncotic pressure due to losses of large quantities ( $\geq 3.5 \text{ g/d}$ ) of protein into the urine and hypoalbuminemia ( $<3.0 \text{ g/dL}$ ). As a result of the reduced colloid osmotic pressure, the sodium and water that are retained cannot be confined within the vascular compartment, and total and effective arterial blood volumes decline. This process initiates the edema-forming sequence of events described above, including activation of the RAAS. The nephrotic syndrome may occur during the course of a variety of kidney diseases, including glomerulonephritis, diabetic glomerulosclerosis, and hypersensitivity reactions. The edema is diffuse, symmetric, and most prominent in the dependent areas; periorbital edema is most prominent in the morning.

**Hepatic Cirrhosis** (See also Chap. 344) This condition is characterized, in part, by hepatic venous outflow obstruction, which in turn expands the splanchnic blood volume, and hepatic lymph formation. Intrahepatic hypertension acts as a stimulus for renal sodium retention and causes a reduction of effective arterial blood volume. These alterations are frequently complicated by hypoalbuminemia secondary to reduced hepatic synthesis, as well as peripheral arterial vasodilation. These effects reduce the effective arterial blood volume, leading to activation

of the sodium- and water-retaining mechanisms described above (Fig. 41-1B). The concentration of circulating aldosterone often is elevated by the failure of the liver to metabolize this hormone. Initially, the excess interstitial fluid is localized preferentially proximal (upstream) to the congested portal venous system, causing ascites (Chap. 50). In later stages, particularly when there is severe hypoalbuminemia, peripheral edema may develop. A sizable accumulation of ascitic fluid may increase intraabdominal pressure and impede venous return from the lower extremities and contribute to the accumulation of the edema.

**Drug-Induced Edema** A large number of widely used drugs can cause edema (Table 41-2). Mechanisms include renal vasoconstriction

TABLE 41-2 Drugs Associated with Edema Formation

Nonsteroidal anti-inflammatory drugs
Antihypertensive agents
Direct arterial/arteriolar vasodilators
Hydralazine
Clonidine
Methyldopa
Guanethidine
Minoxidil
Calcium channel antagonists
$\alpha$ -Adrenergic antagonists
Thiazolidinediones
Steroid hormones
Glucocorticoids
Anabolic steroids
Estrogens
Progesterins
Cyclosporine
Growth hormone
Immunotherapies
Interleukin 2
OKT3 monoclonal antibody

Source: Reproduced with permission from GM Chertow, in E Braunwald, L Goldman (eds): Approach to the patient with edema, in Primary Cardiology, 2nd ed. Philadelphia, Saunders, 2003.

(nonsteroidal anti-inflammatory drugs and cyclosporine), arteriolar dilation (vasodilators), augmented renal sodium reabsorption (steroid hormones), and capillary damage.

**Edema of Nutritional Origin** A diet grossly deficient in calories and particularly in protein over a prolonged period may produce hypoproteinemia and edema. The latter may be intensified by the development of beriberi heart disease, which also is of nutritional origin, in which multiple peripheral arteriovenous fistulae result in reduced effective systemic perfusion and effective arterial blood volume, thereby enhancing edema formation (*Chap. 333*) (Fig. 41-1B). Edema develops or becomes intensified when famished subjects are first provided with an adequate diet. The ingestion of more food may increase the quantity of sodium ingested, which is then retained along with water. So-called refeeding edema also may be linked to increased release of insulin, which directly increases tubular sodium reabsorption. In addition to hypoalbuminemia, hypokalemia and caloric deficits may be involved in the edema of starvation.

### ■ LOCALIZED EDEMA

In thrombophlebitis, varicose veins, and primary venous valve failure, the hydrostatic pressure in the capillary bed upstream (proximal) of the obstruction increases so that an abnormal quantity of fluid is transferred from the vascular to the interstitial space, which may give rise to localized edema. The latter may also occur in lymphatic obstruction caused by chronic lymphangitis, resection of regional lymph nodes, filariasis, and genetic (frequently called primary) lymphedema. The latter is particularly intractable because restriction of lymphatic flow results in both an increase in intracapillary pressure and increased protein concentration in the interstitial fluid, which act in concert to aggravate fluid retention.

**Other Causes of Edema** These causes include hypothyroidism (myxedema) due to deposition of hyaluronic acid; hyperthyroidism (pretibial myxedema secondary to Graves' disease), in which edema is typically nonpitting and, in Graves' disease, exogenous hypercortisolism; pregnancy; and administration of estrogens and vasodilators, particularly dihydropyridines such as nifedipine.

### ■ DISTRIBUTION OF EDEMA

The distribution of edema is an important guide to its cause. Edema associated with heart failure tends to be more extensive in the legs and to be accentuated in the evening, a feature also determined largely by posture. When patients with heart failure are confined to bed, edema may be most prominent in the presacral region.

Edema resulting from hypoproteinemia, as occurs in the nephrotic syndrome, characteristically is generalized, but it is especially evident in the very soft tissues of the eyelids and face and tends to be most pronounced in the morning owing to the recumbent posture assumed during the night. Less common causes of facial edema include trichinosis, allergic reactions, and myxedema. Edema limited to one leg or to one or both arms is usually the result of venous and/or lymphatic obstruction. Unilateral paralysis reduces lymphatic and venous drainage on the affected side and may also be responsible for unilateral edema. In patients with obstruction of the superior vena cava, edema is confined to the face, neck, and upper extremities in which the venous pressure is elevated compared with that in the lower extremities.

## APPROACH TO THE PATIENT

### Edema

An important first question is whether the edema is localized or generalized. If it is localized, the local phenomena that may be responsible should be identified. If the edema is generalized, one should determine if there is serious hypoalbuminemia, e.g., serum albumin <3.0 g/dL. If so, the history, physical examination, urinalysis, and other laboratory data will help evaluate the question of cirrhosis, severe malnutrition, or the nephrotic syndrome as the

underlying disorder. If hypoalbuminemia is not present, it should be determined if there is evidence of heart failure severe enough to promote generalized edema. Finally, it should be ascertained as to whether or not the patient has an adequate urine output or if there is significant oliguria or anuria. [These abnormalities are discussed in Chaps. 52, 310, and 311.](#)

### ■ FURTHER READING

- C AL, C JG: Causes and treatment of oedema in patients with heart failure. *Nature Rev Cardiol* 10:156, 2013.
- D K et al: Congestion in chronic systolic heart failure is related to renal dysfunction and increased mortality. *Eur J Heart Fail* 12:974, 2010.
- F RE et al: *GJC2* missense mutations cause human lymphedema. *Am J Hum Genet* 86:943, 2010.
- F S et al: Omitting edema measurement: How much acute malnutrition are we missing? *Am J Clin Nutr* 102:1176, 2015.
- L JR, M CC: Microvascular fluid exchange and the revised Starling principle. *Cardiovascular Res* 87:198, 2010.
- T N, H VE: Role of the lymphatic vasculature in cardiovascular medicine. *Heart* 105:1777, 2019.

## 42

### Approach to the Patient with a Heart Murmur

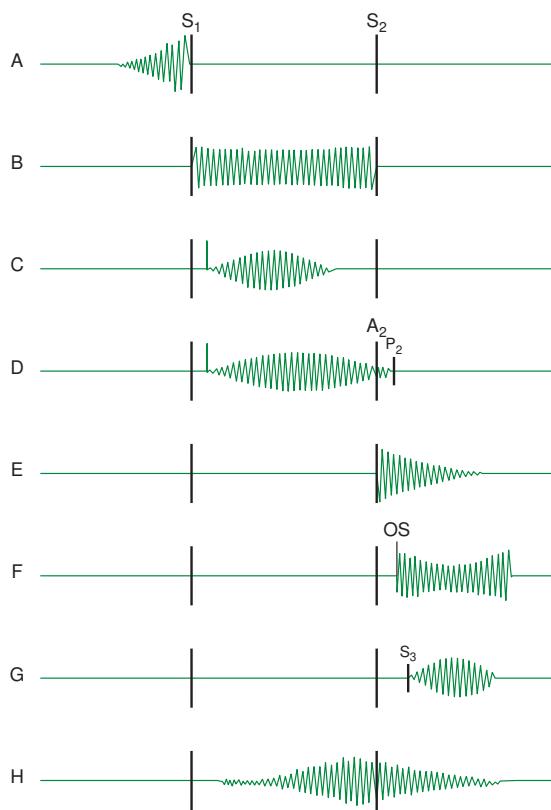
Patrick T. O'Gara, Joseph Loscalzo



The differential diagnosis of a heart murmur begins with a careful assessment of its major attributes and response to bedside maneuvers. The history, clinical context, and associated physical examination findings provide additional clues to help establish the significance of a heart murmur. Accurate bedside identification of a heart murmur can inform decisions regarding the indications for noninvasive testing and the need for referral to a cardiovascular specialist. Preliminary discussions can be held with the patient regarding antibiotic or rheumatic fever prophylaxis, the need to restrict various forms of physical activity, and the potential role for family screening.

Heart murmurs are caused by audible vibrations that are due to increased turbulence from accelerated blood flow through normal or abnormal orifices; flow through a narrowed or irregular orifice into a dilated vessel or chamber; or backward flow through an incompetent valve, ventricular septal defect, or patent ductus arteriosus. They traditionally are defined by their timing within the cardiac cycle (*Fig. 42-1*). *Systolic murmurs* begin with or after the first heart sound ( $S_1$ ) and terminate at or before the component ( $A_2$  or  $P_2$ ) of the second heart sound ( $S_2$ ) that corresponds to their site of origin (left or right, respectively). *Diastolic murmurs* begin with or after the associated component of  $S_2$  and end at or before the subsequent  $S_1$ . *Continuous murmurs* are not confined to either phase of the cardiac cycle but instead begin in early systole and proceed through  $S_2$  into all or part of diastole. The accurate timing of heart murmurs is the first step in their identification. The distinction between  $S_1$  and  $S_2$ , and therefore systole and diastole, is usually a straightforward process but can be difficult in the setting of a tachyarrhythmia, in which case the heart sounds can be distinguished by simultaneous palpation of the carotid upstroke, which should closely follow  $S_1$ .

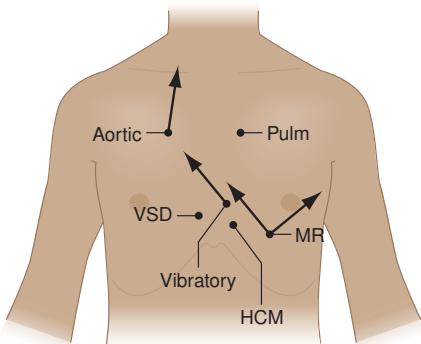
**Duration and Character** The duration of a heart murmur depends on the length of time over which a pressure difference exists between two cardiac chambers, the left ventricle and the aorta, the right ventricle and the pulmonary artery, or the great vessels. The magnitude and



**FIGURE 42-1** Diagram depicting principal heart murmurs. *A*, Presystolic murmur of mitral or tricuspid stenosis. *B*, Holosystolic (pansystolic) murmur of mitral or tricuspid regurgitation or of ventricular septal defect. *C*, Aortic ejection murmur beginning with an ejection click and fading before the second heart sound. *D*, Systolic murmur in pulmonic stenosis spilling through the aortic second sound, pulmonic valve closure being delayed. *E*, Aortic or pulmonary diastolic murmur. *F*, Long diastolic murmur of mitral stenosis after the opening snap (OS). *G*, Short mid-diastolic inflow murmur after a third heart sound. *H*, Continuous murmur of patent ductus arteriosus. (Courtesy of Antony and Julie Wood.)

variability of this pressure difference, coupled with the geometry and compliance of the involved chambers or vessels, dictate the velocity of flow; the degree of turbulence; and the resulting frequency, configuration, and intensity of the murmur. The diastolic murmur of chronic aortic regurgitation (AR) is a blowing, high-frequency event, whereas the murmur of mitral stenosis (MS), indicative of the left atrial–left ventricular diastolic pressure gradient, is a low-frequency event, heard as a rumbling sound with the bell of the stethoscope. The frequency components of a heart murmur may vary at different sites of auscultation. The coarse systolic murmur of aortic stenosis (AS) may sound higher pitched and more acoustically pure at the apex, a phenomenon eponymously referred to as the *Gallavardin effect*. Some murmurs may have a distinct or unusual quality, such as the “honking” sound appreciated in some patients with mitral regurgitation (MR) due to mitral valve prolapse (MVP).

The configuration of a heart murmur may be described as crescendo, decrescendo, crescendo-decrescendo, or plateau. The decrescendo configuration of the murmur of chronic AR (Fig. 42-1E) can be understood in terms of the progressive decline in the diastolic pressure gradient between the aorta and the left ventricle. The crescendo-decrescendo configuration of the murmur of AS reflects the changes in the systolic pressure gradient between the left ventricle and the aorta as ejection occurs, whereas the plateau configuration of the murmur of chronic MR (Fig. 42-1B) is consistent with the large and nearly constant pressure difference between the left ventricle and the left atrium.



**FIGURE 42-2** Maximal intensity and radiation of six isolated systolic murmurs. Aortic, aortic stenosis; HCM, hypertrophic obstructive cardiomyopathy; MR, mitral regurgitation; Pulm, pulmonary stenosis; VSD, ventricular septal defect. (From JB Barlow: Perspectives on the Mitral Valve. Philadelphia, FA Davis, 1987, p 140.)

**Intensity** The intensity of a heart murmur is graded on a scale of 1–6 (or I–VI). A grade 1 murmur is very soft and is heard only with great effort. A grade 2 murmur is easily heard but not particularly loud. A grade 3 murmur is loud but is not accompanied by a palpable thrill over the site of maximal intensity. A grade 4 murmur is very loud and accompanied by a thrill. A grade 5 murmur is loud enough to be heard with only the edge of the stethoscope touching the chest, whereas a grade 6 murmur is loud enough to be heard with the stethoscope slightly off the chest. Murmurs of grade 3 or greater intensity usually signify important structural heart disease and indicate high blood flow velocity at the site of murmur production. Small, restrictive ventricular septal defects (VSDs), for example, are accompanied by loud, usually grade 4 or greater, systolic murmurs as blood is ejected at high velocity from the left ventricle to the right ventricle. Low-velocity events, such as left-to-right shunting across an atrial septal defect (ASD), are usually silent. The intensity of a heart murmur may be diminished by any process that increases the distance between the intracardiac source and the stethoscope on the chest wall, such as obesity, obstructive lung disease, or a large pericardial effusion. The intensity of a murmur also may be misleadingly soft when cardiac output is reduced significantly or when the pressure gradient between the involved cardiac structures is low.

**Location and Radiation** Recognition of the location and radiation of the murmur helps facilitate its accurate identification (Fig. 42-2). Adventitious sounds, such as a systolic click or diastolic snap, or abnormalities of S<sub>1</sub> or S<sub>2</sub> may provide additional clues. Careful attention to the characteristics of the murmur and other heart sounds during the respiratory cycle and the performance of simple bedside maneuvers complete the auscultatory examination. These features, along with recommendations for further testing, are discussed below in the context of specific systolic, diastolic, and continuous heart murmurs (Table 42-1).

## ■ SYSTOLIC HEART MURMURS

**Early Systolic Murmurs** Early systolic murmurs begin with S<sub>1</sub> and extend for a variable period, ending well before S<sub>2</sub>. Their causes are relatively few. *Acute, severe MR* into a normal-sized, relatively non-compliant left atrium results in an early, decrescendo systolic murmur best heard at or just medial to the apical impulse. These characteristics reflect the progressive attenuation of the pressure gradient between the left ventricle and the left atrium during systole owing to the rapid rise in left atrial pressure caused by the sudden volume load into an unprepared, noncompliant chamber, and contrast sharply with the auscultatory features of chronic MR. Clinical settings in which acute, severe MR occur include (1) papillary muscle rupture complicating acute myocardial infarction (MI) (Chap. 275), (2) rupture of chordae tendineae in the setting of myxomatous mitral valve disease (MVP, Chap. 265), (3) infective endocarditis (Chap. 128), and (4) blunt chest wall trauma.

## TABLE 42-1 Principal Causes of Heart Murmurs

## Systolic Murmurs

**Early systolic**

- Mitral
  - Acute MR
- VSD
- Muscular
  - Nonrestrictive with pulmonary hypertension
- Tricuspid
  - TR with normal pulmonary artery pressure

**Midsystolic**

- Aortic
  - Obstructive
    - Supravalvular-supravalvular AS, coarctation of the aorta
    - Valvular-AS and aortic sclerosis
    - Subvalvular-discrete, tunnel or HOCM
  - Increased flow, hyperkinetic states, AR, complete heart block
  - Dilation of ascending aorta, atherosoma, aortitis

**Pulmonary**

- Obstructive
  - Supravalvular-pulmonary artery stenosis
  - Valvular-pulmonic valve stenosis
  - Subvalvular-infundibular stenosis (dynamic)
- Increased flow, hyperkinetic states, left-to-right shunt (e.g., ASD)
- Dilation of pulmonary artery

**Late systolic**

- Mitral
  - MVP, acute myocardial ischemia
- Tricuspid
  - TVP

**Holosystolic**

- Atrioventricular valve regurgitation (MR, TR)
  - Left-to-right shunt at ventricular level (VSD)

## Early Diastolic Murmurs

**AR**

- Valvular: congenital (bicuspid valve), rheumatic deformity, endocarditis, prolapse, trauma, post-valvotomy
- Dilation of valve ring: aorta dissection, annuloaortic ectasia, medial degeneration, hypertension, ankylosing spondylitis
- Widening of commissures: syphilis

**Pulmonic regurgitation**

- Valvular: post-valvotomy, endocarditis, rheumatic fever, carcinoid
- Dilation of valve ring: pulmonary hypertension; Marfan syndrome
- Congenital: isolated or associated with tetralogy of Fallot, VSD, pulmonic stenosis

## Mid-Diastolic Murmurs

**Mitral**

- MS
- Carey-Coombs murmur (mid-diastolic apical murmur in acute rheumatic fever)
- Increased flow across nonstenotic mitral valve (e.g., MR, VSD, PDA, high-output states, and complete heart block)

**Tricuspid**

- Tricuspid stenosis
- Increased flow across nonstenotic tricuspid valve (e.g., TR, ASD, and anomalous pulmonary venous return)
- Left and right atrial tumors (myxoma)
- Severe AR (Austin Flint murmur)

## Continuous Murmurs

Patent ductus arteriosus	Proximal coronary artery stenosis
Coronary AV fistula	Maternal souffle of pregnancy
Ruptured sinus of Valsalva aneurysm	Pulmonary artery branch stenosis
Aortic septal defect	Bronchial collateral circulation
Cervical venous hum	Small (restrictive) ASD with MS
Anomalous left coronary artery	Intercostal AV fistula

**Abbreviations:** AR, aortic regurgitation; AS, aortic stenosis; ASD, atrial septal defect; AV, arteriovenous; HOCM, hypertrophic obstructive cardiomyopathy; MR, mitral regurgitation; MS, mitral stenosis; MVP, mitral valve prolapse; PDA, patent ductus arteriosus; TR, tricuspid regurgitation; TVP, tricuspid valve prolapse; VSD, ventricular septal defect.

**Source:** E Braunwald, JK Perloff, in D Zipes et al (eds): *Braunwald's Heart Disease*, 7th ed. Philadelphia, Elsevier, 2005; PJ Norton, RA O'Rourke, in E Braunwald, L Goldman (eds): *Primary Cardiology*, 2nd ed. Philadelphia, Elsevier, 2003.

Acute, severe MR from papillary muscle rupture usually accompanies an inferior, posterior, or lateral MI and occurs 2–7 days after presentation. It often is signaled by chest pain, hypotension, and pulmonary edema, but a murmur may be absent in up to 50% of cases. The posteromedial papillary muscle is involved 6–10 times more frequently than the anterolateral papillary muscle. The murmur is to be distinguished from that associated with post-MI ventricular septal rupture, which is accompanied by a systolic thrill at the left sternal border in nearly all patients and is holosystolic in duration. A new heart murmur after an MI is an indication for transthoracic echocardiography (TTE) (Chap. 241), which allows bedside delineation of its etiology and pathophysiologic significance. The distinction between acute MR and ventricular septal rupture also can be achieved with right-sided heart catheterization, sequential determination of oxygen saturations, and analysis of the pressure waveforms (tall  $v$  wave in the pulmonary artery wedge pressure in MR). Post-MI mechanical complications of this nature mandate aggressive medical stabilization and prompt referral for surgical repair.

Spontaneous chordal rupture can complicate the course of myxomatous mitral valve disease (MVP) and result in new-onset or “acute on chronic” severe MR. MVP may occur as an isolated phenomenon, or the lesion may be part of a more generalized connective tissue disorder as seen, for example, in patients with Marfan syndrome. Acute, severe MR as a consequence of infective endocarditis results from destruction of leaflet tissue, chordal rupture, or both. Blunt chest wall trauma is usually self-evident but may be disarmingly trivial; it can result in papillary muscle contusion and rupture, chordal detachment, or leaflet avulsion. TTE is indicated in all cases of suspected acute, severe MR to define its mechanism and severity, delineate left ventricular size and systolic function, and provide an assessment of suitability for primary valve repair.

A congenital, small muscular VSD (Chap. 269) may be associated with an early systolic murmur. The defect closes progressively during septal contraction, and thus the murmur is confined to early systole. It is localized to the left sternal border (Fig. 42-2) and is usually of grade 4 or 5 intensity. Signs of pulmonary hypertension or left ventricular volume overload are absent. Anatomically large and uncorrected VSDs, which usually involve the membranous portion of the septum, may lead to pulmonary hypertension. The murmur associated with the left-to-right shunt, which earlier may have been holosystolic, becomes limited to the first portion of systole as the elevated pulmonary vascular resistance leads to an abrupt rise in right ventricular pressure and an attenuation of the interventricular pressure gradient during the remainder of the cardiac cycle. In such instances, signs of pulmonary hypertension (right ventricular lift, loud and single or closely split  $S_2$ ) may predominate. The murmur is best heard along the left sternal border but is softer. Suspicion of a VSD is an indication for TTE.

Tricuspid regurgitation (TR) with normal pulmonary artery pressures, as may occur with infective endocarditis, may produce an early systolic murmur. The murmur is soft (grade 1 or 2), is best heard at the lower left sternal border, and may increase in intensity with inspiration (Carvallo's sign). Regurgitant  $c-v$  waves may be visible in the jugular venous pulse. TR in this setting is not associated with signs of right heart failure, such as ascites or lower extremity edema.

**Midsystolic Murmurs** Midsystolic murmurs begin at a short interval after  $S_1$  and before  $S_2$  (Fig. 42-1C) and are usually crescendo-decrescendo in configuration. AS is the most common cause of a midsystolic murmur in an adult. The murmur of AS is usually loudest to the right of the sternum in the second intercostal space (aortic area, Fig. 42-2) and radiates into the carotids. Transmission of the midsystolic murmur to the apex, where it becomes higher-pitched, is common (Gallavardin effect; see above).

Differentiation of this apical systolic murmur from MR can be difficult. The murmur of AS will increase in intensity or become louder, in the beat after a premature beat, whereas the murmur of MR will have constant intensity from beat to beat. The intensity of the AS murmur also varies directly with the cardiac output. With a normal cardiac output, a systolic thrill at the second right intercostal space and a

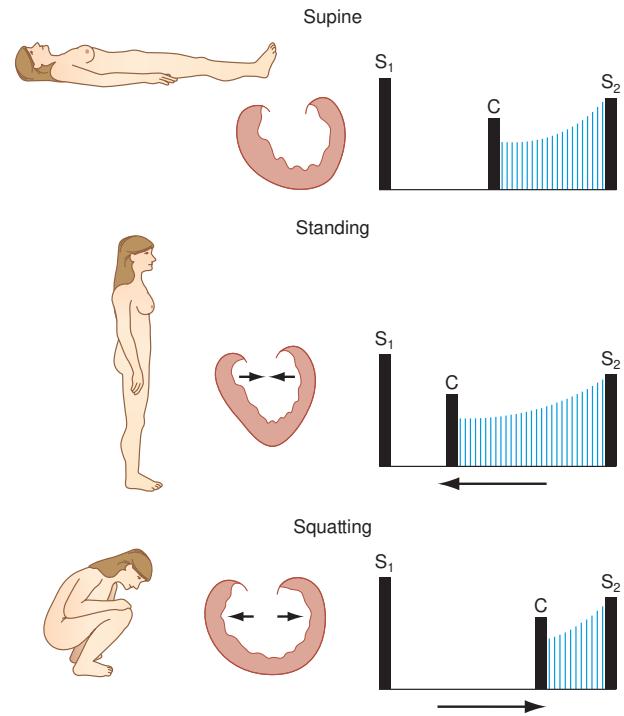
grade 4 or higher murmur suggest severe AS. The murmur is softer in the setting of heart failure and low cardiac output. Other auscultatory findings of severe AS include a soft or absent A<sub>2</sub>, paradoxical splitting of S<sub>1</sub>, an apical S<sub>4</sub>, and a late-peaking systolic murmur. In children, adolescents, and young adults with congenital valvular AS, an early ejection sound (click) is usually audible, more often along the left sternal border than at the base. Its presence signifies a flexible, noncalcified bicuspid valve (or one of its variants) and localizes the left ventricular outflow obstruction to the valvular (rather than sub- or supravalvular) level.

Assessment of the volume and rate of rise of the carotid pulse can provide additional information. A small and delayed upstroke (*parvus et tardus*) is consistent with severe AS. The carotid pulse examination is less discriminatory, however, in older patients with stiffened arteries. The electrocardiogram (ECG) shows signs of left ventricular hypertrophy (LVH) as the severity of the stenosis increases. TTE is indicated to assess the anatomic features of the aortic valve, the severity of the stenosis, left ventricular size, wall thickness and function, and the size and contour of the aortic root and proximal ascending aorta.

The obstructive form of hypertrophic cardiomyopathy (HOCM) is associated with a midsystolic murmur that is usually loudest along the left sternal border or between the left lower sternal border and the apex (Chap. 259, Fig. 42-2). The murmur is produced by both dynamic left ventricular outflow tract obstruction and MR, and thus, its configuration is a hybrid between ejection and regurgitant phenomena. The intensity of the murmur may vary from beat to beat and after provocative maneuvers but usually does not exceed grade 3. The murmur classically will increase in intensity with maneuvers that result in increasing degrees of outflow tract obstruction, such as a reduction in preload or afterload (Valsalva, standing, vasodilators), or with an augmentation of contractility (inotropic stimulation). Maneuvers or medications that increase preload (squatting, passive leg raising, volume administration) or afterload (squatting, vasoconstrictors) or that reduce contractility ( $\beta$ -adrenoreceptor blockers) decrease the intensity of the murmur. In rare patients, there may be reversed splitting of S<sub>2</sub>. A sustained left ventricular apical impulse and an S<sub>4</sub> may be appreciated. In contrast to AS, the carotid upstroke is rapid and of normal volume. Rarely, it is bisferiens or bifid in contour (see Fig. 239-2D) due to midsystolic closure of the aortic valve. LVH is present on the ECG, and the diagnosis is confirmed by TTE. Although the systolic murmur associated with MVP behaves similarly to that due to HOCM in response to the Valsalva maneuver and to standing/squatting (Fig. 42-3), these two lesions can be distinguished on the basis of their associated findings, such as the presence of LVH in HOCM or a nonejection click in MVP.

The midsystolic, crescendo-decrescendo murmur of congenital pulmonic stenosis (PS; Chap. 269) is best appreciated in the second and third left intercostal spaces (pulmonic area) (Figs. 42-2 and 42-4). The duration of the murmur lengthens and the intensity of P<sub>2</sub> diminishes with increasing degrees of valvular stenosis (Fig. 42-1D). An early ejection sound, the intensity of which decreases with inspiration, is heard in younger patients. A parasternal lift and ECG evidence of right ventricular hypertrophy indicate severe pressure overload. If obtained, the chest x-ray may show poststenotic dilation of the main pulmonary artery. TTE is recommended for complete characterization.

Significant left-to-right intracardiac shunting due to an ASD (Chap. 269) leads to an increase in pulmonary blood flow and a grade 2–3 midsystolic murmur at the middle to upper left sternal border attributed to increased flow rates across the pulmonic valve with fixed splitting of S<sub>2</sub>. Ostium secundum ASDs are the most common cause of these shunts in adults. Features suggestive of a primum ASD include the coexistence of MR due to a cleft anterior mitral valve leaflet and left axis deviation of the QRS complex on the ECG. With sinus venosus ASDs, the left-to-right shunt is usually not large enough to result in a systolic murmur, although the ECG may show abnormalities of sinus node function. A grade 2 or 3 midsystolic murmur may also be heard best at the upper left sternal border in patients with idiopathic dilation of the pulmonary artery; a pulmonary ejection sound is also present in these patients. TTE is indicated to evaluate a grade 2 or 3 midsystolic murmur when there are other signs of cardiac disease.

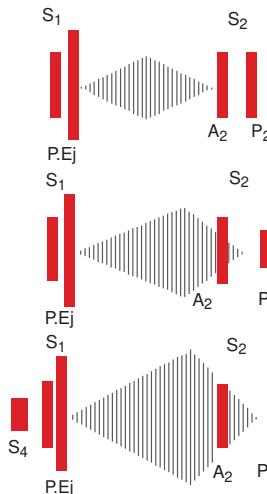


**FIGURE 42-3** A midsystolic nonejection sound (C) occurs in mitral valve prolapse and is followed by a late systolic murmur that crescendos to the second heart sound (S<sub>2</sub>). Standing decreases venous return; the heart becomes smaller; C moves closer to the first heart sound (S<sub>1</sub>), and the mitral regurgitant murmur has an earlier onset. With prompt squatting, venous return and afterload increase; the heart becomes larger; C moves toward S<sub>2</sub>; and the duration of the murmur shortens. The systolic murmur of hypertrophic obstructive cardiomyopathy behaves similarly. (Reprinted with permission *Examination of the Heart, Part IV: Auscultation of the Heart* ©American Heart Association, Inc.)

An isolated grade 1 or 2 midsystolic murmur, heard in the absence of symptoms or signs of heart disease, is most often a benign finding for which no further evaluation, including TTE, is necessary. The most common example of a murmur of this type in an older adult patient is the crescendo-decrescendo murmur of aortic valve sclerosis, heard at the second right interspace (Fig. 42-2). Aortic sclerosis is defined as focal thickening and calcification of the aortic valve to a degree that does not interfere with leaflet opening. The carotid upstrokes are normal, and electrocardiographic LVH is not present. A grade 1 or 2 midsystolic murmur often can be heard at the left sternal border with pregnancy, hyperthyroidism, or anemia, physiologic states that are associated with accelerated blood flow. *Sill's murmur* refers to a benign grade 2, vibratory or musical midsystolic murmur at the mid or lower left sternal border in normal children and adolescents, best heard in the supine position (Fig. 42-2).

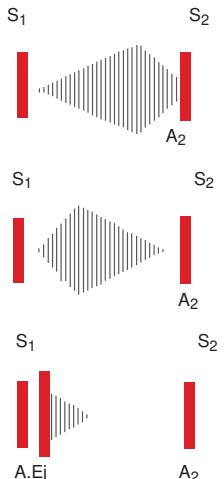
**Late Systolic Murmurs** A late systolic murmur that is best heard at the left ventricular apex is usually due to MVP (Chap. 265). Often, this murmur is introduced by one or more nonejection clicks. The radiation of the murmur can help identify the specific mitral leaflet involved in the process of prolapse or flail. The term *flail* refers to the movement made by an unsupported portion of the leaflet (usually the tip) after loss of its chordal attachment(s). With posterior leaflet prolapse or flail, the resultant jet of MR is directed anteriorly and medially, as a result of which the murmur radiates to the base of the heart and masquerades as AS. Anterior leaflet prolapse or flail results in a posteriorly directed MR jet that radiates to the axilla or left infrascapular region. Leaflet flail is associated with a murmur of grade 3 or 4 intensity that can be heard throughout the precordium in thin-chested patients. The presence of an S<sub>3</sub> or a short, rumbling mid-diastolic murmur due to enhanced flow signifies severe MR.

## Pulmonic stenosis



P.Ej = Pulmonary ejection (valvular)

## Tetralogy of Fallot



A.Ej = Aortic ejection (root)

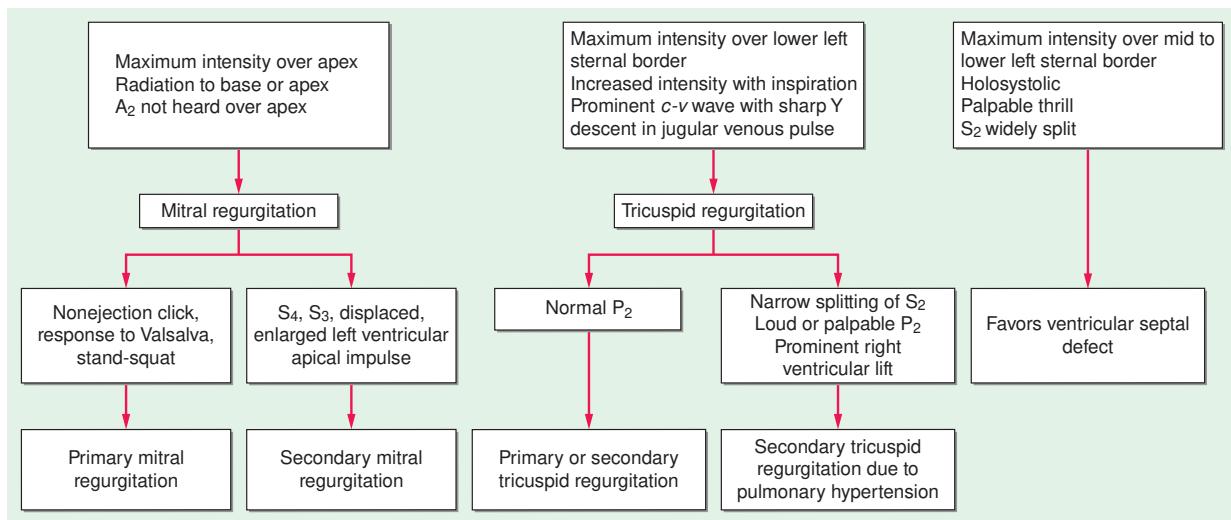
**FIGURE 42-4** *Left.* In valvular pulmonic stenosis with intact ventricular septum, right ventricular systolic ejection becomes progressively longer, with increasing obstruction to flow. As a result, the murmur becomes longer and louder, enveloping the aortic component of the second heart sound ( $A_2$ ). The pulmonic component ( $P_2$ ) occurs later, and splitting becomes wider but more difficult to hear because  $A_2$  is lost in the murmur and  $P_2$  becomes progressively fainter and lower pitched. As the pulmonic gradient increases, the isometric contraction phase shortens until the pulmonic valve ejection sound fuses with the first heart sound ( $S_1$ ). In severe pulmonic stenosis with concentric hypertrophy and decreasing right ventricular compliance, a fourth heart sound appears. *Right.* In tetralogy of Fallot with increasing obstruction at the pulmonic infundibular area, an increasing amount of right ventricular blood is shunted across the silent ventricular septal defect and flow across the obstructed outflow tract decreases. Therefore, with increasing obstruction, the murmur becomes shorter, earlier, and fainter.  $P_2$  is absent in severe tetralogy of Fallot. A large aortic root receives almost all cardiac output from both ventricular chambers, and the aorta dilates and is accompanied by a root ejection sound that does not vary with respiration. (Reprinted with permission Examination of the Heart, Part IV: Auscultation of the Heart ©American Heart Association, Inc.)

Bedside maneuvers that decrease left ventricular preload, such as standing, will cause the click and murmur of MVP to move closer to the first heart sound, as leaflet prolapse occurs earlier in systole. Standing also causes the murmur to become louder and longer. With squatting, left ventricular preload and afterload are increased abruptly, leading to an increase in left ventricular volume, and the click and murmur move away from the first heart sound as leaflet prolapse is delayed; the murmur becomes softer and shorter in duration (Fig. 42-3). As noted above, these responses to standing and squatting are directionally similar to those observed in patients with HOCM.

A late, apical systolic murmur indicative of MR may be heard transiently in the setting of acute myocardial ischemia; it is due to apical tethering and malcoaptation of the leaflets in response to structural and functional changes of the ventricle and mitral annulus. The intensity of the murmur varies as a function of left ventricular afterload and will increase in the setting of hypertension. TTE is recommended for assessment of late systolic murmurs.

**Holosystolic Murmurs** (Figs. 42-1B and 42-5) Holosystolic murmurs begin with  $S_1$  and continue through systole to  $S_2$ . They are usually indicative of chronic mitral or tricuspid valve regurgitation or a VSD and warrant TTE for further characterization. The holosystolic murmur of chronic MR is best heard at the left ventricular apex and radiates to the axilla (Fig. 42-2); it is usually high-pitched and plateau in configuration because of the wide difference between left ventricular and left atrial pressure throughout systole. In contrast to acute MR, left atrial compliance is normal or even increased in chronic MR. As a result, there is only a small increase in left atrial pressure for any increase in regurgitant volume.

Several conditions are associated with chronic MR and an apical holosystolic murmur, including rheumatic scarring of the leaflets, mitral annular calcification, postinfarction left ventricular remodeling, and severe left ventricular chamber enlargement in the setting of a dilated cardiomyopathy (Chap. 259). The severity of the MR is worsened by any contribution from apical displacement of the papillary muscles and leaflet tethering (remodeling). Because the mitral annulus is contiguous with the left atrial endocardium, gradual enlargement of the left atrium from chronic MR will result in further stretching of the annulus and more MR; thus, “MR begets MR.” Chronic severe MR results in enlargement and leftward displacement of the left ventricular



**FIGURE 42-5** Differential diagnosis of a holosystolic murmur. The murmur of mitral regurgitation is best heard over the left ventricular apex. The radiation of the murmur depends on the direction in which the jet of mitral regurgitation enters into the left atrium. Differentiation of primary and secondary causes of mitral regurgitation is usually accomplished with transthoracic echocardiography, although the presence of a nonejection click and a mid-late apical systolic murmur, for example, can establish a bedside diagnosis of mitral valve prolapse (primary mitral regurgitation). Secondary mitral regurgitation can occur as a result of left ventricular remodeling. The murmur may be soft and difficult to hear. Other signs of left ventricular dysfunction may be present. Greater than 80% of the tricuspid regurgitation encountered clinically is due to a secondary cause. Severe pulmonary hypertension can be appreciated by a loud, single  $P_2$ . Primary tricuspid regurgitation may be present in the setting of pacemaker leads or in patients with carcinoid syndrome who usually have signs of liver involvement. A ventricular septal defect is usually manifested by a holosystolic murmur with a palpable thrill along the mid- to lower left sternal edge.

apex beat and, in some patients, a diastolic filling complex, as described previously (Fig. 42-1G).

The holosystolic murmur of chronic TR is generally softer than that of MR, is loudest at the left lower sternal border, and usually increases in intensity with inspiration (Carvallo's sign). Associated signs include *c-v* waves in the jugular venous pulse, an enlarged and pulsatile liver, ascites, and peripheral edema. The abnormal jugular venous waveforms are the predominant finding and seen very often in the absence of an audible murmur despite Doppler echocardiographic verification of TR. Causes of primary TR include myxomatous disease (prolapse), endocarditis, rheumatic disease, radiation, carcinoid, Ebstein's anomaly, leaflet trauma due to intracardiac device leads, or chordal detachment as a complication of right ventricular endomyocardial biopsy. TR is much more commonly a passive process that results secondarily from annular enlargement due to right ventricular dilation in the face of volume or pressure overload or adverse right ventricular remodeling.

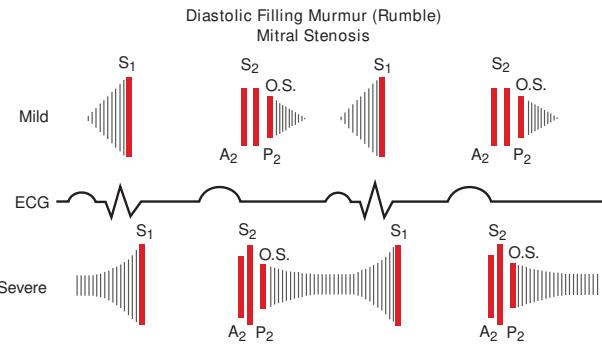
The holosystolic murmur of a VSD is loudest at the mid- to lower-left sternal border (Fig. 42-2) and radiates widely. A thrill is present at the site of maximal intensity in the majority of patients. There is no change in the intensity of the murmur with inspiration. The intensity of the murmur varies as a function of the anatomic size of the defect. Small, restrictive VSDs, as exemplified by the *maladie de Roger*, create a very loud murmur due to the significant and sustained systolic pressure gradient between the left and right ventricles. With large defects, the ventricular pressures tend to equalize, shunt flow is balanced, and a murmur is not appreciated. The distinction between post-MI ventricular septal rupture and MR has been reviewed previously.

## ■ DIASTOLIC HEART MURMURS

**Early Diastolic Murmurs** (Fig. 42-1E) Chronic AR results in a high-pitched, blowing, decrescendo, early- to mid-diastolic murmur that begins after the aortic component of S<sub>2</sub> (A<sub>2</sub>) and is best heard at the second right interspace and along the left sternal border. The murmur may be soft and difficult to hear unless auscultation is performed with the patient leaning forward at end expiration. This maneuver brings the aortic root closer to the anterior chest wall. Radiation of the murmur may provide a clue to the cause of the AR. With primary valve disease, such as that due to congenital bicuspid disease, prolapse, or endocarditis, the diastolic murmur tends to radiate along the left sternal border, where it is often louder than appreciated in the second right interspace. When AR is caused by aortic root disease, the diastolic murmur may radiate along the right sternal border. Diseases of the aortic root cause dilation or distortion of the aortic annulus and failure of leaflet coaptation. Causes include Marfan syndrome with aneurysm formation, annuloaortic ectasia, ankylosing spondylitis, and aortic dissection.

Chronic, severe AR also may produce a lower-pitched mid to late, grade 1 or 2 diastolic murmur at the apex (Austin Flint murmur), which is thought to reflect turbulence at the mitral inflow area from the admixture of regurgitant (aortic) and forward (mitral) blood flow. This lower-pitched, apical diastolic murmur can be distinguished from that due to MS by the absence of an opening snap and the response of the murmur to a vasodilator challenge. Lowering afterload with an agent such as amyl nitrite will decrease the duration and magnitude of the aortic-left ventricular diastolic pressure gradient, and thus, the Austin Flint murmur of severe AR will become shorter and softer. The intensity of the diastolic murmur of MS (Fig. 42-6) may either remain constant or increase with afterload reduction because of the reflex increase in cardiac output and mitral valve flow.

Although AS and AR may coexist, a grade 2 or 3 crescendo-decrescendo midsystolic murmur frequently is heard at the base of the heart in patients with isolated, severe AR and is due to an increased volume and rate of systolic flow. Accurate bedside identification of coexistent AS can be difficult unless the carotid pulse examination is abnormal or the midsystolic murmur is of grade 4 or greater intensity. In the absence of heart failure, chronic severe AR is accompanied by several peripheral signs of significant diastolic runoff, including a wide pulse pressure, a "water-hammer" carotid upstroke (Corrigan's pulse), and Quincke's pulsations of the nail beds. The diastolic murmur of



**FIGURE 42-6** Diastolic filling murmur (rumble) in mitral stenosis. In mild mitral stenosis, the diastolic gradient across the valve is limited to the phases of rapid ventricular filling in early diastole and presystole. The rumble may occur during either or both periods. As the stenotic process becomes severe, a large pressure gradient exists across the valve during the entire diastolic filling period, and the rumble persists throughout diastole. As the left atrial pressure becomes greater, the interval between A<sub>2</sub> (or P<sub>2</sub>) and the opening snap (O.S.) shortens. In severe mitral stenosis, secondary pulmonary hypertension develops and results in a loud P<sub>2</sub> and the splitting interval usually narrows. ECG, electrocardiogram. (Reprinted with permission Examination of the Heart, Part IV: Auscultation of the Heart ©American Heart Association, Inc.)

acute, severe AR is notably shorter in duration and lower pitched than the murmur of chronic AR. It can be very difficult to appreciate in the presence of a rapid heart rate. These attributes reflect the abrupt rate of rise of diastolic pressure within the unprepared and noncompliant left ventricle and the correspondingly rapid decline in the aortic-left ventricular diastolic pressure gradient. Left ventricular diastolic pressure may increase sufficiently to result in premature closure of the mitral valve and a soft first heart sound. Peripheral signs of significant diastolic runoff are generally not present.

Pulmonic regurgitation (PR) results in a decrescendo, early to mid-diastolic murmur (*Graham Steell murmur*) that begins after the pulmonic component of S<sub>2</sub> (P<sub>2</sub>), is best heard at the second left interspace, and radiates along the left sternal border. The intensity of the murmur may increase with inspiration. PR is most commonly due to dilation of the valve annulus from chronic elevation of the pulmonary artery pressure. Signs of pulmonary hypertension, including a right ventricular lift and a loud, single or narrowly split S<sub>2</sub>, are present. These features also help distinguish PR from AR as the cause of a decrescendo diastolic murmur heard along the left sternal border. PR in the absence of pulmonary hypertension can occur with endocarditis or a congenitally deformed valve. It is usually present after repair of tetralogy of Fallot in childhood. When pulmonary hypertension is not present, the diastolic murmur is softer and lower pitched than the classic Graham Steell murmur, and the severity of the PR can be difficult to appreciate.

TTE is indicated for the further evaluation of a patient with an early to mid-diastolic murmur. Longitudinal assessment of lesion severity, ventricular size, and systolic function helps guide a potential decision for surgical management. TTE also can provide anatomic information regarding the root and proximal ascending aorta, although computed tomographic or magnetic resonance angiography may be indicated for more precise characterization (Chap. 241).

**Mid-Diastolic Murmurs** (Figs. 42-1F and 42-1G) Mid-diastolic murmurs result from obstruction and/or augmented flow at the level of the mitral or tricuspid valve. Rheumatic fever is the most common cause of MS (Fig. 42-6). In younger patients with pliable valves, S<sub>1</sub> is loud and the murmur begins after an opening snap, which is a high-pitched sound that occurs shortly after S<sub>2</sub>. The interval between the pulmonic component of the second heart sound (P<sub>2</sub>) and the opening snap is inversely related to the magnitude of the left atrial-left ventricular pressure gradient. The murmur of MS is low-pitched and thus is best heard with the bell of the stethoscope. It is loudest at the left ventricular apex and often is appreciated only when the patient is turned in the left lateral decubitus position. It is usually of grade 1 or 2 intensity

but may be absent when the cardiac output is severely reduced despite significant obstruction. The intensity of the murmur increases during maneuvers that increase cardiac output and mitral valve flow, such as exercise. The duration of the murmur reflects the length of time over which left atrial pressure exceeds left ventricular diastolic pressure. An increase in the intensity of the murmur just before  $S_1$ , a phenomenon known as *presystolic accentuation* (Figs. 42-1A and 42-6), occurs in patients in sinus rhythm and is due to a late increase in transmural flow with atrial contraction. Presystolic accentuation does not occur in patients with atrial fibrillation.

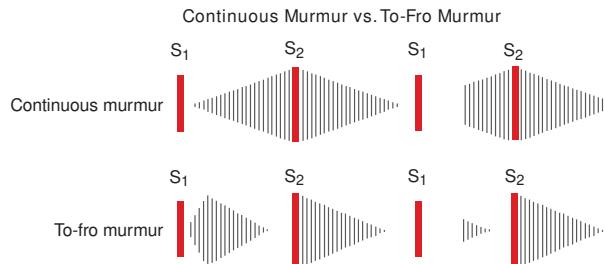
The mid-diastolic murmur associated with tricuspid stenosis is best heard at the lower left sternal border and increases in intensity with inspiration. A prolonged y descent may be visible in the jugular venous waveform. This murmur is very difficult to hear and most often is obscured by left-sided acoustical events.

There are several other causes of mid-diastolic murmurs. Large left atrial myxomas may prolapse across the mitral valve and cause variable degrees of obstruction to left ventricular inflow (Chap. 271). The murmur associated with an atrial myxoma may change in duration and intensity with changes in body position. An opening snap is not present, and there is no presystolic accentuation. Augmented mitral diastolic flow can occur with isolated severe MR or with a large left-to-right shunt at the ventricular or great vessel level and produce a soft, rapid filling sound ( $S_1$ ) followed by a short, low-pitched mid-diastolic apical murmur (Fig. 42-1G). The Austin Flint murmur of severe, chronic AR has already been described.

A short, mid-diastolic murmur is rarely heard during an episode of acute rheumatic fever (Carey-Coombs murmur) and probably is due to flow through an edematous mitral valve. An opening snap is not present in the acute phase, and the murmur dissipates with resolution of the acute attack. Complete heart block with dysynchronous atrial and ventricular activation may be associated with intermittent mid- to late diastolic murmurs if atrial contraction occurs when the mitral valve is partially closed. Mid-diastolic murmurs indicative of increased tricuspid valve flow can occur with severe, isolated TR and with large ASDs and significant left-to-right shunting. Other signs of an ASD are present (Chap. 269), including fixed splitting of  $S_2$  and a midsystolic murmur at the mid- to upper left sternal border. TTE is indicated for evaluation of a patient with a mid- to late diastolic murmur. Findings specific to the diseases discussed above will help guide management.

## ■ CONTINUOUS MURMURS

(Figs. 42-1H and 42-7) Continuous murmurs begin in systole, peak near the second heart sound, and continue into all or part of diastole. Their presence throughout the cardiac cycle implies a pressure gradient



**FIGURE 42-7** Comparison of the continuous murmur and the to-fro murmur. During abnormal communication between high-pressure and low-pressure systems, a large pressure gradient exists throughout the cardiac cycle, producing a continuous murmur. A classic example is patent ductus arteriosus. At times, this type of murmur can be confused with a to-fro murmur, which is a combination of systolic ejection murmur and a murmur of semilunar valve incompetence. A classic example of a to-fro murmur is aortic stenosis and regurgitation. A continuous murmur crescendos to near the second heart sound ( $S_2$ ), whereas a to-fro murmur has two components. The midsystolic ejection component decrescendos and disappears as it approaches  $S_2$ . (Reprinted with permission Examination of the Heart, Part IV: Auscultation of the Heart ©American Heart Association, Inc.)

between two chambers or vessels during both systole and diastole. The continuous murmur associated with a patent ductus arteriosus is best heard lateral to the upper left sternal border. Large, uncorrected shunts may lead to pulmonary hypertension, attenuation or obliteration of the diastolic component of the murmur, reversal of shunt flow, and differential cyanosis of the lower extremities. A ruptured sinus of Valsalva aneurysm creates a continuous murmur of abrupt onset at the upper right sternal border. Rupture typically occurs into a right heart chamber, and the murmur is indicative of a continuous pressure difference between the aorta and either the right atrium or the right ventricle. A continuous murmur also may be audible along the left sternal border with a coronary arteriovenous fistula and at the site of an arteriovenous fistula used for hemodialysis access. Enhanced flow through enlarged intercostal collateral arteries in patients with aortic coarctation may produce a continuous murmur along the course of one or more ribs. A cervical bruit with both systolic and diastolic components (a to-fro murmur, Fig. 42-7) usually indicates a high-grade carotid artery stenosis.

Not all continuous murmurs are pathologic. A continuous venous hum can be heard in healthy children and young adults, especially during pregnancy; it is best appreciated in the right supraclavicular fossa and can be obliterated by pressure over the right internal jugular vein or by having the patient turn his or her head toward the examiner. The continuous mammary souffle of pregnancy is created by enhanced arterial flow through engorged breasts and usually appears during the late third trimester or early puerperium. The murmur is louder in systole. Firm pressure with the diaphragm of the stethoscope can eliminate the diastolic portion of the murmur.

## ■ DYNAMIC AUSCULTATION

(Table 42-2; see Table 239-1) Careful attention to the behavior of heart murmurs during simple maneuvers that alter cardiac hemodynamics can provide important clues to their cause and significance.

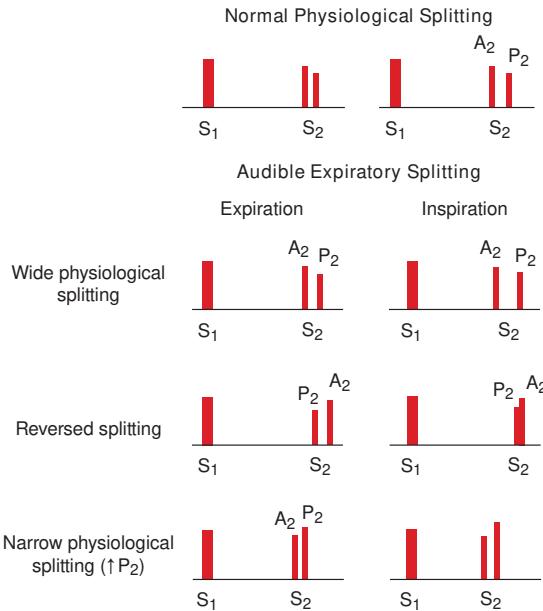
**Respiration** Auscultation should be performed during quiet respiration or with a modest increase in inspiratory effort, as more forceful movement of the chest tends to obscure the heart sounds. Left-sided murmurs may be best heard at end expiration, when lung volumes are minimized, and the heart and great vessels are brought closer to the chest wall. This phenomenon is characteristic of the murmur of AR. Murmurs of right-sided origin, such as tricuspid or pulmonic regurgitation, increase in intensity during inspiration. The intensity of left-sided murmurs either remains constant or decreases with inspiration.

Bedside assessment also should evaluate the behavior of  $S_2$  with respiration and the dynamic relationship between the aortic and pulmonic components (Fig. 42-8). Reversed splitting can be a feature of severe AS, HOCM, left bundle branch block, right ventricular pacing, or acute myocardial ischemia. Fixed splitting of  $S_2$  in the presence of a grade 2 or 3 midsystolic murmur at the mid- or upper left sternal border indicates an ASD. Physiologic but wide splitting during the respiratory cycle implies either premature aortic valve closure, as can occur with severe MR, or delayed pulmonic valve closure due to PS or right bundle branch block.

**Alterations of Systemic Vascular Resistance** Murmurs can change characteristics after maneuvers that alter systemic vascular

**TABLE 42-2** Dynamic Auscultation: Bedside Maneuvers That can be Used to Change the Intensity of Cardiac Murmurs (See Text)

1. Respiration
2. Isometric exercise (handgrip)
3. Transient arterial occlusion
4. Pharmacologic manipulation of preload and/or afterload
5. Valsalva maneuver
6. Rapid standing/squatting
7. Passive leg raising
8. Post-premature beat



**FIGURE 42-8** Top. Normal physiologic splitting of the second heart sound. During expiration, the aortic ( $A_2$ ) and pulmonic ( $P_2$ ) components of the second heart sound are separated by <30 ms and are appreciated as a single sound. During inspiration, the splitting interval widens, and  $A_2$  and  $P_2$  are clearly separated into two distinct sounds. Bottom. Audible expiratory splitting. Wide physiologic splitting is caused by a delay in  $P_2$  (as, for example, with right bundle branch block) or by early closure of the aortic valve ( $A_2$ ), as for example with severe mitral regurgitation). Reversed splitting is caused by a delay in  $A_2$ , resulting in paradoxical movement; i.e., with inspiration  $P_2$  moves toward  $A_2$  and the splitting interval narrows. Narrow physiologic splitting occurs in pulmonary hypertension, and both  $A_2$  and  $P_2$  are heard during expiration at a narrow splitting interval because of the increased intensity and high-frequency composition of  $P_2$ . (Reprinted with permission Examination of the Heart, Part IV: Auscultation of the Heart ©American Heart Association, Inc.)

resistance and left ventricular afterload. The systolic murmurs of MR and VSD become louder during sustained handgrip, simultaneous inflation of blood pressure cuffs on both upper extremities to pressures 20–40 mmHg above systolic pressure for 20 s, or infusion of a vasopressor agent. The murmurs associated with AS or HOCM will become softer or remain unchanged with these maneuvers. The diastolic murmur of AR becomes louder in response to interventions that raise systemic vascular resistance.

Opposite changes in systolic and diastolic murmurs may occur with the use of pharmacologic agents that lower systemic vascular resistance. Inhaled amyl nitrite is now rarely used for this purpose but can help distinguish the murmur of AS or HOCM from that of either MR or VSD, if necessary. The former two murmurs increase in intensity, whereas the latter two become softer after exposure to amyl nitrite. As noted previously, the Austin Flint murmur of severe AR becomes softer, but the mid-diastolic rumble of MS becomes louder, in response to the abrupt lowering of systemic vascular resistance with amyl nitrite and enhanced transmural valve flow.

**Changes in Venous Return** The Valsalva maneuver results in an increase in intrathoracic pressure, followed by a decrease in venous return, ventricular filling, and cardiac output. The majority of murmurs decrease in intensity during the strain phase of the maneuver. Two notable exceptions are the murmurs associated with MVP and HOCM, both of which become louder during the Valsalva maneuver. The murmur of MVP may also become longer as leaflet prolapse occurs earlier in systole at smaller ventricular volumes. These murmurs behave in a similar and parallel fashion with standing. Both the click and the murmur of MVP move closer in timing to S<sub>1</sub> on rapid standing from a squatting position (Fig. 42-3). The increase in the

intensity of the murmur of HOCM is predicated on the augmentation of the dynamic left ventricular outflow tract gradient that occurs with reduced ventricular filling. Squatting results in abrupt increases in both venous return (preload) and left ventricular afterload that increase ventricular volume, changes that predictably cause a decrease in the intensity and duration of the murmurs associated with MVP and HOCM; the click and murmur of MVP move away from S<sub>1</sub> with squatting. Passive leg raising can be used to increase venous return in patients who are unable to squat and stand. This maneuver may lead to a decrease in the intensity of the murmur associated with HOCM but has less effect in patients with MVP.

**Post-Premature Ventricular Contraction** A change in the intensity of a systolic murmur in the first beat after a premature beat, or in the beat after a long cycle length in patients with atrial fibrillation, can help distinguish AS from MR, particularly in an older patient in whom the murmur of AS is well transmitted to the apex. Systolic murmurs due to left ventricular outflow obstruction, including that due to AS, increase in intensity in the beat after a premature beat because of the combined effects of enhanced left ventricular filling and post-extrasystolic potentiation of contractile function. Forward flow accelerates, causing an increase in the gradient and a louder murmur. The intensity of the murmur of MR does not change in the post-premature beat as there is relatively little further increase in mitral valve flow or change in the left ventricular-left atrial gradient.

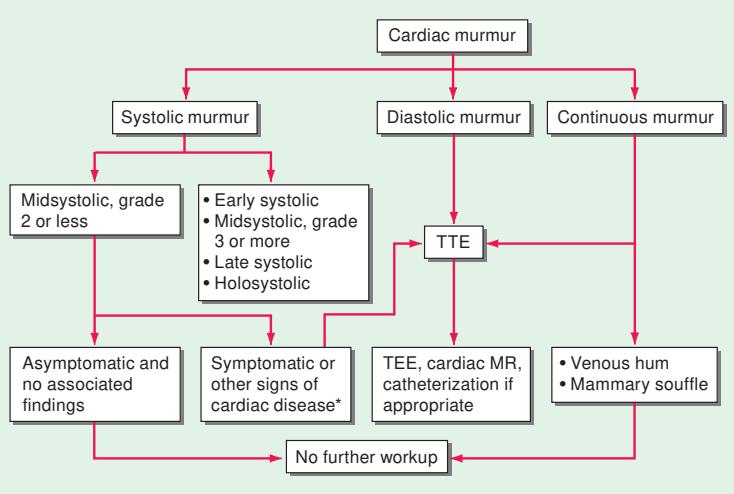
## THE CLINICAL CONTEXT

Additional clues to the etiology and importance of a heart murmur can be gleaned from the history and other physical examination findings. Symptoms suggestive of cardiovascular, neurologic, or pulmonary disease help focus the differential diagnosis, as do findings relevant to the jugular venous pressure and waveforms, the arterial pulses, other heart sounds, the lungs, the abdomen, the skin, and the extremities. In many instances, laboratory studies, an ECG, and/or a chest x-ray may have been obtained earlier and may contain valuable information. A patient with suspected infective endocarditis, for example, may have a murmur in the setting of fever, chills, anorexia, fatigue, dyspnea, splenomegaly, petechiae, and positive blood cultures. A new systolic murmur in a patient with a marked fall in blood pressure after a recent MI suggests myocardial rupture. By contrast, an isolated grade 1 or 2 midsystolic murmur at the left sternal border in a healthy, active, and asymptomatic young adult is most likely a benign finding for which no further evaluation is indicated. The context in which the murmur is appreciated often dictates the need for further testing and the pace of the evaluation.

## ECHOCARDIOGRAPHY

(Fig. 42-9; Chaps. 239 and 241) Echocardiography with color flow and spectral Doppler is a valuable tool for the assessment of cardiac murmurs. Information regarding valve structure and function, chamber size, wall thickness, ventricular function, estimated pulmonary artery pressures, intracardiac shunt flow, pulmonary and hepatic vein flow, and aortic flow can be ascertained readily. It is important to note that Doppler signals of trace or mild valvular regurgitation of no clinical consequence can be detected with structurally normal tricuspid, pulmonic, and mitral valves. Such signals are not likely to generate enough turbulence to create an audible murmur.

Echocardiography is indicated for the evaluation of patients with early, late, or holosystolic murmurs and patients with grade 3 or louder midsystolic murmurs. Patients with grade 1 or 2 midsystolic murmurs but other symptoms or signs of cardiovascular disease, including those from ECG or chest x-ray, should also undergo echocardiography. Echocardiography is also indicated for the evaluation of any patient with a diastolic murmur and for patients with continuous murmurs not due to a venous hum or mammary souffle. Echocardiography should be considered when there is a clinical need to verify normal cardiac structure and function in a patient whose symptoms and signs are probably noncardiac in origin. The performance of serial



**FIGURE 42-9** Strategy for evaluating heart murmurs. \*If an electrocardiogram or chest x-ray has been obtained and is abnormal, echocardiography is indicated. MR, magnetic resonance; TEE, transesophageal echocardiography; TTE, transthoracic echocardiography. (Adapted from RO Bonow et al: 1998 ACC/AHA Guideline for the management of patients with valvular heart disease. *J Am Coll Cardiol* 32:1486, 1998.)

echocardiography to follow the course of asymptomatic individuals with valvular heart disease is a central feature of their longitudinal assessment, and it provides valuable information that may have an impact on decisions regarding the timing of surgery. Routine echocardiography is *not* recommended for asymptomatic patients with a grade 1 or 2 midsystolic murmur without other signs of heart disease. For this category of patients, referral to a cardiovascular specialist could be considered if there is doubt about the significance of the murmur after the initial examination.

The selective use of echocardiography outlined above has not been subjected to rigorous analysis of its cost-effectiveness. For some clinicians, handheld or miniaturized cardiac ultrasound devices have replaced the stethoscope. Although several reports attest to the improved sensitivity of such devices for the detection of valvular heart disease (e.g., rheumatic heart disease in susceptible populations), accuracy is highly operator-dependent, and incremental cost considerations and outcomes have not been addressed adequately for most patient scenarios. The use of electronic or digital stethoscopes with spectral display capabilities has also been proposed as a method to improve the characterization of heart murmurs and the mentored teaching of cardiac auscultation.

### ■ OTHER CARDIAC TESTING

(Chap. 241, Fig. 42-9) In relatively few patients, clinical assessment and TTE do not adequately characterize the origin and significance of a heart murmur. Transesophageal echocardiography (TEE) can be considered for further evaluation, especially when the TTE windows are limited by body size, chest configuration, or intrathoracic pathology. TEE offers enhanced sensitivity for the detection of a wide range of structural cardiac disorders. Electrocardiographically gated cardiac magnetic resonance (CMR) imaging can provide quantitative information regarding valvular function, regurgitant fraction, regurgitant volume, shunt flow, chamber and great vessel size, ventricular function, and myocardial perfusion. CMR imaging has largely supplanted the need for cardiac catheterization and invasive hemodynamic assessment when there is a discrepancy between the clinical and echocardiographic findings in patients with regurgitant heart valve disease, such as MR or AR. Both CMR and cardiac CT can provide assessment of aortic valve leaflet number when there is uncertainty by TTE regarding whether the valve is bi- or tricuspid, as well as provide information on aortic root and ascending aortic anatomy. The use of coronary CT angiography to exclude coronary artery disease in selected patients with a low pretest probability of disease before valve surgery has gained

wider acceptance. Invasive angiography and hemodynamic assessment may be required for a more complete preoperative evaluation.

### ■ INTEGRATED APPROACH

The accurate identification of a heart murmur begins with a systematic approach to cardiac auscultation. Characterization of its major attributes, as reviewed above, allows the examiner to construct a preliminary differential diagnosis, which is then refined by integration of information available from the history, associated cardiac findings, the general physical examination, and the clinical context. The need for and urgency of further testing follow sequentially. Correlation of the findings on auscultation with the noninvasive data provides an educational feedback loop and an opportunity for improving physical examination skills. Cost considerations mandate that noninvasive imaging be justified on the basis of its incremental contribution to diagnosis, treatment, and outcome. Cardiac auscultation using a stethoscope remains a time-honored tradition in medicine, the benefits of which extend beyond accurate recognition of heart sounds. Selective augmentation with, rather than wholesale replacement by, handheld ultrasound and

newer technologies may improve diagnostic accuracy and better guide therapeutic decisions.

### ■ FURTHER READING

- E ER, W BN: Tenuous tether. *N Engl J Med* 373:2199, 2015.
- E A et al: Hand-held cardiac ultrasound screening performed by family doctors with remote expert support interpretation. *Heart* 102:376, 2016.
- F LC, OG PT: The history and physical examination. An evidence-based approach, in *Braunwald's Heart Disease. A Textbook of Cardiovascular Medicine*, 11th ed, DP Zipes et al (eds). Philadelphia, Elsevier/Saunders, 2019, pp 83-101.
- F V: The stethoscope's prognosis. Very much alive and very necessary. *J Am Coll Cardiol* 67:1118, 2016.
- O CM et al: 2020 AHA/ACC guideline for the management of patients with valvular heart disease. *J Am Coll Cardiol* 143:e72, 2021.
- S TM et al: Brief group training of medical students in focused cardiac ultrasound may improve diagnostic accuracy of physical examination. *J Am Soc Echocardiogr* 27:1238, 2014.

43

## Palpitations

Joseph Loscalzo



Palpitations are extremely common among patients who present to their internists and can best be defined as a “thumping,” “pounding,” or “fluttering” sensation in the chest. This sensation can be either intermittent or sustained and either regular or irregular. Most patients interpret palpitations as an unusual awareness of the heartbeat and become especially concerned when they sense that they have had “skipped” or “missing” heartbeats. Palpitations are often noted when the patient is quietly resting, during which time other stimuli are minimal. Palpitations that are positional generally reflect a structural process within (e.g., atrial myxoma) or adjacent to (e.g., mediastinal mass) the heart.

Palpitations are brought about by cardiac (43%), psychiatric (31%), miscellaneous (10%), and unknown (16%) causes, according to one large series. Among the cardiovascular causes are premature atrial and ventricular contractions, supraventricular and ventricular arrhythmias, mitral valve prolapse (with or without associated arrhythmias), aortic insufficiency, atrial myxoma, myocarditis, and pulmonary embolism. Intermittent palpitations are commonly caused by premature atrial or ventricular contractions: the post-extrasystolic beat is sensed by the patient owing to the increase in ventricular end-diastolic dimension following the pause in the cardiac cycle and the increased strength of contraction (post-extrasystolic potentiation) of that beat. Regular, sustained palpitations can be caused by regular supraventricular and ventricular tachycardias. Irregular, sustained palpitations can be caused by atrial fibrillation. It is important to note that most arrhythmias are not associated with palpitations. In those that are, it is often useful either to ask the patient to “tap out” the rhythm of the palpitations or to take his or her pulse during palpitations. In general, hyperdynamic cardiovascular states caused by catecholaminergic stimulation from exercise, stress, or pheochromocytoma can lead to palpitations. Palpitations are common among athletes, especially older endurance athletes. In addition, the enlarged ventricle of aortic regurgitation and accompanying hyperdynamic precordium frequently lead to the sensation of palpitations. Other factors that enhance the strength of myocardial contraction, including tobacco, caffeine, aminophylline, atropine, thyroxine, cocaine, and amphetamines, can cause palpitations.

Psychiatric causes of palpitations include panic attacks or disorders, anxiety states, and somatization, alone or in combination. Patients with psychiatric causes for palpitations more commonly report a longer duration of the sensation (>15 min) and other accompanying symptoms than do patients with other causes. Among the miscellaneous causes of palpitations are thyrotoxicosis, drugs (see above) and ethanol, spontaneous skeletal muscle contractions of the chest wall, pheochromocytoma, and systemic mastocytosis.

## APPROACH TO THE PATIENT

### Palpitations

The principal goal in assessing patients with palpitations is to determine whether the symptom is caused by a life-threatening arrhythmia. Patients with preexisting coronary artery disease (CAD) or risk factors for CAD are at greatest risk for ventricular arrhythmias (**Chap. 246**) as a cause for palpitations. In addition, the association of palpitations with other symptoms suggesting hemodynamic compromise, including syncope or lightheadedness, supports this diagnosis. Palpitations caused by sustained tachyarrhythmias in patients with CAD can be accompanied by angina pectoris or dyspnea, and, in patients with ventricular dysfunction (systolic or diastolic), aortic stenosis, hypertrophic cardiomyopathy, or mitral stenosis (with or without CAD), can be accompanied by dyspnea from increased left atrial and pulmonary venous pressure.

Key features of the physical examination that will help confirm or refute the presence of an arrhythmia as a cause for palpitations (as well as its adverse hemodynamic consequences) include measurement of the vital signs, assessment of the jugular venous pressure and pulse, and auscultation of the chest and precordium. A resting electrocardiogram can be used to document the arrhythmia. If exertion is known to induce the arrhythmia and accompanying palpitations, exercise electrocardiography can be used to make the diagnosis. If the arrhythmia is sufficiently infrequent, other methods must be used, including continuous electrocardiographic (Holter) monitoring; telephonic monitoring, through which the patient can transmit an electrocardiographic tracing during a sensed episode; loop recordings (external or implantable), which can capture the electrocardiographic event for later review; and mobile (self-monitoring) cardiac outpatient telemetry. Data suggest that Holter monitoring is of limited clinical utility, while the implantable loop recorder and mobile cardiac outpatient telemetry are safe and

possibly more cost-effective in the assessment of patients with (infrequent) recurrent, unexplained palpitations. The use of a diary or an electronic marker to indicate the timing of palpitations sensed by the patient is essential for appropriate interpretation of these studies.

Most patients with palpitations do not have serious arrhythmias or underlying structural heart disease. If sufficiently troubling to the patient, occasional benign atrial or ventricular premature contractions can often be managed with beta-blocker therapy. Palpitations incited by alcohol, tobacco, or illicit drugs need to be managed by abstention, while those caused by pharmacologic agents should be addressed by considering alternative therapies when appropriate or possible. Psychiatric causes of palpitations may benefit from cognitive therapy or pharmacotherapy. The physician should note that palpitations are at the very least bothersome and, on occasion, frightening to the patient. Once serious causes for the symptom have been excluded, the patient should be reassured that the palpitations will not adversely affect prognosis.

### FURTHER READING

- C S, B L: Problem based review: The patient with palpitations. *Acute Med* 11:169, 2012.
- J N et al: Emergency management of palpitations in the elderly: Epidemiology, diagnostic approaches, and therapeutic options. *Clin Geriatr Med* 29:205, 2013.
- M H, R et al: Mobile self-monitoring ECG devices to diagnose arrhythmias that coincide with palpitations: A scoping review. *Healthcare (Basel)* 7:pii: E96, 2019.
- S R et al: Insertable cardiac monitors: current indications and devices. *Expert Rev Med Devices* 16:45, 2019.
- W BE, K WN: Evaluation and outcomes of patients with palpitations. *Am J Med* 100:138, 1996.

## Section 6 Alterations in Gastrointestinal Function

### 44

### Dysphagia

Ikuo Hirano, Peter J. Kahrilas



Dysphagia—difficulty with swallowing—refers to problems with the transit of food or liquid from the mouth to the hypopharynx or through the esophagus. Severe dysphagia can compromise nutrition, cause aspiration, and reduce quality of life. Additional terminology pertaining to swallowing dysfunction is as follows. *Aphagia* (inability to swallow) typically denotes complete esophageal obstruction, most commonly encountered in the acute setting of a food bolus or foreign body impaction. *Odynophagia* refers to painful swallowing, typically resulting from mucosal ulceration within the oropharynx or esophagus. It commonly is accompanied by dysphagia, but the converse is not true. *Globus pharyngeus* is a foreign body sensation localized in the neck that does not interfere with swallowing and sometimes is relieved by swallowing. *Transfer dysphagia* frequently results in nasal regurgitation or pulmonary aspiration during swallowing and is characteristic of oropharyngeal dysphagia. *Phagophobia* (fear of swallowing) and *refusal to swallow* may be psychogenic or related to anticipatory anxiety about food bolus obstruction, odynophagia, or aspiration.

### PHYSIOLOGY OF SWALLOWING

Swallowing begins with a voluntary (oral) phase that includes preparation during which food is masticated and mixed with saliva. This is followed by a transfer phase during which the bolus is pushed into the

pharynx by the tongue. Bolus entry into the hypopharynx initiates the pharyngeal swallow response, which is centrally mediated and involves a complex series of actions, the net result of which is to propel food through the pharynx into the esophagus while preventing its entry into the airway. To accomplish this, the larynx is elevated and pulled forward, actions that also facilitate upper esophageal sphincter (UES) opening. Tongue pulsion then propels the bolus through the UES, followed by a peristaltic contraction that clears residue from the pharynx and through the esophagus. The lower esophageal sphincter (LES) relaxes as the food enters the esophagus and remains relaxed until the peristaltic contraction has delivered the bolus into the stomach. Peristaltic contractions elicited in response to a swallow are called *primary peristalsis* and involve sequenced inhibition followed by contraction of the musculature along the entire length of the esophagus. The inhibition that precedes the peristaltic contraction is called *deglutitive inhibition*. Local distention of the esophagus anywhere along its length, as may occur with gastroesophageal reflux, activates *secondary peristalsis* that begins at the point of distention and proceeds distally. Tertiary esophageal contractions are nonperistaltic, disordered esophageal contractions that may be observed to occur spontaneously during fluoroscopic observation.

The musculature of the oral cavity, pharynx, UES, and cervical esophagus is striated and directly innervated by lower motor neurons carried in cranial nerves (Fig. 44-1). Oral cavity muscles are innervated by the fifth (trigeminal) and seventh (facial) cranial nerves; the tongue, by the twelfth (hypoglossal) cranial nerve. Pharyngeal muscles are innervated by the ninth (glossopharyngeal) and tenth (vagus) cranial nerves.

Physiologically, the UES consists of the cricopharyngeus muscle, the adjacent inferior pharyngeal constrictor, and the proximal portion of the cervical esophagus. UES innervation is derived from the vagus nerve, whereas the innervation to the musculature acting on the UES to facilitate its opening during swallowing comes from the fifth, seventh, and twelfth cranial nerves. The UES remains closed at rest owing to both its inherent elastic properties and neurogenically mediated contraction of the cricopharyngeus muscle. UES opening during swallowing involves both cessation of vagal excitation to the

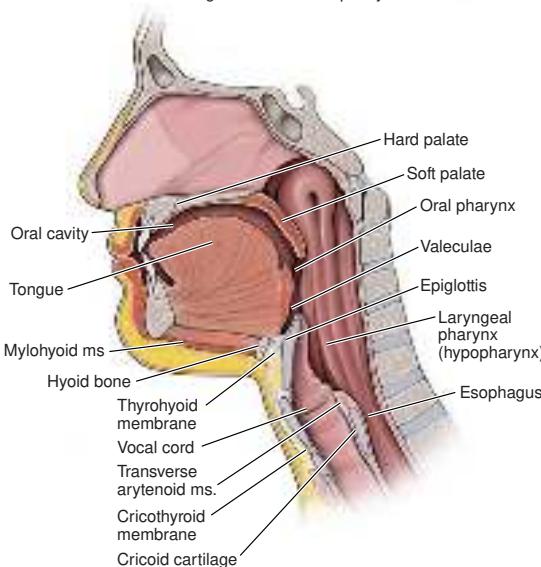
cricopharyngeus and simultaneous contraction of the suprathyroid and geniohyoid muscles that pull open the UES in conjunction with the upward and forward displacement of the larynx.

The neuromuscular apparatus for peristalsis is distinct in proximal and distal parts of the esophagus. The cervical esophagus, like the pharyngeal musculature, consists of striated muscle and is directly innervated by lower motor neurons of the vagus nerve. Peristalsis in the proximal esophagus is governed by the sequential activation of the vagal motor neurons in the nucleus ambiguus. In contrast, the distal esophagus and LES are composed of smooth muscle and are controlled by excitatory and inhibitory neurons within the esophageal myenteric plexus. Medullary preganglionic neurons from the dorsal motor nucleus of the vagus trigger peristalsis via these ganglionic neurons during primary peristalsis. Neurotransmitters of the excitatory ganglionic neurons are acetylcholine and substance P; those of the inhibitory neurons are vasoactive intestinal peptide and nitric oxide. Peristalsis results from the patterned activation of inhibitory followed by excitatory ganglionic neurons, with progressive dominance of the inhibitory neurons distally. Similarly, LES relaxation occurs with the onset of deglutitive inhibition and persists until the peristaltic sequence is complete. At rest, the LES is contracted because of excitatory ganglionic stimulation and its intrinsic myogenic tone, a property that distinguishes it from the adjacent esophagus. The function of the LES is supplemented by the surrounding muscle of the right diaphragmatic crus, which acts as an external sphincter during inspiration, cough, or abdominal straining.

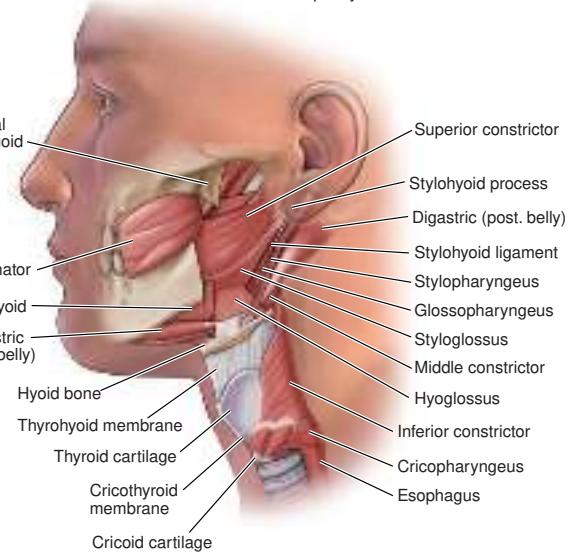
## ■ PATHOPHYSIOLOGY OF DYSPHAGIA

Dysphagia can be subclassified both by location and by the circumstances in which it occurs. With respect to location, distinct considerations apply to oral, pharyngeal, or esophageal dysphagia. Normal transport of an ingested bolus depends on the consistency and size of the bolus, the caliber of the lumen, the integrity of peristaltic contraction, and deglutitive inhibition of both the UES and the LES. Dysphagia caused by an oversized bolus or a narrow lumen is called *structural dysphagia*, whereas dysphagia due to abnormalities of peristalsis or impaired sphincter relaxation after swallowing is called *propulsive* or

Sagittal view of the pharynx



Musculature of the pharynx



**FIGURE 44-1** Sagittal and diagrammatic views of the musculature involved in enacting oropharyngeal swallowing. Note the dominance of the tongue in the sagittal view and the intimate relationship between the entrance to the larynx (airway) and the esophagus. In the resting configuration illustrated, the esophageal inlet is closed. This is transiently reconfigured such that the esophageal inlet is open and the laryngeal inlet closed during swallowing. (Adapted from PJ Kahrilas, in DW Gelfand and JE Richter [eds]: *Dysphagia: Diagnosis and Treatment*. New York, Igaku-Shoin Medical Publishers, 1989, pp. 11–28.)

*motor dysphagia.* More than one mechanism may be operative in a patient with dysphagia. Scleroderma commonly presents with absent peristalsis as well as a weakened LES that predisposes patients to peptic stricture formation. Likewise, radiation therapy for head and neck cancer may compound the functional deficits in the oropharyngeal swallow attributable to the tumor and cause cervical esophageal stenosis. It is worth noting that in addition to bolus transit, symptom reporting of dysphagia is dependent upon intact sensory innervation and central nervous system perception.

**Oral and Pharyngeal (Oropharyngeal) Dysphagia** Oral-phase dysphagia is associated with poor bolus formation and control so that food has prolonged retention within the oral cavity and may seep out of the mouth. Drooling and difficulty in initiating swallowing are other characteristic signs. Poor bolus control also may lead to premature spillage of food into the hypopharynx with resultant aspiration into the trachea or regurgitation into the nasal cavity. Pharyngeal-phase dysphagia is associated with retention of food in the pharynx due to poor tongue or pharyngeal propulsion or obstruction at the UES. Signs and symptoms of concomitant hoarseness or cranial nerve dysfunction may be associated with oropharyngeal dysphagia.

Oropharyngeal dysphagia may be due to neurologic, muscular, structural, iatrogenic, infectious, and metabolic causes. Iatrogenic, neurologic, and structural pathologies are most common. Iatrogenic causes include surgery and radiation, often in the setting of head and neck cancer. Neurogenic dysphagia resulting from cerebrovascular accidents, Parkinson's disease, and amyotrophic lateral sclerosis is a major source of morbidity related to aspiration and malnutrition. Medullary nuclei directly innervate the oropharynx. Lateralization of pharyngeal dysphagia implies either a structural pharyngeal lesion or a neurologic process that selectively targeted the ipsilateral brainstem nuclei or cranial nerve. Advances in functional brain imaging have elucidated an important role of the cerebral cortex in swallow function and dysphagia. Asymmetry in the cortical representation of the pharynx provides an explanation for the dysphagia that occurs as a consequence of unilateral cortical cerebrovascular accidents.

Oropharyngeal structural lesions causing dysphagia include Zenker's diverticulum, cricopharyngeal bar, and neoplasia. Zenker's diverticulum typically is encountered in elderly patients. In addition to dysphagia, patients may present with regurgitation of particulate food debris, aspiration, and halitosis. The pathogenesis is related to stenosis of the cricopharyngeus that causes diminished opening of the UES and results in increased hypopharyngeal pressure during swallowing with development of a pulsion diverticulum immediately above the cricopharyngeus in a region of potential weakness known as Killian's dehiscence. A cricopharyngeal bar, appearing as a prominent indentation behind the lower third of the cricoid cartilage, is related to Zenker's diverticulum in that it involves limited distensibility of the cricopharyngeus and can lead to the formation of a Zenker's diverticulum. However, a cricopharyngeal bar is a common radiographic finding, and most patients with transient cricopharyngeal bars are asymptomatic, making it important to rule out alternative etiologies of dysphagia before treatment. Furthermore, cricopharyngeal bars may be secondary to other neuromuscular disorders that impair opening of the UES.

Since the pharyngeal phase of swallowing occurs in less than a second, rapid-sequence fluoroscopy is necessary to evaluate for functional abnormalities. Adequate fluoroscopic examination requires that the patient be conscious and cooperative. The study incorporates recordings of swallow sequences during ingestion of food and liquids of varying consistencies. The pharynx is examined to detect bolus retention, regurgitation into the nose, or aspiration into the trachea. Timing and integrity of pharyngeal contraction and opening of the UES with a swallow are analyzed to assess both aspiration risk and the potential for swallow therapy. Structural abnormalities of the oropharynx, especially those that may require biopsies, also should be assessed by direct laryngoscopic examination.

**Esophageal Dysphagia** The adult esophagus measures 18–26 cm in length and is anatomically divided into the cervical esophagus, extending from the pharyngoesophageal junction to the suprasternal notch, and the thoracic esophagus, which continues to the diaphragmatic hiatus. When distended, the esophageal lumen has internal dimensions of about 2 cm in the anteroposterior plane and 3 cm in the lateral plane. Solid food dysphagia becomes common when the lumen is narrowed to <13 mm, but also can occur with larger diameters in the setting of poorly masticated food or motor dysfunction. Circumferential lesions are more likely to cause dysphagia than are lesions that involve only a partial circumference of the esophageal wall. The most common structural causes of dysphagia are Schatzki's rings, eosinophilic esophagitis, and peptic strictures. Dysphagia also occurs in the setting of gastroesophageal reflux disease without a stricture, perhaps on the basis of altered esophageal sensation, reduced esophageal mural distensibility, or motor dysfunction.

Propulsive disorders leading to esophageal dysphagia result from abnormalities of peristalsis and/or degllutitive inhibition, potentially affecting the cervical or thoracic esophagus. Since striated muscle pathology usually involves both the oropharynx and the cervical esophagus, the clinical manifestations usually are dominated by oropharyngeal dysphagia. Diseases affecting smooth muscle involve both the thoracic esophagus and the LES. A dominant manifestation of this, absent peristalsis, refers to either the complete absence of swallow-induced contraction (absent contractility) or the presence of nonperistaltic, disordered contractions. Absent peristalsis and failure of degllutitive LES relaxation are the defining features of achalasia. In diffuse esophageal spasm (DES), LES function is normal, with the disordered motility restricted to the esophageal body. Absent contractility combined with severe weakness of the LES is a pattern commonly found in patients with scleroderma.

## APPROACH TO THE PATIENT

### Dysphagia

Figure 44-2 shows an algorithm for the approach to a patient with dysphagia.

#### HISTORY

The patient history is extremely valuable in making a presumptive diagnosis or at least substantially limiting the differential diagnoses in most patients. Key elements of the history are the localization of dysphagia, the circumstances in which dysphagia is experienced, other symptoms associated with dysphagia, and progression. Dysphagia that localizes to the suprasternal notch may indicate either an oropharyngeal or an esophageal etiology as distal dysphagia is referred proximally about 30% of the time. Dysphagia that localizes to the chest is esophageal in origin. Nasal regurgitation and tracheobronchial aspiration manifest by coughing with swallowing are hallmarks of oropharyngeal dysphagia. Severe cough with swallowing may also be a sign of a tracheoesophageal fistula. The presence of hoarseness may be another important diagnostic clue. When hoarseness precedes dysphagia, the primary lesion is usually laryngeal; hoarseness that occurs after the development of dysphagia may result from compromise of the recurrent laryngeal nerve by a malignancy. The type of food causing dysphagia is an important consideration. Intermittent dysphagia that occurs only with solid food implies structural dysphagia, whereas constant dysphagia with both liquids and solids strongly suggests an esophageal motor abnormality. Two caveats to this pattern are that despite having a motor abnormality, patients with scleroderma generally develop mild dysphagia for solids only and that patients with oropharyngeal dysphagia often have greater difficulty managing liquids than solids. Dysphagia that is progressive over the course of weeks to months raises concern for neoplasia. Episodic dysphagia to solids that is unchanged or slowly progressive over years indicates a benign disease process such as a Schatzki ring or eosinophilic

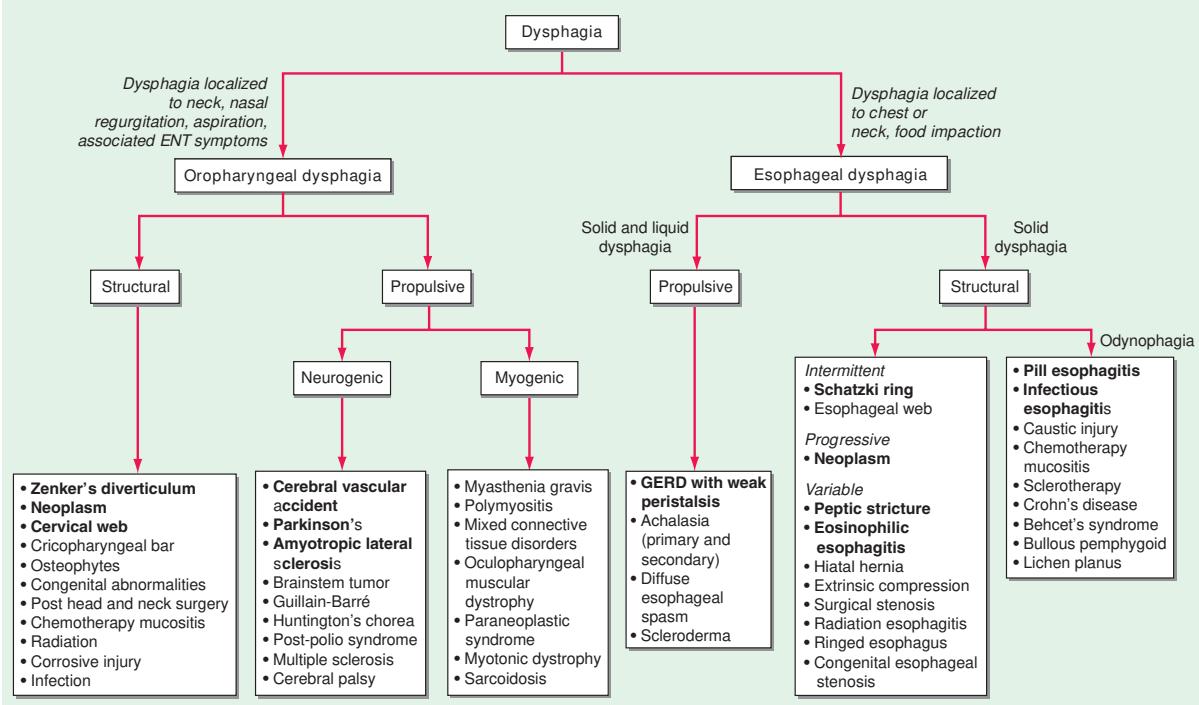


FIGURE 44-2 Approach to the patient with dysphagia. Etiologies in bold print are the most common. ENT, ear, nose, and throat; GERD, gastroesophageal reflux disease.

esophagitis. Food impaction with a prolonged inability to pass an ingested bolus even with ingestion of liquid is typical of a structural dysphagia. Chest pain may accompany dysphagia whether it is related to motor disorders, structural disorders, or reflux disease. A prolonged history of heartburn preceding the onset of dysphagia is suggestive of peptic stricture and, infrequently, esophageal adenocarcinoma. A history of prolonged nasogastric intubation, esophageal or head and neck surgery, ingestion of caustic agents or pills, previous radiation or chemotherapy, or associated mucocutaneous diseases may help isolate the cause of dysphagia. With accompanying odynophagia, which usually is indicative of ulceration, infectious or pill-induced esophagitis should be suspected. In patients with AIDS or other immunocompromised states, esophagitis due to opportunistic infections such as *Candida*, herpes simplex virus, or cytomegalovirus and to tumors such as Kaposi's sarcoma and lymphoma should be considered. A history of atopy increases concerns for eosinophilic esophagitis, which is most prevalent in Caucasian male patients between the ages of 20 and 40 years. Medication use should identify agents associated with pill esophagitis and narcotics that are associated with opioid-induced esophageal dysmotility.

#### PHYSICAL EXAMINATION

Physical examination is important in the evaluation of oral and pharyngeal dysphagia because dysphagia is usually only one of many manifestations of a more global disease process. Signs of bulbar or pseudobulbar palsy, including dysarthria, dysphonia, ptosis, and tongue atrophy, in addition to evidence of generalized neuromuscular disease, should be elicited. The neck should be examined for thyromegaly or lymphadenopathy. A careful inspection of the mouth and pharynx should disclose inflammatory or infectious lesions. Missing dentition can interfere with mastication and exacerbate an existing cause of dysphagia. Physical examination is less helpful in the evaluation of esophageal dysphagia as most relevant

pathology is restricted to the esophagus. The notable exception is skin disease. Changes in the skin and oral mucosa may suggest a diagnosis of scleroderma or mucocutaneous diseases such as pemphigoid, lichen planus, and epidermolysis bullosa, all of which can involve the esophagus.

#### DIAGNOSTIC PROCEDURES

Although most instances of dysphagia are attributable to benign disease processes, dysphagia is also a cardinal symptom of several malignancies, making it an important symptom to evaluate. Cancer may result in dysphagia most commonly as the result of intraluminal obstruction (esophageal or proximal gastric cancer, metastatic deposits) and less commonly due to extrinsic compression (lymphoma, lung cancer) or paraneoplastic syndromes. Even when not attributable to malignancy, dysphagia is usually a manifestation of an identifiable and treatable disease entity, making its evaluation beneficial to the patient and gratifying to the practitioner. The specific diagnostic algorithm to pursue is guided by the details of the history (Fig. 44-2). If oral or pharyngeal dysphagia is suspected, a fluoroscopic swallow study, usually done by a swallow therapist, is the procedure of choice. Otolaryngoscopic and neurologic evaluation also can be important, depending on the circumstances. For suspected esophageal dysphagia, upper endoscopy is the single most useful test. Endoscopy allows better visualization of mucosal lesions than does barium radiography and also allows for procurement of mucosal biopsies. Endoscopic or histologic abnormalities are evident in the leading causes of esophageal dysphagia: Schatzki's ring, gastroesophageal reflux disease, and eosinophilic esophagitis. Furthermore, therapeutic intervention with esophageal dilation can be done as part of the procedure if it is deemed necessary. The emergence of eosinophilic esophagitis as a leading cause of dysphagia in both children and adults has led to the recommendation that esophageal mucosal biopsies be obtained routinely in the

# 45

## Nausea, Vomiting, and Indigestion

William L. Hasler



evaluation of unexplained dysphagia even if characteristic, endoscopically identified esophageal mucosal features are absent. For cases of suspected esophageal motility disorders, endoscopy is still the appropriate initial evaluation as neoplastic and inflammatory conditions can secondarily produce patterns of either achalasia or esophageal spasm. Esophageal manometry is done if dysphagia is not adequately explained by endoscopy or to confirm the diagnosis of a suspected esophageal motor disorder. Barium radiography can provide useful adjunctive information in cases of subtle or complex esophageal strictures, prior esophageal surgery, esophageal diverticula, or paraesophageal herniation. Use of a barium tablet in conjunction with fluoroscopy can identify strictures and esophageal motility disorders that may be overlooked with liquid barium. In specific cases, computed tomography (CT) examination, esophageal manometry with solid meal challenge, and endoscopic ultrasonography may be useful.

### TREATMENT

Treatment of dysphagia depends on both the locus and the specific etiology. Oropharyngeal dysphagia most commonly results from functional deficits caused by neurologic disorders. In such circumstances, the treatment focuses on utilizing postures or maneuvers devised to reduce pharyngeal residue and enhance airway protection learned under the direction of a swallow therapist. Aspiration risk may be reduced by altering the consistency of ingested food and liquid. Dysphagia resulting from a cerebrovascular accident usually, but not always, spontaneously improves within the first few weeks after the event. More severe and persistent cases may require consideration of gastrostomy and enteral feeding. Patients with myasthenia gravis (*Chap. 448*) and polymyositis (*Chap. 365*) may respond to medical treatment of the primary neuromuscular disease. Surgical intervention with cricopharyngeal myotomy is usually not helpful, with the exception of specific disorders such as symptomatic cricopharyngeal bar, Zenker's diverticulum, and oculopharyngeal muscular dystrophy. Chronic neurologic disorders such as Parkinson's disease and amyotrophic lateral sclerosis may manifest with severe oropharyngeal dysphagia. Feeding by a nasogastric tube or an endoscopically placed gastrostomy tube may be considered for nutritional support; however, these maneuvers do not provide protection against aspiration of salivary secretions or refluxed gastric contents.

Treatment of esophageal dysphagia is covered in detail in *Chap. 323*. The majority of causes of structural, esophageal dysphagia are effectively managed by means of esophageal dilation using bougie or balloon dilators. Cancer and achalasia are often managed surgically, although endoscopic techniques are available for both palliation and primary therapy, respectively. Infectious etiologies respond to antimicrobial medications or treatment of the underlying immunosuppressive state. Finally, eosinophilic esophagitis is an important and increasingly recognized cause of dysphagia that is amenable to treatment by elimination of dietary allergens, proton pump inhibition or swallowed, topically acting glucocorticoids in combination with esophageal dilation for persistent strictures.

### FURTHER READING

- H I: Esophagus: Anatomy and structural anomalies, in *Yamada Atlas of Gastroenterology*, 6th ed. New York, Wiley-Blackwell Publishing Co., 2016, pp 42–59.
- K PJ et al: The Chicago Classification of esophageal motility disorders, v3.0. *Neurogastroenterol Motil* 27:160, 2015.
- K JP, K PJ: How I approach dysphagia. *Curr Gastroenterol Rep* 21:49, 2019.
- P JP, K PJ: Esophageal neuromuscular function and motility disorders, in *Sleisenger and Fordtran's Gastrointestinal and Liver Disease*, 10th ed. Feldman M, Friedman LS, Brandt LJ (eds). Philadelphia, Elsevier, 2016, pp 701–732.
- S R et al (eds): *Principles of Deglutition: A Multidisciplinary Text for Swallowing and Its Disorders*. New York, Springer, 2013.

**Nausea** is the feeling of a need to vomit. **Vomiting** (emesis) is the oral expulsion of gastrointestinal contents resulting from gut and thoraco-abdominal wall contractions. Vomiting is contrasted with **regurgitation**, the effortless passage of gastric contents into the mouth. **Rumination** is the repeated regurgitation of food residue, which may be rechewed and reswallowed. In contrast to emesis, these phenomena exhibit voluntary control. **Indigestion** encompasses a range of complaints including nausea, vomiting, heartburn, regurgitation, and dyspepsia (symptoms thought to originate in the gastroduodenal region). Some individuals with dyspepsia experience postprandial fullness, early satiety (inability to complete a meal due to premature fullness), bloating, eructation (belching), and anorexia. Others report predominantly epigastric burning or pain. Nausea, vomiting, and dyspepsia have been correlated with a condition now called avoidant/restrictive food intake disorder.

## NAUSEA AND VOMITING

### ■ MECHANISMS

Vomiting is coordinated by the brainstem and is effected by responses in the gut, pharynx, and somatic musculature. Mechanisms underlying nausea are poorly understood but likely involve the cerebral cortex, as nausea requires cognitive and emotional input and is associated with autonomic responses including diaphoresis, pallor, and altered heart rate. Functional brain imaging studies support this idea showing activation of cerebral regions including the insula, anterior cingulate cortex, and amygdala during nausea.

**Coordination of Emesis** Brainstem nuclei—including the nucleus tractus solitarius; dorsal vagal and phrenic nuclei; medullary nuclei regulating respiration; and nuclei that control pharyngeal, facial, and tongue movements—coordinate initiation of emesis involving neurokinin NK<sub>1</sub>, serotonin 5-HT<sub>3</sub>, endocannabinoid, and vasopressin pathways.

Somatic and visceral muscles respond stereotypically during emesis. Inspiratory thoracic and abdominal wall muscles contract, increasing intrathoracic and intraabdominal pressures to evacuate the stomach. Under normal conditions, distally migrating gut contractions are coordinated by an electrical phenomenon, the slow wave, which cycles at 3 cycles/min in the stomach and 11 cycles/min in the duodenum. During emesis, slow waves are abolished and replaced by orally propagating spikes that evoke retrograde contractions to facilitate expulsion of gut contents.

**Activators of Emesis** Emetic stimuli act at several sites. Emesis evoked by unpleasant thoughts or smells originates in the brain. Motion sickness and inner ear disorders act on labyrinthine pathways. Gastric irritants and cytotoxic agents like cisplatin stimulate gastroduodenal vagal afferent nerves. Nongastric afferents are activated by bowel obstruction and mesenteric ischemia. The area postrema, in the medulla, responds to bloodborne stimuli (emetogenic drugs, bacterial toxins, uremia, hypoxia, ketoacidosis) and is termed the *chemoreceptor trigger zone*.

Neurotransmitters mediating vomiting are selective for different sites. Labyrinthine disorders stimulate vestibular muscarinic M<sub>1</sub> and histaminergic H<sub>1</sub> receptors. Vagal afferent stimuli activate 5-HT<sub>3</sub> receptors. The area postrema is served by nerves acting on 5-HT<sub>3</sub>, M<sub>1</sub>, H<sub>1</sub>, and dopamine D<sub>2</sub> subtypes. NK<sub>1</sub> receptors in the central nervous system (CNS) mediate both nausea and vomiting. Cannabinoid CB<sub>1</sub> pathways may participate in the cerebral cortex and brainstem. Therapies for vomiting act on these receptor-mediated pathways.

TABLE 45-1 Causes of Nausea and Vomiting

INTRAPERITONEAL	EXTRAPERITONEAL	MEDICATIONS/METABOLIC DISORDERS
Obstructing disorders	Cardiopulmonary disease	Drugs
Pyloric obstruction	Cardiomyopathy	Cancer chemotherapy
Small-bowel obstruction	Myocardial infarction	Analgesics
Colonic obstruction	Labyrinthine disease	Opioids
Superior mesenteric artery syndrome	Motion sickness	Antibiotics
Enteric infections	Labyrinthitis	Cardiac antiarrhythmics
Viral	Malignancy	Digoxin
Bacterial	Intracerebral disorders	Oral hypoglycemics
Inflammatory diseases	Malignancy	Oral contraceptives
Cholecystitis	Hemorrhage	Antidepressants
Pancreatitis	Abscess	Restless legs/Parkinson's therapies
Appendicitis	Hydrocephalus	Smoking cessation agents
Hepatitis	Psychiatric illness	Endocrine/metabolic disease
Altered sensorimotor function	Anorexia and bulimia nervosa	Pregnancy
Gastroparesis	Depression	Uremia
Intestinal pseudoobstruction	Postoperative vomiting	Ketoacidosis
Gastroesophageal reflux		Thyroid and parathyroid disease
Chronic nausea vomiting syndrome		Adrenal insufficiency
Cyclic vomiting syndrome		Toxins
Cannabinoid hyperemesis syndrome		Liver failure
Rumination syndrome		Ethanol
Mesenteric insufficiency		
Celiac artery stenosis		
Median arcuate ligament syndrome		
Biliary colic		
Abdominal irradiation		

## ■ DIFFERENTIAL DIAGNOSIS

Nausea and vomiting are caused by conditions within and outside the gut, drugs, and circulating toxins (Table 45-1). Unexplained chronic nausea and vomiting is reported by 2–3% of the population.

**Intraperitoneal Disorders** Obstruction and inflammation of hollow and solid viscera may elicit vomiting. Ulcers and malignancy cause gastric obstruction, while adhesions, benign or malignant tumors, volvulus, intussusception, or inflammatory diseases like Crohn's disease cause small intestinal and colonic obstruction. The superior mesenteric artery syndrome, occurring after weight loss or prolonged bed rest, results when the duodenum is compressed by the overlying superior mesenteric artery. Median arcuate ligament syndrome, with compression of the celiac artery, is a rare cause of vomiting. Abdominal irradiation impairs intestinal motility and induces strictures. Biliary colic causes nausea by acting on afferent nerves. Vomiting with pancreatitis, cholecystitis, and appendicitis results from visceral irritation and induction of ileus. Enteric infectious causes of vomiting include viruses (norovirus, rotavirus), bacteria (*Staphylococcus aureus*, *Bacillus cereus*), and opportunistic organisms like cytomegalovirus or herpes simplex in immunocompromised individuals.

Gut sensorimotor dysfunction often causes nausea and vomiting. *Gastroparesis* presents with these symptoms with evidence of delayed gastric emptying and occurs after vagotomy or with pancreatic carcinoma, mesenteric vascular insufficiency, or organic diseases like diabetes, scleroderma, and amyloidosis. Idiopathic gastroparesis is the most prevalent etiology; it occurs in the absence of systemic illness and follows a viral illness in 15–20% of cases. Rapid gastric emptying

is associated with nausea and vomiting in some conditions. *Intestinal pseudoobstruction* is characterized by disrupted intestinal motility with retention of food residue and secretions; bacterial overgrowth; nutrient malabsorption; and symptoms of nausea, vomiting, bloating, pain, and altered defecation. Intestinal pseudoobstruction may be idiopathic, inherited, result from systemic disease like scleroderma or an infiltrative process like amyloidosis, or occur as a paraneoplastic consequence of malignancy (e.g., small-cell lung carcinoma). Patients with gastroesophageal reflux, irritable bowel syndrome (IBS), or chronic constipation often report nausea and vomiting.

Other functional gastroduodenal disorders without organic abnormalities have been characterized. *Chronic nausea vomiting syndrome* is defined as bothersome nausea at least 1 day and/or one or more vomiting episodes weekly in the absence of an eating disorder or psychiatric disease. *Cyclic vomiting syndrome (CVS)* causes 3–14% of cases of unexplained nausea and vomiting and presents with discrete episodes of relentless vomiting and is associated with migraines. Some adult cases have been associated with rapid gastric emptying. A related condition, *cannabinoid hyperemesis syndrome (CHS)*, presents with cyclical vomiting in individuals (mostly men) with long-standing use of large quantities of cannabis and resolves with its discontinuation. *Rumination syndrome* is often misdiagnosed as refractory vomiting.

**Extraperitoneal Disorders** Myocardial infarction and congestive heart failure may cause nausea and vomiting. Postoperative emesis occurs after 25% of surgeries, especially abdominal and orthopedic surgery. Increased intracranial pressure from tumors, bleeding, abscess, or blockage of cerebrospinal fluid outflow produces vomiting with or without nausea. Patients with anorexia nervosa, bulimia nervosa, anxiety, and depression often report significant nausea associated with delayed gastric emptying.

**Medications and Metabolic Disorders** Drugs evoke vomiting by action on the stomach (analgesics, erythromycin) or area postrema (opioids, anti-parkinsonian drugs). Other emetogenic agents include antibiotics, cardiac antiarrhythmics, antihypertensives, oral hypoglycemics, antidepressants (selective serotonin and serotonin norepinephrine reuptake inhibitors), smoking cessation drugs (varenicline, nicotine), and contraceptives. Cancer chemotherapy causes acute (within hours of administration), delayed (after 1 or more days), or anticipatory vomiting. Acute emesis from highly emetogenic agents (e.g., cisplatin) is mediated by 5-HT<sub>3</sub> pathways. Delayed emesis is more dependent on NK<sub>1</sub> mechanisms. Anticipatory nausea may respond to anxiolytic therapy rather than antiemetics.

Metabolic disorders elicit nausea and vomiting. Nausea affects 70% of women in the first trimester of pregnancy. Hyperemesis gravidarum is a severe form of nausea of pregnancy that produces dehydration and electrolyte disturbances and has been proposed to result from excessive amounts of a blood protein—growth differentiation factor 15. Uremia, ketoacidosis, adrenal insufficiency, and parathyroid and thyroid disease are other metabolic etiologies.

Circulating toxins evoke emesis via effects on the area postrema. Endogenous toxins are generated in fulminant liver failure, whereas exogenous enterotoxins may be produced by enteric bacterial infection. Ethanol intoxication is a common toxic etiology of nausea and vomiting.

## APPROACH TO THE PATIENT

### Nausea and Vomiting

#### HISTORY AND PHYSICAL EXAMINATION

The history helps define the etiology of nausea and vomiting. Drugs, toxins, and infections often cause acute symptoms, whereas established illnesses evoke chronic complaints. Gastroparesis and pyloric obstruction elicit vomiting within an hour of eating. Emesis from intestinal blockage occurs later. Vomiting occurring minutes after meal consumption prompts consideration of rumination syndrome. With severe gastric emptying delays, vomitus may contain food residue ingested days before. Hematemesis raises suspicion

of ulcer, malignancy, or Mallory-Weiss tear. Feculent emesis is noted with distal intestinal or colonic obstruction. Bilious vomiting excludes gastric obstruction, whereas emesis of undigested food is consistent with a Zenker's diverticulum or achalasia. Vomiting can relieve abdominal pain from a bowel obstruction but has no effect in pancreatitis or cholecystitis. Weight loss raises concern about malignancy. Taking prolonged hot baths or showers is associated with CHS and CVS. Intracranial sources are considered if there are headaches or visual changes. Vertigo or tinnitus indicates labyrinthine disease.

The physical examination complements the history. Orthostatic hypotension and reduced skin turgor indicate intravascular fluid loss. Pulmonary abnormalities raise concern for aspiration of vomitus. Bowel sounds are absent with ileus. High-pitched rushes suggest bowel obstruction, whereas a succussion splash is found with gastroparesis or pyloric obstruction. Involuntary guarding raises suspicion of inflammation. Fecal blood suggests ulcer, ischemia, or tumor. Neurologic disease presents with papilledema, visual loss, or focal neural abnormalities. Neoplasm is suggested by palpable masses or adenopathy.

#### DIAGNOSTIC TESTING

For intractable symptoms or an elusive diagnosis, screening testing can direct care. Electrolyte replacement is indicated for hypokalemia or metabolic alkalosis. Iron-deficiency anemia mandates exclusion of mucosal causes. Abnormal pancreatic or liver biochemistries are found with pancreaticobiliary disease. Endocrinologic, rheumatologic, or paraneoplastic etiologies are suggested by hormone or serologic abnormalities. Supine and upright abdominal radiographs may show intestinal air-fluid levels and reduced colonic air with small-bowel obstruction. Ileus is characterized by diffusely dilated air-filled bowel loops.

Anatomic studies are indicated if initial testing is nondiagnostic. Upper endoscopy detects ulcers, malignancy, and retained food in gastroparesis. Small-bowel barium radiography or computed tomography (CT) diagnoses partial bowel obstruction. Colonoscopy or contrast enema radiography detects colonic obstruction. Ultrasound or CT defines intraperitoneal inflammation; CT and magnetic resonance imaging (MRI) enterography define inflammation in Crohn's disease. Brain CT or MRI delineates intracranial disease. Mesenteric angiography, CT, or MRI is useful for suspected ischemia.

Gastrointestinal motility testing can detect an underlying motor disorder. Gastroparesis commonly is diagnosed by gastric scintigraphy, which measures emptying of a radiolabeled meal. A nonradioactive <sup>13</sup>C-labeled gastric emptying breath test is an alternative to scintigraphy. Intestinal pseudoobstruction is suggested by luminal dilation on imaging or abnormal transit on contrast radiography or intestinal scintigraphy. Wireless motility capsules diagnose gastroparesis or small-bowel dysmotility by detecting local or generalized transit delays in the stomach or small bowel from characteristic pH changes between regions. Small-intestinal manometry confirms a diagnosis of pseudoobstruction and discriminates between neuropathic or myopathic disease based on contractile patterns. Manometry can obviate the need for surgical intestinal biopsy to detect smooth muscle or neuronal degeneration. Combined ambulatory esophageal pH/impedance testing and high-resolution manometry facilitates diagnosis of rumination syndrome. Impedance planimetry detects reduced pyloric distensibility in some cases of gastroparesis.

## TREATMENT

### Nausea and Vomiting

#### GENERAL PRINCIPLES

Therapy of vomiting is tailored to correct remediable abnormalities if possible. Patients with severe dehydration should be hospitalized if oral fluid replenishment is unsustainable. Once oral intake is

tolerated, low-fat liquid nutrients are restarted because lipids delay gastric emptying. Low-residue, small-particle diets have shown efficacy in gastroparesis. Glycemic control should be optimized to reduce diabetic gastroparesis symptoms.

#### ANTIEMETIC MEDICATIONS

Most antiemetic agents act on CNS sites (Table 45-2). Antihistamines like dimenhydrinate and meclizine and anticholinergics like scopolamine act on vestibular pathways to treat motion sickness and labyrinthine disorders. D<sub>2</sub> antagonists treat emesis evoked by area postrema stimuli including medications, toxins, and metabolic disturbances. Dopamine antagonists cross the blood-brain barrier and cause anxiety, movement disorders, and hyperprolactinemic effects (galactorrhea, sexual dysfunction).

Other classes exhibit antiemetic properties. 5-HT<sub>3</sub> antagonists like ondansetron and granisetron prevent postoperative vomiting, radiation therapy-induced symptoms, and cancer chemotherapy-induced emesis, but also are used for other conditions. NK<sub>1</sub> antagonists like aprepitant are approved for chemotherapy-induced vomiting. Aprepitant reduces gastroparesis symptoms. Tricyclic antidepressants reduce symptoms in some patients with functional causes of vomiting, but did not show benefits in a controlled trial in gastroparesis. Other antidepressants such as mirtazapine and olanzapine and the pain-modulating agent gabapentin also exhibit antiemetic effects in some clinical settings.

#### GASTROINTESTINAL MOTOR STIMULANTS

Drugs that stimulate gastric emptying are used for gastroparesis (Table 45-2). Metoclopramide, a combined 5-HT<sub>4</sub> agonist and D<sub>2</sub> antagonist, is effective in gastroparesis, but antidopaminergic side effects, including dystonias and mood disturbances, limit use in 25% of cases. Erythromycin increases gastroduodenal motility by action on receptors for motilin, an endogenous transmitter that regulates fasting motility. Intravenous erythromycin is useful for inpatients with refractory gastroparesis. Benefits of long-term oral erythromycin are limited by development of tolerance. Domperidone, a D<sub>2</sub> antagonist not available in the United States, exhibits prokinetic and antiemetic effects but does not cross into most brain regions. The drug rarely causes dystonic reactions but can induce hyperprolactinemic side effects via penetration of pituitary regions served by a porous blood-brain barrier. Prucalopride, a 5-HT<sub>4</sub> agonist, has shown efficacy in accelerating gastric emptying and improving symptoms in idiopathic gastroparesis.

Refractory motility disorders pose challenges. Intestinal pseudoobstruction may respond to the somatostatin analogue octreotide, which induces propagative small-intestinal motor complexes. Acetylcholinesterase inhibitors like pyridostigmine benefit some patients with small-bowel dysmotility. Pyloric botulinum toxin injections reduced gastroparesis symptoms in uncontrolled studies, but small controlled trials observed benefits no greater than sham treatments. Surgical pyloroplasty and gastric peroral endoscopic myotomy (G-POEM) of the pylorus improved symptoms in case series. Enteral feedings through a jejunostomy reduce hospitalizations and improve overall health in some patients with refractory gastroparesis. Subtotal gastric resection may improve some cases of postvagotomy gastroparesis, but its utility for other gastroparesis etiologies is unproven. Implanted gastric electrical stimulators may reduce symptoms, enhance nutrition, improve quality of life, and decrease health care expenditures in medication-refractory gastroparesis; a controlled trial has confirmed modest improvement in vomiting.

#### SAFETY CONSIDERATIONS

Safety concerns have been raised about selected antiemetics. Metoclopramide can cause irreversible movement disorders like tardive dyskinesia, particularly in older patients. This complication should be explained and documented in the medical record. Domperidone, erythromycin, tricyclic antidepressants, and 5-HT<sub>3</sub> antagonists increase risk of cardiac arrhythmias and sudden cardiac death in

TABLE 45-2 Treatment of Nausea and Vomiting

TREATMENT	MECHANISM	EXAMPLES	CLINICAL INDICATIONS
Antiemetic agents	Antihistaminergic	Dimenhydrinate, meclizine	Motion sickness, inner ear disease
	Anticholinergic	Scopolamine	Motion sickness, inner ear disease
	Antidopaminergic	Prochlorperazine, thiethylperazine, haloperidol	Medication-, toxin-, or metabolic-induced emesis, chemotherapy-induced nausea and vomiting, ?cannabinoid hyperemesis syndrome
	5-HT <sub>3</sub> antagonist	Ondansetron, granisetron	Chemotherapy- and radiation-induced emesis, postoperative emesis, opioid-induced nausea and vomiting
	Cannabinoids	Tetrahydrocannabinol	Chemotherapy-induced emesis
	Tricyclic antidepressant	Amitriptyline, nortriptyline	Functional vomiting, chronic idiopathic nausea, cyclic vomiting syndrome, ?gastroparesis
	Other antidepressant	Mirtazapine, olanzapine	Functional dyspepsia, ?gastroparesis
	Neuropathic modulator	Gabapentin	Chemotherapy-induced nausea and vomiting
	Neurokinin (NK1) receptor antagonists	Aprepitant, fosaprepitant, netupitant, rolapitant	Chemotherapy-induced emesis
Prokinetic agents	5-HT <sub>4</sub> agonist and antidopaminergic	Metoclopramide	Gastroparesis
	Motilin agonist	Erythromycin	Gastroparesis, ?intestinal pseudoobstruction
	Peripheral antidopaminergic	Domperidone	Gastroparesis
	Pure 5-HT <sub>4</sub> agonist	Prucalopride	?Idiopathic gastroparesis
	Somatostatin analogue	Octreotide	Intestinal pseudoobstruction
	Acetylcholinesterase inhibitor	Pyridostigmine	?Small-intestinal dysmotility/pseudoobstruction
Special settings	Benzodiazepines	Lorazepam	Anticipatory nausea and vomiting with chemotherapy, cyclic vomiting syndrome
	5-HT <sub>1A</sub> agonist	Buspirone	Functional dyspepsia
	Glucocorticoids	Methylprednisolone, dexamethasone	Chemotherapy-induced emesis
	Anticonvulsants	Topiramate, zonisamide, levetiracetam	Cyclic vomiting syndrome
	Antimigraine agents	Sumatriptan	Cyclic vomiting syndrome
	Topical analgesic	Capsaicin cream	?Cannabinoid hyperemesis syndrome
	Atypical antipsychotic agent	Olanzapine	Chemotherapy-induced and breakthrough emesis

Note: ?, indication is uncertain.

those with QTc interval prolongation on electrocardiography (ECG). Surveillance ECG testing is advocated for some of these agents.

#### OTHER CLINICAL SETTINGS

Some cancer chemotherapies are intensely emetogenic (Chap. 73). Combining a 5-HT<sub>3</sub> antagonist, an NK<sub>1</sub> antagonist, and a glucocorticoid can control both acute and delayed vomiting after highly emetogenic chemotherapy. Benzodiazepines like lorazepam reduce anticipatory nausea and vomiting. Other therapies with benefit in chemotherapy-induced emesis include cannabinoids, olanzapine, gabapentin, and alternative therapies like ginger. Most antiemetic regimens produce greater reductions in chemotherapy-induced vomiting than nausea.

Clinicians should exercise caution in managing nausea of pregnancy. Studies of the teratogenic effects of antiemetic agents provide conflicting results. Antihistamines like meclizine and doxylamine, antidopaminergics like prochlorperazine, and antiserotonergics like ondansetron demonstrate limited efficacy. Some obstetricians recommend alternative therapies including pyridoxine, acupressure, or ginger.

Managing CVS and CHS is challenging. Prophylaxis with tricyclic antidepressants or anticonvulsants (topiramate, zonisamide, levetiracetam) reduces the severity and frequency of CVS attacks in uncontrolled reports. Combining intravenous 5-HT<sub>3</sub> antagonists with the sedating effects of a benzodiazepine like lorazepam are mainstays for aborting acute flares. Small studies report benefits with aprepitant and injectable or intranasal forms of the 5-HT<sub>1</sub> agonist sumatriptan to manage acute CVS episodes. These treatments are reportedly less effective for CHS, but haloperidol and topical capsaicin cream may reduce acute CHS attacks.

## INDIGESTION

### MECHANISMS

Several mechanisms may contribute to indigestion, including acid reflux, altered gut motility or sensation, inflammation, and microbial processes.

**Gastroesophageal Reflux** Gastroesophageal reflux results from many defects. Reduced lower esophageal sphincter (LES) tone causes reflux in scleroderma and pregnancy and may be a factor in some patients without systemic illness. Other cases exhibit frequent transient LES relaxations (TLESRs). Reductions in esophageal body motility or saliva production prolong esophageal fluid clearance. Increased intragastric pressure promotes gastroesophageal reflux with obesity. Many reflux patients have hiatal hernias, and large hernias can increase symptomatic reflux.

**Gastric Motor Dysfunction** Disturbed gastric motility may contribute to gastroesophageal reflux in up to one-third of cases. Delayed gastric emptying is found in 30% of functional dyspeptics, while rapid gastric emptying affects 5%. Impaired gastric fundus relaxation after eating (i.e., accommodation) may underlie selected dyspeptic symptoms like bloating, nausea, and early satiety in 40% of patients and may predispose to TLESRs and acid reflux.

**Visceral Afferent Hypersensitivity** Disturbed gastric sensation is another pathogenic factor in functional dyspepsia. Approximately 35% of dyspeptic patients note discomfort with fundic distention to lower pressures than in healthy controls. Other individuals with dyspepsia exhibit hypersensitivity to chemical stimulation of the stomach with capsaicin or with duodenal acid or lipid perfusion. Some cases of functional heartburn without increased acid or nonacid reflux exhibit heightened perception of normal esophageal acidity.

**Immune Activation** Increases in duodenal epithelial permeability in functional dyspepsia may relate to increases in eosinophils and mast cells adjacent to submucosal neurons. Increased activation of these cells is proposed to contribute to gastric emptying delays and altered sensory function in functional dyspepsia and may selectively elicit early satiety and epigastric pain. Proliferations in duodenal bacteria were shown to correlate with meal-induced symptoms in functional dyspepsia, suggesting a role for microbiome alterations. Intestinal bile salt release also is proposed to worsen dyspeptic symptoms after

eating. Both dysbiosis and bile may contribute to mucosal permeability defects.

**Other Factors** *Helicobacter pylori* has a proven etiologic role in peptic ulcer disease but is a minor factor in the genesis of functional dyspepsia. Anxiety and depression may play contributing roles in some functional dyspepsia cases. Functional MRI studies show increased activation of several brain regions, emphasizing CNS contributions. Up to 20% of functional dyspepsia patients report symptom onset after a viral illness, suggesting an infectious trigger. Analgesics cause dyspepsia, whereas nitrates, calcium channel blockers, theophylline, and progesterone promote gastroesophageal reflux. Ethanol, tobacco, and caffeine induce LES relaxation and reflux. Genetic factors predispose to development of reflux and dyspepsia in some cases.

## ■ DIFFERENTIAL DIAGNOSIS

**Gastroesophageal Reflux Disease** Heartburn or regurgitation is reported weekly by 18–28% of the population, highlighting the prevalence of gastroesophageal reflux disease (GERD). Most cases of heartburn result from excess acid reflux, but reflux of weakly acidic or nonacidic fluid can produce similar symptoms. Alkaline reflux esophagitis elicits GERD symptoms in patients who have had surgery for peptic ulcer disease. Ten percent of patients with heartburn exhibit no acidic or nonacidic esophageal reflux and are considered to have functional heartburn.

**Functional Dyspepsia** Approximately 20% of the populace has dyspepsia at least six times yearly, but only 10–20% present to clinicians. Functional dyspepsia, the cause of symptoms in 70–80% of dyspeptic patients, is defined as bothersome postprandial fullness, early satiety, or epigastric pain or burning with symptom onset  $\leq$  6 months before diagnosis in the absence of organic cause. Functional dyspepsia is subdivided into postprandial distress syndrome (61% of cases), characterized by meal-induced fullness and early satiety, and epigastric pain syndrome (18% of cases), with epigastric pain or burning that may or may not be meal related. Twenty-one percent of individuals present with overlapping postprandial distress and epigastric pain syndromes. Functional dyspepsia is associated with other functional gut disorders including irritable bowel syndrome and nongastrointestinal disorders like fibromyalgia, chronic fatigue, and anxiety. Most cases follow a benign course, but some with *H. pylori* infection or on nonsteroidal anti-inflammatory drugs (NSAIDs) develop ulcers.

**Ulcer Disease** Most GERD patients do not exhibit esophageal injury, but 5% develop esophageal ulcers. Symptoms cannot distinguish nonerosive from erosive or ulcerative esophagitis. A minority of cases of dyspepsia stem from gastric or duodenal ulcers. The most common causes of ulcers are *H. pylori* infection and NSAID use. Other rare causes of gastroduodenal ulcers include Crohn's disease (Chap. 326) and Zollinger-Ellison syndrome (Chap. 324), resulting from gastrin overproduction by an endocrine tumor.

**Malignancy** Dyspeptic patients may seek care because of fear of cancer, but few cases result from malignancy. Esophageal squamous cell carcinoma occurs most often with long-standing tobacco or ethanol intake. Other risks include prior caustic ingestion, achalasia, and the hereditary disorder tylosis. Esophageal adenocarcinoma usually complicates prolonged acid reflux. Eight to 20% of GERD patients exhibit esophageal intestinal metaplasia, termed *Barrett's metaplasia*, which predisposes to esophageal adenocarcinoma (Chap. 80). Gastric malignancies include adenocarcinoma, which is prevalent in certain Asian societies, and lymphoma.

**Other Causes** Opportunistic fungal or viral esophageal infections may produce heartburn but more often cause odynophagia. Other causes of esophageal inflammation include eosinophilic esophagitis and pill esophagitis. Biliary colic is a potential cause unexplained upper abdominal pain, but most patients report discrete acute episodes of right upper quadrant or epigastric pain rather than chronic burning or fullness. Twenty percent of gastroparesis patients note a predominance

of pain rather than nausea and vomiting. Intestinal lactase deficiency may cause gas, bloating, and discomfort and occurs more commonly in blacks and Asians. Intolerance of other carbohydrates (e.g., fructose, sorbitol) produces similar symptoms. Small-intestinal bacterial overgrowth may cause dyspepsia, as well as bowel dysfunction, distension, and malabsorption. Celiac disease, nonceliac gluten sensitivity, pancreatic disease (chronic pancreatitis, malignancy), hepatocellular carcinoma, Ménétrier's disease, infiltrative diseases (sarcoidosis, mastocytosis, eosinophilic gastroenteritis), mesenteric ischemia, thyroid and parathyroid disease, and abdominal wall strain cause dyspepsia. Extraperitoneal etiologies of indigestion include congestive heart failure and tuberculosis.

## APPROACH TO THE PATIENT

### Indigestion

#### HISTORY AND PHYSICAL EXAMINATION

Managing indigestion requires a thorough interview. GERD classically produces heartburn, a substernal warmth that moves toward the neck. Heartburn often is exacerbated by meals and may awaken the patient. Associated symptoms include regurgitation of acid or nonacidic fluid and water brash, the reflex release of salty saliva into the mouth. Atypical symptoms include pharyngitis, asthma, cough, bronchitis, hoarseness, and chest pain that mimics angina. Some patients with acid reflux on esophageal pH testing note abdominal pain instead of heartburn.

Dyspeptic patients report symptoms referable to the upper abdomen that may be meal-related (postprandial distress syndrome) or independent of food ingestion (epigastric pain syndrome). The history in functional dyspepsia may also report symptoms of GERD, IBS, or idiopathic gastroparesis.

The physical exam with GERD and functional dyspepsia usually is normal. In atypical GERD, pharyngeal erythema and wheezing may be noted. Recurrent regurgitation may cause poor dentition. Dyspeptics may exhibit epigastric tenderness or distention.

Discriminating functional from organic causes of indigestion mandates excluding certain historic and exam features. Odynophagia suggests esophageal infection. Dysphagia is concerning for a benign or malignant esophageal blockage. Other alarm features include unexplained weight loss, recurrent vomiting, dysphagia, occult or gross bleeding, nocturnal symptoms, jaundice, palpable mass or adenopathy, and a family history of gastrointestinal neoplasm. Patients with an abdominal wall source of upper abdominal pain may exhibit a positive Carnett's sign of increased tenderness with tensing of abdominal muscles upon lifting the head from the exam table.

#### DIAGNOSTIC TESTING

Because indigestion is prevalent and most cases result from GERD or functional dyspepsia, it is generally recommended to perform no more than limited and directed diagnostic testing in most individuals.

After excluding alarm factors (Table 45-3), patients with typical GERD do not need further evaluation and are treated empirically. Upper endoscopy is indicated only in cases with atypical symptoms or these alarm factors. For heartburn  $>5$  years in duration,

TABLE 45-3 Alarm Symptoms in Gastroesophageal Reflux Disease

Odynophagia or dysphagia
Unexplained weight loss
Recurrent vomiting
Occult or gross gastrointestinal bleeding
Jaundice
Palpable mass or adenopathy
Family history of gastroesophageal malignancy

especially in patients >50 years old, endoscopy is advocated to screen for Barrett's metaplasia. Endoscopy is not needed in low-risk patients who respond to acid suppressants. Ambulatory esophageal pH testing using a catheter method or a wireless capsule endoscopically attached to the esophageal wall is considered for drug-refractory symptoms and atypical symptoms like unexplained chest pain. High-resolution esophageal manometry is ordered when surgical treatment of GERD is considered. A low LES pressure predicts failure of drug therapy and provides a rationale to proceed to surgery. Poor esophageal body peristalsis raises concern about postoperative dysphagia and directs the choice of surgical technique. Nonacidic reflux may be detected by combined esophageal impedance-pH testing in medication-unresponsive patients.

Upper endoscopy is recommended as the initial test in patients with unexplained dyspepsia who are >60 years old to exclude malignancy—a finding in only 0.3% of endoscopies performed for uninvestigated dyspepsia. Management of patients <60 years old depends on the local *H. pylori* prevalence. In regions with low prevalence (<10%), a 4-week trial of an acid-suppressing medication such as a proton pump inhibitor (PPI) is recommended. If empiric acid suppression fails, a “test and treat” approach for *H. pylori* status is initiated with urea breath testing or stool antigen measurement. Those who are *H. pylori* positive are given therapy to eradicate infection. For patients in areas with high *H. pylori* prevalence (>10%), an initial “test and treat” approach is advocated, and empiric PPI therapy is reserved for those who are negative for infection or who fail to respond to *H. pylori* treatment. Patients who are treated for *H. pylori* should undergo confirmation of eradication with repeat urea breath testing or fecal antigen testing 4–6 weeks after completing therapy. Those under age 60 only warrant upper endoscopy if their symptoms fail to respond to these therapies. Some advocate initial endoscopy for patients <60 years old who report alarm symptoms, but some guidelines have not endorsed this practice unless symptoms persist despite treatment.

Further testing is indicated in some settings. For suspected bleeding, a blood count can exclude anemia. Thyroid chemistries or calcium levels screen for metabolic disease. Specific serologies may suggest celiac disease. Pancreatic and liver chemistries are obtained for suspected pancreaticobiliary causes, which are further investigated with ultrasound, CT, or MRI. Gastric emptying testing is considered to exclude gastroparesis for dyspeptic symptoms resembling postprandial distress when therapy fails. Breath testing after carbohydrate ingestion detects lactase deficiency, intolerance to other carbohydrates, or small-intestinal bacterial overgrowth.

## TREATMENT

### Indigestion

#### LIFESTYLE, DIET, AND NONMEDICATION RECOMMENDATIONS

Patients with mild indigestion can be reassured that a careful evaluation revealed no serious disease and are offered no other intervention. If possible, drugs that cause gastroesophageal reflux or dyspepsia should be stopped. GERD patients should limit ethanol, caffeine, chocolate, and tobacco use and can ingest a low-fat diet, avoid snacks before bedtime, and elevate the head of the bed. Functional dyspepsia patients can be advised to reduce intake of fat, spicy foods, caffeine, and alcohol. Dietary lactose restriction is appropriate for lactase deficiency, while gluten exclusion is indicated for celiac disease. Low FODMAP (fermentable oligosaccharide, disaccharide, monosaccharide, and polyol) diets are effective for gaseous symptoms in IBS. In a systematic review, FODMAP intake correlated with functional dyspepsia symptoms, suggesting potential utility in this disorder as well.

## ACID-SUPPRESSING OR -NEUTRALIZING MEDICATIONS

Drugs that reduce or neutralize gastric acid are often prescribed for GERD. Histamine H<sub>2</sub> antagonists like cimetidine, ranitidine, famotidine, and nizatidine are useful in mild to moderate GERD. For severe symptoms or for many cases of erosive or ulcerative esophagitis, PPIs like omeprazole, lansoprazole, rabeprazole, pantoprazole, esomeprazole, or dexlansoprazole are needed. These drugs inhibit gastric H<sup>+</sup>, K<sup>+</sup>-ATPase and are more potent than H<sub>2</sub> antagonists. Up to one-third of GERD patients do not respond to standard PPI doses; one-third of these patients have nonacidic reflux, whereas 10% have persistent acid-related disease. Heartburn responds better to PPI therapy than regurgitation or atypical GERD symptoms. Some individuals respond to doubling of the PPI dose or adding an H<sub>2</sub> antagonist. Complications of long-term PPI therapy include diarrhea (*Clostridium difficile* infection, microscopic colitis), small-intestinal bacterial overgrowth, nutrient deficiency (vitamin B<sub>12</sub>, iron, calcium), hypomagnesemia, bone demineralization, interstitial nephritis, and impaired medication absorption (clopidogrel). Many patients started on a PPI can be stepped down to an H<sub>2</sub> antagonist or switched to on-demand use.

Acid suppressants also are effective for both the postprandial distress and epigastric pain subtypes of functional dyspepsia. A meta-analysis of 18 controlled trials calculated a risk ratio of 0.88, with a 95% confidence interval of 0.82–0.94, favoring PPI therapy over placebo in functional dyspepsia. H<sub>2</sub> antagonists also improve symptoms in functional dyspepsia, but a guideline has advocated PPIs over H<sub>2</sub> antagonists as first-line therapies for functional dyspepsia. In addition to acid suppression, PPIs may have the additional action of reducing duodenal eosinophil counts in dyspepsia.

Antacids are useful for short-term control of mild GERD but have less benefit in severe cases unless given at high doses that cause side effects (diarrhea and constipation with magnesium- and aluminum-containing agents, respectively). Alginic acid combined with antacids forms a floating barrier to reflux in patients with upright symptoms. Sucralfate, a salt of aluminum hydroxide and sucrose octasulfate that buffers acid and binds pepsin and bile salts, shows efficacy in GERD similar to H<sub>2</sub> antagonists.

#### *HELICOBACTER PYLORI* ERADICATION

*H. pylori* eradication is indicated for peptic ulcer and mucosa-associated lymphoid tissue gastric lymphoma. The benefits of eradication therapy in functional dyspepsia are limited but are statistically significant. A systematic review of 25 controlled trials calculated a pooled risk ratio of 1.24, with a 95% confidence interval of 1.12–1.37, favoring *H. pylori* eradication over placebo. Most drug combinations (Chaps. 163 and 324) include 7–14 days of a PPI with two or three antibiotics with or without bismuth products. *H. pylori* infection is associated with reduced prevalence of GERD. However, eradication of infection does not worsen GERD symptoms. No consensus recommendations regarding *H. pylori* eradication in GERD patients have been offered.

#### AGENTS THAT MODIFY GASTROINTESTINAL MOTOR ACTIVITY

The γ-aminobutyric acid B (GABA-B) agonist baclofen reduces esophageal exposure to acid and nonacidic fluids by reducing TLESRs by 40%. This drug can be used in patients with refractory acid or nonacid reflux. Several studies have promoted the efficacy of agents that stimulate gastric emptying in functional dyspepsia with 33% relative risk reductions, but publication bias and small sample sizes raise questions about reported benefits of these agents. Some clinicians suggest that patients with the postprandial distress subtype may respond preferentially to such prokinetic drugs. The newer 5-HT<sub>4</sub> agonist prucalopride was reported to reduce symptoms in patients with idiopathic gastroparesis, but no similar studies have been conducted in functional dyspepsia. The 5-HT<sub>1A</sub> agonists buspirone and tандospirone may improve

# 46

## Diarrhea and Constipation



Michael Camilleri, Joseph A. Murray

some functional dyspepsia symptoms by enhancing meal-induced gastric accommodation. Acotiamide stimulates gastric emptying and augments accommodation by enhancing acetylcholine release via muscarinic receptor antagonism and acetylcholinesterase inhibition. This agent is approved for functional dyspepsia in Japan and India.

### ANTIDEPRESSANTS

Some patients with refractory functional heartburn may respond to antidepressants in the tricyclic and selective serotonin reuptake inhibitor (SSRI) classes, although studies are limited. Their mechanism of action may involve blunting of visceral pain processing in the brain. In a controlled trial in functional dyspepsia, the tricyclic drug amitriptyline produced symptom reductions, whereas the SSRI escitalopram had no benefit in a three-way comparison with placebo. In another controlled trial in functional dyspepsia, the antidepressant mirtazapine produced superior symptom reductions versus placebo. However, in a meta-analysis of 13 trials, SSRIs and serotonin-norepinephrine reuptake inhibitors showed no benefits in functional dyspepsia.

### OTHER OPTIONS

Antireflux surgery (fundoplication) to enhance the barrier function of the LES may be offered to GERD patients who are young and require lifelong therapy, have typical heartburn, are responsive to PPIs, and show acid reflux on pH monitoring. Surgery also is effective for some cases of nonacidic reflux. Individuals who respond less well to fundoplication include those with atypical symptoms, those who have functional heartburn without reflux on testing, or those who have esophageal body motor disturbances. Dysphagia, gas-bloat syndrome, and gastroparesis are long-term complications of fundoplication; 60% develop recurrent GERD symptoms over time. Magnetic sphincter augmentation may be appropriate for GERD treatment, while endoscopic radiofrequency therapies can be considered for some patients. Other endoscopic options including transoral incisionless fundoplication, endoscopic stapling, and antireflux mucosectomy are not yet advocated.

Gas and bloating are bothersome in some patients with indigestion and are difficult to treat. Simethicone, activated charcoal, and alpha-galactosidase provide benefits in some cases. One trial suggested possible benefits of the nonabsorbable antibiotic rifaximin in functional dyspepsia, while another reported improvement with the probiotic *Lactobacillus gasseri*. Herbal remedies like STW 5 (Iberogast, a mixture of nine herbal agents) and formulations of caraway oil and menthol are useful in some dyspeptic patients. Psychological treatments (e.g., behavioral therapy, psychotherapy, hypnotherapy) may be offered for refractory functional dyspepsia; a meta-analysis of four trials reported benefits in patients with persistent dyspepsia.

### FURTHER READING

- G CP et al: ACG Clinical Guidelines: clinical use of esophageal physiologic testing. Am J Gastroenterol 115:1412, 2020.
- M -O J et al: Gastroesophageal reflux disease: a review. JAMA 324:2536, 2020.
- S RN et al: Management of cyclic vomiting syndrome in adults: evidence review. Neurogastroenterol Motil 31(Suppl 2):e13605, 2019.
- V T et al: Role of chronic cannabis use: cyclic vomiting syndrome vs. cannabinoid hyperemesis syndrome. Neurogastroenterol Motil 31(Suppl 2):e13606, 2019.
- W L et al: Novel concepts in the pathophysiology and treatment of functional dyspepsia. Gut 69:591, 2020.

Diarrhea and constipation are exceedingly common and, together, exact an enormous toll in terms of mortality, morbidity, social inconvenience, loss of work productivity, and consumption of medical resources. Worldwide, >1 billion individuals suffer one or more episodes of acute diarrhea each year. Among the 100 million persons affected annually by acute diarrhea in the United States, nearly half must restrict activities, 10% consult physicians, ~250,000 require hospitalization, and ~5000 die (primarily the elderly). Updated 2014–2015 annual disease burden data from the United States show 3.4 million annual clinic or emergency department visits, about 130,000 hospital admissions, and annual economic burden to society (excluding all costs for inflammatory bowel disease) exceeding \$8 billion. Acute infectious diarrhea remains one of the most common causes of mortality in developing countries, particularly among impoverished infants, accounting for 1.8 million deaths per year. Recurrent, acute diarrhea in children in tropical countries results in environmental enteropathy with long-term impacts on physical and intellectual development.

Constipation, by contrast, is rarely associated with mortality and is exceedingly common in developed countries, leading to frequent self-medication and, in a third of those, to medical consultation. Annual disease burden data for 2014–2015 show about 5 million clinic or emergency department visits for constipation or hemorrhoids, 50,000 admissions to hospital, and average cost of \$3500 per patient, about double that of controls in a nested controlled study.

Population statistics on chronic diarrhea and constipation are more uncertain, perhaps due to variable definitions and reporting, but the frequency of these conditions is also high. U.S. population surveys put prevalence rates for chronic diarrhea at 2–7% and for chronic constipation at 12–19%, with women being affected twice as often as men, reaching parity at 70 years of age. Diarrhea and constipation are among the most common patient complaints presenting in primary care and account for nearly 50% of referrals to gastroenterologists.

Although diarrhea and constipation may present as mere nuisance symptoms at one extreme, they can be severe or life threatening at the other. Even mild symptoms may signal a serious underlying gastrointestinal (GI) lesion, such as colorectal cancer, or systemic disorder, such as thyroid disease. Given the heterogeneous causes and potential severity of these common complaints, it is imperative for clinicians to appreciate the pathophysiology, etiologic classification, diagnostic strategies, and principles of management of diarrhea and constipation so that rational and cost-effective care can be delivered.

### NORMAL PHYSIOLOGY

While the primary function of the small intestine is the digestion and assimilation of nutrients from food, the small intestine and colon together perform important functions that regulate the secretion and absorption of water and electrolytes, the storage and subsequent transport of intraluminal contents aborally, and the salvage of some nutrients that are not absorbed in the small intestine after bacterial metabolism of carbohydrate allows salvage of short-chain fatty acids. The main motor functions are summarized in Table 46-1. Alterations in fluid and electrolyte handling contribute significantly to diarrhea. Alterations in motor and sensory functions of the colon result in highly prevalent syndromes such as irritable bowel syndrome (IBS), chronic diarrhea, and chronic constipation.

### NEURAL CONTROL

The small intestine and colon have intrinsic and extrinsic innervation. The *intrinsic innervation*, also called the enteric nervous system, comprises myenteric, submucosal, and mucosal neuronal layers. The function of these layers is modulated by interneurons through the actions

TABLE 46-1 Normal Gastrointestinal Motility: Functions at Different Anatomic Levels

## Stomach and Small Bowel

Synchronized MMC in fasting

Accommodation, trituration, mixing, transit

Stomach ~3 h

Small bowel ~3 h

Ileal reservoir empties boluses

## Colon: Irregular Mixing, Fermentation, Absorption, Transit

Ascending, transverse: reservoirs

Descending: conduit

Sigmoid/rectum: volitional reservoir

Abbreviation: MMC, migrating motor complex.

of neurotransmitter amines or peptides, including acetylcholine, vasoactive intestinal peptide (VIP), opioids, norepinephrine, serotonin, adenosine triphosphate (ATP), and nitric oxide (NO). The myenteric plexus regulates smooth-muscle function through intermediary pacemaker-like cells called the interstitial cells of Cajal, and the submucosal plexus affects secretion, absorption, and mucosal blood flow. The enteric nervous system receives input from the extrinsic nerves, but it is capable of independent control of these functions.

The *extrinsic innervations* of the small intestine and colon are part of the autonomic nervous system and also modulate motor and secretory functions. The parasympathetic nerves convey visceral sensory pathways from and excitatory pathways to the small intestine and colon. Parasympathetic fibers via the vagus nerve reach the small intestine and proximal colon along the branches of the superior mesenteric artery. The distal colon is supplied by sacral parasympathetic nerves ( $S_{2-4}$ ) via the pelvic plexus; these fibers course through the wall of the colon as ascending intracolonic fibers as far as, and in some instances including, the proximal colon. The chief excitatory

neurotransmitters controlling motor function are acetylcholine and the tachykinins, such as substance P. The sympathetic nerve supply modulates motor functions and reaches the small intestine and colon alongside their arterial vessels. Sympathetic input to the gut is generally excitatory to sphincters and inhibitory to nonsphincteric muscle. Visceral afferents convey sensation from the gut to the central nervous system (CNS). Some afferent fibers synapse in the prevertebral ganglia and reflexly modulate intestinal motility, blood flow, and secretion.

## ■ INTESTINAL FLUID ABSORPTION AND SECRETION

On an average day, 9 L of fluid enter the GI tract, ~1 L of residual fluid reaches the colon, and the stool excretion of fluid constitutes about 0.2 L/d. The colon has a large capacitance and functional reserve and may recover up to four times its usual volume of 0.8 L/d, provided the rate of flow permits reabsorption to occur. Thus, the colon can partially compensate for excess fluid delivery to the colon that may result from intestinal absorptive or secretory disorders.

In the small intestine and colon, sodium absorption is predominantly electrogenic (i.e., it can be measured as an ionic current across the membrane because there is not an equivalent loss of a cation from the cell), and uptake takes place at the apical membrane; it is compensated for by the export functions of the basolateral sodium pump. There are several active transport proteins at the apical membrane, especially in the small intestine, whereby sodium ion entry is coupled to monosaccharides (e.g., glucose through the transporter SGLT1, or fructose through GLUT-5). Glucose then exits the basal membrane through a specific transport protein, GLUT-2, creating a glucose concentration and osmotic gradient between the lumen and the intercellular space, drawing water and electrolytes passively from the lumen. Several channels mediate the secretion of chloride ions in diarrheal diseases or in response to medications administered for the treatment of constipation. The diverse ion channels (chloride channels and cystic fibrosis transmembrane regulator), transporters (SGLT1, GLUT-2), and receptors (e.g., guanylate cyclase C receptor) are summarized in Figure 46-1.

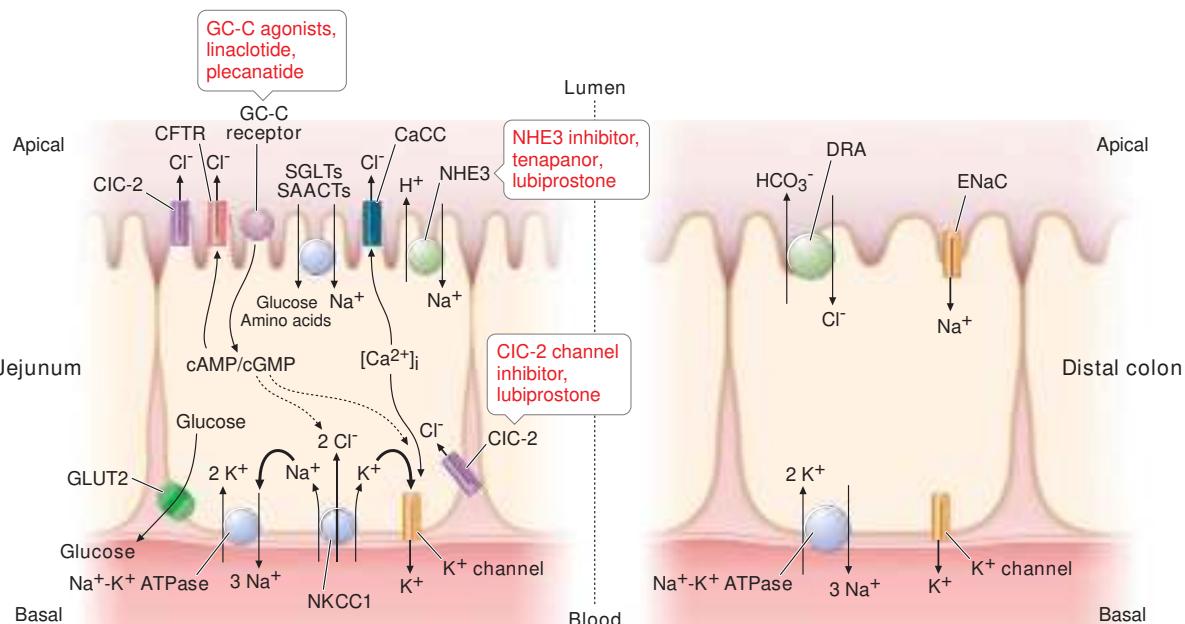


FIGURE 46-1 Important ion transport mechanisms in the jejunum and colon, and the site of action of medications used as secretagogues in the treatment of chronic constipation. CFTR, cystic fibrosis transmembrane regulator; CIC-2, type 2 chloride channel, DRA, downregulated in adenoma (also called SLC26A3); ENaC, epithelial sodium channel; GC-C, guanylate cyclase C; Na<sup>+</sup>-K<sup>+</sup> ATPase, sodium potassium adenosine triphosphatase; NHE3, sodium-hydrogen exchanger; NKCC1, Na-K-Cl cotransporter; SAACT, sodium amino acid co-transporters; SGLT, sodium glucose transporters.

A variety of neural and nonneuronal mediators regulate colonic fluid and electrolyte balance, including cholinergic, adrenergic, and serotonergic mediators. Angiotensin and aldosterone also influence colonic absorption, reflecting the common embryologic development of the distal colonic epithelium and the renal tubules.

### ■ SMALL INTESTINAL MOTILITY

During the fasting period, the motility of the small intestine is characterized by a cyclical event called the migrating motor complex (MMC), which serves to clear nondigestible residue from the small intestine (the intestinal “housekeeper”). This organized, propagated series of contractions lasts, on average, 4 min, occurs every 60–90 min, and usually involves the entire small intestine. After food ingestion, the small intestine produces irregular, mixing contractions of relatively low amplitude, except in the distal ileum where more powerful contractions occur intermittently and empty the ileum by bolus transfers.

### ■ ILEOCOLONIC STORAGE AND SALVAGE

The distal ileum acts as a reservoir, emptying intermittently by bolus movements. This action allows time for salvage of fluids, electrolytes, and nutrients. Segmentation by haustra compartmentalizes the colon and facilitates mixing, retention of residue, and formation of solid stools. There is increased appreciation of the intimate interaction between the colonic function and the luminal ecology. The resident microorganisms, predominantly anaerobic bacteria, in the colon are necessary for the digestion of unabsorbed carbohydrates that reach the colon even in health, thereby providing a vital source of nutrients to the mucosa. Normal intestinal flora also keeps pathogens at bay by a variety of mechanisms including a crucial role in the development and maintenance of a potent but well-regulated immune response capacity to pathogens and tolerance to normal ingesta. In health, the ascending and transverse regions of colon function as reservoirs (average transit time, 15 h), and the descending colon acts as a conduit (average transit time, 3 h). The colon is efficient at conserving sodium and water, a function that is particularly important in sodium-depleted patients in whom the small intestine alone is unable to maintain sodium balance. Diarrhea or constipation may result from alteration in the reservoir function of the proximal colon or the propulsive function of the left colon. Constipation may also result from disturbances of the rectal or sigmoid reservoir, typically as a result of dysfunction of the pelvic floor, the anal sphincters, the coordination of defecation, or dehydration.

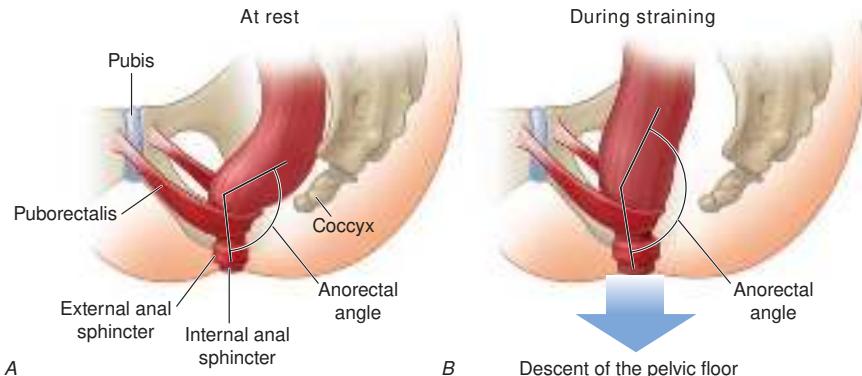
### ■ COLONIC MOTILITY AND TONE

The small-intestinal MMC only rarely continues into the colon. However, short duration or phasic contractions mix colonic contents, and high-amplitude (>75 mmHg) propagated contractions (HAPCs) are sometimes associated with mass movements through the colon and normally occur approximately five times per day, usually on awakening in the morning and postprandially. Increased frequency of HAPCs may result in diarrhea or urgency. The predominant phasic contractions in the colon are irregular and nonpropagated and serve a “mixing” function.

Colonic tone refers to the background contractility upon which phasic contractile activity (typically contractions lasting <15 s) is superimposed. It is an important cofactor in the colon’s capacitance (volume accommodation) and sensation.

### ■ COLONIC MOTILITY AFTER MEAL INGESTION

After meal ingestion, colonic phasic and tonic contractility increase for a period of ~2 h. The initial phase (~10 min) is mediated by the vagus



**FIGURE 46-2** Sagittal view of the anorectum (*A*) at rest and (*B*) during straining to defecate. Continence is maintained by normal rectal sensation and tonic contraction of the internal anal sphincter and the puborectalis muscle, which wraps around the anorectum, maintaining an anorectal angle between 80° and 110°. During defecation, the pelvic floor muscles (including the puborectalis) relax, allowing the anorectal angle to straighten by at least 15°, and the perineum descends by 1–3.5 cm. The external anal sphincter also relaxes and reduces pressure on the anal canal. (*From A Lembo, M Camilleri: Chronic constipation. N Engl J Med 349:1360, 2003 Massachusetts Medical Society. Reprinted with permission.*)

nerve in response to mechanical distention of the stomach. The subsequent response of the colon requires caloric stimulation (e.g., intake of at least 500 kcal) and is mediated, at least in part, by hormones (e.g., gastrin and serotonin).

### ■ DEFECATION

Tonic contraction of the puborectalis muscle, which forms a sling around the rectoanal junction, is important to maintain continence; during defecation, sacral parasympathetic nerves relax this muscle, facilitating the straightening of the rectoanal angle (Fig. 46-2). Distension of the rectum results in transient relaxation of the internal anal sphincter via intrinsic and reflex sympathetic innervation. As sigmoid and rectal contractions, as well as straining (Valsalva maneuver), which increases intraabdominal pressure, increase the pressure within the rectum, the rectosigmoid angle opens by >15°. Voluntary relaxation of the external anal sphincter (striated muscle innervated by the pudendal nerve) in response to the sensation produced by distention permits the evacuation of feces. Defecation can also be delayed voluntarily by contraction of the external anal sphincter.

## DIARRHEA

### ■ DEFINITION

Diarrhea is loosely defined as passage of abnormally liquid or unformed stools at an increased frequency. For adults on a typical Western diet, stool weight >200 g/d can generally be considered diarrheal. Diarrhea may be further defined as *acute* if <2 weeks, *persistent* if 2–4 weeks, and *chronic* if >4 weeks in duration.

Two common conditions, usually associated with the passage of stool totaling <200 g/d, must be distinguished from diarrhea, because diagnostic and therapeutic algorithms differ. *Pseudodiarrhea*, or the frequent passage of small volumes of stool, is often associated with rectal urgency, tenesmus, or a feeling of incomplete evacuation and accompanies IBS or proctitis. *Fecal incontinence* is the involuntary discharge of rectal contents and is most often caused by neuromuscular disorders or structural anorectal problems. Diarrhea and urgency, especially if severe, may aggravate or cause incontinence. Pseudodiarrhea and fecal incontinence occur at prevalence rates comparable to or higher than that of chronic diarrhea and should always be considered in patients complaining of “diarrhea.” Overflow diarrhea may occur in nursing home patients due to fecal impaction that is readily detectable by rectal examination. A careful history and physical examination generally allow these conditions to be discriminated from true diarrhea.

### ■ ACUTE DIARRHEA

More than 90% of cases of acute diarrhea are caused by infectious agents; these cases are often accompanied by vomiting, fever, and

abdominal pain. The remaining 10% or so are caused by medications, toxic ingestions, ischemia, food indiscretions, and other conditions.

**Infectious Agents** Most infectious diarrheas are acquired by fecal-oral transmission or, more commonly, via ingestion of food or water contaminated with pathogens from human or animal feces. In the immunocompetent person, the resident fecal microflora, containing >500 taxonomically distinct species, are rarely the source of diarrhea and may actually play a role in suppressing the growth of ingested pathogens. Disturbances of flora by antibiotics can lead to diarrhea by reducing the digestive function or by allowing the overgrowth of pathogens, such as *Clostridium difficile* (Chap. 134). Acute infection or injury occurs when the ingested agent overwhelms or bypasses the host's mucosal immune and nonimmune (gastric acid, digestive enzymes, mucus secretion, peristalsis, and suppressive resident flora) defenses. Established clinical associations with specific enteropathogens may offer diagnostic clues. Diarrhea occasionally is an early symptom of infection such as SARS-CoV-2 and *Legionella*.

In the United States, five high-risk groups are recognized:

1. **Travelers.** Nearly 40% of tourists to endemic regions of Latin America, Africa, and Asia develop so-called traveler's diarrhea, most commonly due to enterotoxigenic or enteroaggregative *Escherichia coli* as well as to *Campylobacter*, *Shigella*, *Aeromonas*, norovirus, *Coronavirus*, and *Salmonella*. Visitors to Russia (especially St. Petersburg) may have increased risk of *Giardia*-associated diarrhea; visitors to Nepal may acquire *Cyclospora*. Campers, backpackers, and swimmers in wilderness areas may become infected with *Giardia*. Cruise ships may be affected by outbreaks of gastroenteritis caused by agents such as norovirus.
2. **Consumers of certain foods.** Diarrhea closely following food consumption at a picnic, banquet, or restaurant may suggest infection with *Salmonella*, *Campylobacter*, or *Shigella* from chicken; enterohemorrhagic *E. coli* (O157:H7) from undercooked hamburger; *Bacillus cereus* from fried rice or other reheated food; *Staphylococcus aureus* or *Salmonella* from mayonnaise or creams; *Salmonella* from eggs; *Listeria* from fresh or frozen uncooked foods, mushrooms, or dairy

products; and *Vibrio* species, *Salmonella*, or acute hepatitis A from seafood, especially if raw. State departments of public health issue communications regarding domestic and foreign food-related illnesses, often identified by rapid DNA typing (PulseNet), that cause epidemics in the United States (e.g., the *Listeria* epidemic of 2020 from imported enoki mushrooms).

3. **Immunodeficient persons.** Individuals at risk for diarrhea include those with either primary immunodeficiency (e.g., IgA deficiency, common variable hypogammaglobulinemia, chronic granulomatous disease) or the much more common secondary immunodeficiency states (e.g., AIDS, senescence, pharmacologic suppression). Common enteric pathogens often cause a more severe and protracted diarrheal illness, and, particularly in persons with AIDS, opportunistic infections, such as by *Mycobacterium* species, certain viruses (cytomegalovirus, adenovirus, and herpes simplex), and protozoa (*Cryptosporidium*, *Isospora belli*, *Microsporidia*, and *Blastocystis hominis*) may also play a role (Chap. 202). In patients with AIDS, agents transmitted venereally per rectum or by extension from vaginal infection (e.g., *Neisseria gonorrhoeae*, *Treponema pallidum*, *Chlamydia*) may contribute to proctocolitis. Symptoms suggesting anorectal disease, particularly pain, may result from constipation occurring coincidentally in a person with immunodeficiency. Persons with hemochromatosis are especially prone to invasive, even fatal, enteric infections with *Vibrio* species and *Yersinia* infections and should avoid raw fish and exposing open wounds to seawater.
4. **Daycare attendees and their family members.** Infections with *Shigella*, *Giardia*, *Cryptosporidium*, rotavirus, and other agents are very common and should be considered.
5. **Institutionalized persons.** Infectious diarrhea is one of the most frequent categories of nosocomial infections in many hospitals and long-term care facilities; the causes are a variety of microorganisms but most commonly *C. difficile*. *C. difficile* can affect those with no history of antibiotic use and is often community acquired.

The pathophysiology underlying acute diarrhea by infectious agents produces specific clinical features that may also be helpful in diagnosis (Table 46-2). Profuse, watery diarrhea secondary to small-bowel hypersecretion occurs with ingestion of preformed bacterial toxins,

TABLE 46-2 Association Between Pathobiology of Causative Agents and Clinical Features in Acute Infectious Diarrhea

PATHOBIOLOGY/AGENTS	INCUBATION PERIOD	VOMITING	ABDOMINAL PAIN	FEVER	DIARRHEA
Toxin producers					
Preformed toxin					
<i>Bacillus cereus</i> , <i>Staphylococcus aureus</i> , <i>Clostridium perfringens</i>	1–8 h 8–24 h	3–4+	1–2+	0–1+	3–4+, watery
Enterotoxin					
<i>Vibrio cholerae</i> , enterotoxigenic <i>Escherichia coli</i> , <i>Klebsiella pneumoniae</i> , <i>Aeromonas</i> species	8–72 h	2–4+	1–2+	0–1+	3–4+, watery
Enteroadherent					
Enteropathogenic and enteroadherent <i>E. coli</i> , <i>Giardia</i> organisms, cryptosporidiosis, helminths	1–8 d	0–1+	1–3+	0–2+	1–2+, watery, mushy
Cytotoxin producers					
<i>Clostridium difficile</i>	1–3 d	0–1+	3–4+	1–2+	1–3+, usually watery, occasionally bloody
Hemorrhagic <i>E. coli</i>	12–72 h	0–1+	3–4+	1–2+	1–3+, initially watery, quickly bloody
Invasive organisms					
Minimal inflammation					
<i>Rotavirus</i> and norovirus	1–3 d	1–3+	2–3+	3–4+	1–3+, watery
Variable inflammation					
<i>Salmonella</i> , <i>Campylobacter</i> , and <i>Aeromonas</i> species, <i>Vibrio parahaemolyticus</i> , <i>Yersinia</i>	12 h–11 d	0–3+	2–4+	3–4+	1–4+, watery or bloody
Severe inflammation					
<i>Shigella</i> species, enteroinvasive <i>E. coli</i> , <i>Entamoeba histolytica</i>	12 h–8 d	0–1+	3–4+	3–4+	1–2+, bloody

Source: Adapted from DW Powell, in T Yamada (ed): *Textbook of Gastroenterology and Hepatology*, 4th ed. Philadelphia, Lippincott Williams & Wilkins, 2003.

enterotoxin-producing bacteria, and enteroadherent pathogens. Diarrhea associated with marked vomiting and minimal or no fever may occur abruptly within a few hours after ingestion of the former two types; vomiting is usually less, abdominal cramping or bloating is greater, and fever is higher with the latter. Cytotoxin-producing and invasive microorganisms all cause high fever and abdominal pain. Invasive bacteria and *Entamoeba histolytica* often cause bloody diarrhea (referred to as *dysentery*). *Yersinia* invades the terminal ileal and proximal colon mucosa and may cause especially severe abdominal pain with tenderness mimicking acute appendicitis.

Finally, infectious diarrhea may be associated with systemic manifestations. Reactive arthritis (formerly known as Reiter's syndrome), arthritis, urethritis, and conjunctivitis may accompany or follow infections by *Salmonella*, *Campylobacter*, *Shigella*, and *Yersinia*. Yersiniosis may also lead to an autoimmune-type thyroiditis, pericarditis, and glomerulonephritis. Both enterohemorrhagic *E. coli* (O157:H7) and *Shigella* can lead to the *hemolytic-uremic syndrome* with an attendant high mortality rate. The syndrome of postinfectious IBS has now been recognized as a complication of infectious diarrhea. Similarly, acute gastroenteritis may precede the diagnosis of celiac disease or Crohn's disease. Acute diarrhea can also be a major symptom of several systemic infections including *viral hepatitis*, *listeriosis*, *legionellosis*, and *toxic shock syndrome*.

**Other Causes** Side effects from medications are probably the most common noninfectious causes of acute diarrhea, and etiology may be suggested by a temporal association between use and symptom onset. Although innumerable medications may produce diarrhea, some of the more frequently incriminated include antibiotics, cardiac antidysrhythmics, antihypertensives, nonsteroidal anti-inflammatory drugs (NSAIDs), certain antidepressants, chemotherapeutic agents, bronchodilators, antacids, and laxatives. Occlusive or nonocclusive ischemic colitis typically occurs in persons aged >50 years; often presents as acute lower abdominal pain preceding watery, then bloody diarrhea; and generally results in acute inflammatory changes in the sigmoid or left colon while sparing the rectum. Acute diarrhea may accompany colonic diverticulitis and graft-versus-host disease. Acute diarrhea, often associated with systemic compromise, can follow ingestion of toxins including organophosphate insecticides, amanita and other mushrooms, arsenic, and preformed toxins in seafood such as ciguatera (from algae that the fish eat) and scombrotoxin (an excess of histamine due to inadequate refrigeration). Acute anaphylaxis to food ingestion can have a similar presentation. Conditions causing chronic diarrhea can also be confused with acute diarrhea early in their course. This confusion may occur with inflammatory bowel disease (IBD) and some of the other inflammatory chronic diarrheas that may have an abrupt rather than insidious onset and exhibit features that mimic infection.

## APPROACH TO THE PATIENT

### Acute Diarrhea

The decision to evaluate acute diarrhea depends on its severity and duration and on various host factors (Fig. 46-3). Most episodes of acute diarrhea are mild and self-limited and do not justify the cost and potential morbidity rate of diagnostic or pharmacologic interventions. Indications for evaluation include profuse diarrhea with dehydration, grossly bloody stools, fever  $\geq 38.5^{\circ}\text{C}$  ( $\geq 101^{\circ}\text{F}$ ), duration  $>48$  h without improvement, recent antibiotic use, new community outbreaks, associated severe abdominal pain in patients aged >50 years, and elderly ( $\geq 70$  years) or immunocompromised patients. In some cases of moderately severe febrile diarrhea associated with fecal leukocytes (or increased fecal levels of the leukocyte proteins, such as calprotectin) or with gross blood, a diagnostic evaluation might be avoided in favor of an empirical antibiotic trial (see below).

The cornerstone of diagnosis in those suspected of severe acute infectious diarrhea is microbiologic analysis of the stool. Workup

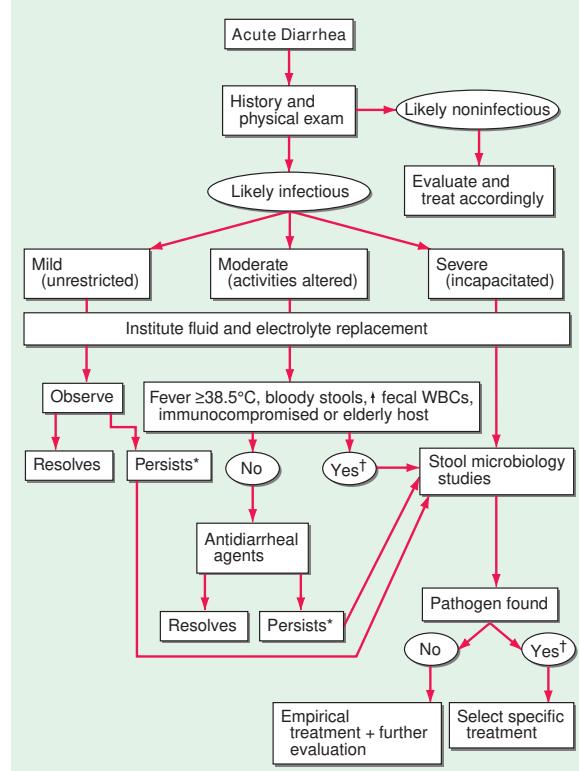


FIGURE 46-3 Algorithm for the management of acute diarrhea. Consider empirical treatment before evaluation with (\*) metronidazole and with (†) quinolone. WBCs, white blood cells.

includes cultures for bacterial and viral pathogens; direct inspection for ova and parasites; and immunoassays for certain bacterial toxins (*C. difficile*), viral antigens (rotavirus), and protozoal antigens (*Giardia*, *E. histolytica*). The aforementioned clinical and epidemiologic associations may assist in focusing the evaluation. If a particular pathogen or set of possible pathogens is so implicated, either the whole panel of routine studies may not be necessary or, in some instances, special cultures may be appropriate, as for enterohemorrhagic and other types of *E. coli*, *Vibrio* species, and *Yersinia*. Molecular diagnosis of pathogens in stool can be made by identification of unique DNA sequences, and evolving microarray technologies have led to more rapid, sensitive, specific, and cost-effective diagnosis.

Persistent diarrhea is commonly due to *Giardia* (Chap. 223), but additional causative organisms that should be considered include *C. difficile* (especially if antibiotics had been administered), *E. histolytica*, *Cryptosporidium*, *Campylobacter*, and others. If stool studies are unrevealing, flexible sigmoidoscopy with biopsies and upper endoscopy with duodenal aspirates and biopsies may be indicated. Brainerd diarrhea is an increasingly recognized entity characterized by an abrupt-onset diarrhea that persists for at least 4 weeks, but may last 1–3 years, and is thought to be of infectious origin. It may be associated with subtle inflammation of the distal small intestine or proximal colon.

Structural examination by sigmoidoscopy, colonoscopy, or abdominal computed tomography (CT) scanning (or other imaging approaches) may be appropriate in patients with uncharacterized persistent diarrhea to exclude IBD or as an initial approach in patients with suspected noninfectious acute diarrhea such as might be caused by ischemic colitis, diverticulitis, or partial bowel obstruction.

## TREATMENT

### Acute Diarrhea

Fluid and electrolyte replacement are of central importance to all forms of acute diarrhea. Fluid replacement alone may suffice for mild cases. Oral sugar-electrolyte solutions (iso-osmolar sport drinks or designed formulations) should be instituted promptly with severe diarrhea to limit dehydration, which is the major cause of death. Profoundly dehydrated patients, especially infants and the elderly, require IV rehydration.

In moderately severe nonfebrile and nonbloody diarrhea, antimotility and antisecretory agents such as loperamide can be useful adjuncts to control symptoms. Such agents should be avoided with febrile dysentery, which may be prolonged by them, and should be used with caution with drugs that increase levels due to cardiotoxicity. Bismuth subsalicylate may reduce symptoms of vomiting and diarrhea but should not be used to treat immunocompromised patients or those with renal impairment because of the risk of bismuth encephalopathy.

Judicious use of antibiotics is appropriate in selected instances of acute diarrhea and may reduce its severity and duration (Fig. 46-3). Many physicians treat moderately to severely ill patients with febrile dysentery empirically without diagnostic evaluation using a quinolone, such as ciprofloxacin (500 mg bid for 3–5 d). Empirical treatment can also be considered for suspected giardiasis with metronidazole (250 mg qid for 7 d). Selection of antibiotics and dosage regimens are otherwise dictated by specific pathogens, geographic patterns of resistance, and conditions found (Chaps. 133, 161, and 165–171). Because of resistance to first-line treatments, newer agents such as nitazoxanide may be required for *Giardia* and *Cryptosporidium* infections. Antibiotic coverage is indicated, whether or not a causative organism is discovered, in patients who are immunocompromised, have mechanical heart valves or recent vascular grafts, or are elderly. Bismuth subsalicylate may reduce the frequency of traveler's diarrhea. Antibiotic prophylaxis is only indicated for certain patients traveling to high-risk countries in whom the likelihood or seriousness of acquired diarrhea would be especially high, including those with immunocompromise, IBD, hemochromatosis, or gastric achlorhydria. Use of ciprofloxacin, azithromycin, or rifaximin may reduce bacterial diarrhea in such travelers by 90%, though rifaximin is not suitable for invasive disease but rather as treatment for uncomplicated traveler's diarrhea. There is little role for endoscopic evaluation in most circumstances except in immunocompromised patients. Finally, physicians should be vigilant to identify if an outbreak of diarrheal illness is occurring and to alert the public health authorities promptly. This may reduce the ultimate size of the affected population.

### CHRONIC DIARRHEA

Diarrhea lasting >4 weeks warrants evaluation to exclude serious underlying pathology. In contrast to acute diarrhea, most of the causes of chronic diarrhea are noninfectious. The classification of chronic diarrhea by pathophysiologic mechanism facilitates a rational approach to management, although many diseases cause diarrhea by more than one mechanism (Table 46-3).

**Secretory Causes** Secretory diarrheas are due to derangements in fluid and electrolyte transport across the enterocolonic mucosa. They are characterized clinically by watery, large-volume fecal outputs that are typically painless and persist with fasting. Because there is no malabsorbed solute, stool osmolality is accounted for by normal endogenous electrolytes with no fecal osmotic gap.

**MEDICATIONS** Side effects from regular ingestion of drugs and toxins are the most common secretory causes of chronic diarrhea. Hundreds of prescription and over-the-counter medications (see earlier section, "Acute Diarrhea, Other Causes") may produce diarrhea. Surreptitious or habitual use of stimulant laxatives (e.g., senna, cascara, bisacodyl,

TABLE 46-3 Major Causes of Chronic Diarrhea According to Predominant Pathophysiologic Mechanism

#### Secretory Causes

- Exogenous stimulant laxatives
- Chronic ethanol ingestion
- Other drugs and toxins
- Endogenous laxatives (dihydroxy bile acids)
- Idiopathic secretory diarrhea or bile acid diarrhea
- Certain bacterial infections
- Bowel resection, disease, or fistula ( $\downarrow$  absorption)
- Partial bowel obstruction or fecal impaction
- Hormone-producing tumors (carcinoid, VIPoma, medullary cancer of thyroid, mastocytosis, gastrinoma, colorectal villous adenoma)
- Addison's disease
- Congenital electrolyte absorption defects

#### Osmotic Causes

- Osmotic laxatives ( $Mg^{2+}$ ,  $PO_4^{-3}$ ,  $SO_4^{-2}$ )
- Lactase and other disaccharide deficiencies
- Nonabsorbable carbohydrates (sorbitol, lactulose, polyethylene glycol)
- Gluten and FODMAP intolerance

#### Steatorrheal Causes

- Intraluminal maldigestion (pancreatic exocrine insufficiency, bacterial overgrowth, bariatric surgery, liver disease)
- Mucosal malabsorption (celiac sprue, Whipple's disease, infections, abetalipoproteinemia, ischemia, drug-induced enteropathy)
- Postmucosal obstruction (1° or 2° lymphatic obstruction)

#### Inflammatory Causes

- Idiopathic inflammatory bowel disease (Crohn's, chronic ulcerative colitis)
- Lymphocytic and collagenous colitis
- Immune-related mucosal disease (1° or 2° immunodeficiencies, food allergy, eosinophilic gastroenteritis, graft-versus-host disease)
- Infections (invasive bacteria, viruses, and parasites, Brainerd diarrhea)
- Radiation injury
- Gastrointestinal malignancies

#### Dysmotile Causes

- Irritable bowel syndrome (including postinfectious IBS)
- Visceral neuromopathies
- Hyperthyroidism
- Drugs (prokinetic agents)
- Postvagotomy

#### Factitious Causes

- Munchausen
- Eating disorders

#### Iatrogenic Causes

- Cholecystectomy
- Ileal resection
- Bariatric surgery
- Vagotomy, fundoplication

*Abbreviations:* FODMAP fermentable oligosaccharides, disaccharides, monosaccharides, and polyols; IBS, irritable bowel syndrome.

ricinoleic acid [castor oil]) must also be considered. Chronic ethanol consumption may cause a secretory-type diarrhea due to enterocyte injury with impaired sodium and water absorption as well as rapid transit and other alterations. Inadvertent ingestion of certain environmental toxins (e.g., arsenic) may lead to chronic rather than acute forms of diarrhea. Certain bacterial infections may occasionally persist and be associated with a secretory-type diarrhea. The oral angiotensin receptor blocker olmesartan is associated with diarrhea due to sprue-like enteropathy.

**BOWEL RESECTION, MUCOSAL DISEASE, OR ENTEROCOLIC FISTULA** These conditions may result in a secretory-type diarrhea because of inadequate surface for reabsorption of secreted fluids and electrolytes. Unlike other secretory diarrheas, this subset of conditions tends to worsen with eating. With disease (e.g., Crohn's ileitis) or resection of <100 cm of terminal ileum, dihydroxy bile acids may escape absorption and stimulate colonic secretion (cholerheic diarrhea). This mechanism may contribute to so-called *idiopathic secretory diarrhea or bile acid diarrhea (BAD)*, in which bile acids are functionally malabsorbed from a normal-appearing terminal ileum. This *idiopathic bile acid malabsorption (BAM)* may account for an average of 40% of unexplained chronic diarrhea. Reduced negative feedback regulation of bile acid synthesis in hepatocytes by fibroblast growth factor 19 (FGF-19) produced by ileal enterocytes results in a degree of bile-acid synthesis that exceeds the normal capacity for ileal reabsorption, producing BAD. An alternative cause of BAD is a genetic variation in the receptor proteins ( $\beta$ -klotho and fibroblast growth factor 4) on the hepatocyte that normally mediate the effect of FGF-19. Dysfunction of these proteins prevents FGF-19 inhibition of hepatocyte bile acid synthesis. Another mechanism is based on genetic variation in the bile acid receptor (TGR5) in the colon, resulting in accelerated colonic transit.

Partial bowel obstruction, ostomy stricture, or fecal impaction may paradoxically lead to increased fecal output due to fluid hypersecretion.

**HORMONES** Although uncommon, the classic examples of secretory diarrhea are those mediated by hormones. *Metastatic gastrointestinal carcinoid tumors* or, rarely, *primary bronchial carcinoids* may produce watery diarrhea alone or as part of the carcinoid syndrome that comprises episodic flushing, wheezing, dyspnea, and right-sided valvular heart disease. Diarrhea is due to the release into the circulation of potent intestinal secretagogues including serotonin, histamine, prostaglandins, and various kinins. Pellagra-like skin lesions may rarely occur as the result of serotonin overproduction with niacin depletion. *Gastrinoma*, one of the most common neuroendocrine tumors, most typically presents with refractory peptic ulcers, but diarrhea occurs in up to one-third of cases and may be the only clinical manifestation in 10%. While other secretagogues released with gastrin may play a role, the diarrhea most often results from fat maldigestion owing to pancreatic enzyme inactivation by low intraduodenal pH. The watery diarrhea hypokalemia achlorhydria syndrome, also called *pancreatic cholera*, is due to a non- $\beta$  cell pancreatic adenoma, referred to as a *VIPoma*, that secretes VIP and a host of other peptide hormones including pancreatic polypeptide, secretin, gastrin, gastrin-inhibitory polypeptide (also called glucose-dependent insulinotropic peptide), neurotensin, calcitonin, and prostaglandins. The secretory diarrhea is often massive with stool volumes >3 L/d; daily volumes as high as 20 L have been reported. Life-threatening dehydration; neuromuscular dysfunction from associated hypokalemia, hypomagnesemia, or hypercalcemia; flushing; and hyperglycemia may accompany a VIPoma. *Medullary carcinoma of the thyroid* may present with watery diarrhea caused by calcitonin, other secretory peptides, or prostaglandins. Prominent diarrhea is often associated with metastatic disease and poor prognosis. *Systemic mastocytosis*, which may be associated with the skin lesion urticaria pigmentosa, may cause diarrhea that is either secretory and mediated by histamine or inflammatory due to intestinal infiltration by mast cells. Large *colorectal villous adenomas* may rarely be associated with a secretory diarrhea that may cause hypokalemia, can be inhibited by NSAIDs, and are apparently mediated by prostaglandins.

**CONGENITAL DEFECTS IN ION ABSORPTION** Rarely, defects in specific carriers associated with ion absorption cause watery diarrhea from birth. These disorders include defective  $\text{Cl}^-/\text{HCO}_3^-$  exchange (*congenital chloridorrhea*) with alkalosis (which results from a mutated *DRA* [down-regulated in adenoma] gene) and defective  $\text{Na}^+/\text{H}^+$  exchange (*congenital sodium diarrhea*), which results from a mutation in the *NHE3* (sodium-hydrogen exchanger) gene and results in acidosis.

Some hormone deficiencies may be associated with watery diarrhea, such as occurs with adrenocortical insufficiency (Addison's disease) that may be accompanied by skin hyperpigmentation.

**Osmotic Causes** Osmotic diarrhea occurs when ingested, poorly absorbable, osmotically active solutes draw enough fluid into the lumen to exceed the reabsorptive capacity of the colon. Fecal water output increases in proportion to such a solute load. Osmotic diarrhea characteristically ceases with fasting or with discontinuation of the causative agent.

**OSMOTIC LAXATIVES** Ingestion of magnesium-containing antacids, health supplements, or laxatives may induce osmotic diarrhea typified by a stool osmotic gap (>50 mosmol/L): serum osmolarity (typically 290 mosmol/kg) – (2 × [fecal sodium + potassium concentration]). Measurement of fecal osmolarity is no longer recommended because, even when measured immediately after evacuation, it may be erroneous because carbohydrates are metabolized by colonic bacteria, causing an increase in osmolarity.

**CARBOHYDRATE MALABSORPTION** Carbohydrate malabsorption due to acquired or congenital defects in brush-border disaccharidases and other enzymes leads to osmotic diarrhea with a low pH. One of the most common causes of chronic diarrhea in adults is *lactase deficiency*, which affects three-fourths of nonwhites worldwide and 5–30% of persons in the United States; the total lactose load at any one time influences the symptoms experienced. Most patients learn to avoid milk products without requiring treatment with enzyme supplements. Some sugars, such as sorbitol, lactulose, or fructose, are frequently malabsorbed, and diarrhea ensues with ingestion of medications, gum, or candies sweetened with these poorly or incompletely absorbed sugars.

**WHEAT AND FODMAP INTOLERANCE** Chronic diarrhea, bloating, and abdominal pain are recognized as symptoms of nonceliac gluten intolerance (which is associated with impaired intestinal or colonic barrier function) and intolerance of fermentable oligosaccharides, disaccharides, monosaccharides, and polyols (FODMAPs). The latter's effects represent the interaction between the GI microbiome and the nutrients.

**Steatorrhea** Causes Fat malabsorption may lead to greasy, foul-smelling, difficult-to-flush diarrhea often associated with weight loss and nutritional deficiencies due to concomitant malabsorption of amino acids and vitamins. Increased fecal output is caused by the osmotic effects of fatty acids, especially after bacterial hydroxylation, and, to a lesser extent, by the neutral fat. Quantitatively, steatorrhea is defined as stool fat exceeding the normal 7 g/d; rapid-transit diarrhea may result in fecal fat up to 14 g/d; daily fecal fat averages 15–25 g with small-intestinal diseases and is often >32 g with pancreatic exocrine insufficiency. Intraluminal maldigestion, mucosal malabsorption, or lymphatic obstruction may produce steatorrhea.

**INTRALUMINAL MALDIGESTION** This condition most commonly results from pancreatic exocrine insufficiency, which occurs when >90% of pancreatic secretory function is lost. *Chronic pancreatitis*, usually a sequel of ethanol abuse, most frequently causes pancreatic insufficiency. Other causes include *cystic fibrosis*, *pancreatic duct obstruction*, and, rarely, *somatostatinoma*. Bacterial overgrowth in the small intestine may deconjugate bile acids and alter micelle formation, impairing fat digestion; it occurs with stasis from a blind-loop, small-bowel diverticulum or dysmotility and is especially likely in the elderly. Finally, cirrhosis or biliary obstruction may lead to mild steatorrhea due to deficient intraluminal bile acid concentration.

**MUCOSAL MALABSORPTION** Mucosal malabsorption occurs from a variety of enteropathies, but it most commonly occurs from *celiac disease*. This gluten-sensitive enteropathy affects all ages and is characterized by villous atrophy and crypt hyperplasia in the proximal small bowel and can present with fatty diarrhea associated with multiple nutritional deficiencies of varying severity. Celiac disease is much more frequent than previously thought; it affects ~1% of the population, frequently presents without steatorrhea, can mimic IBS, and has many other GI and extraintestinal manifestations. *Tropical sprue* may produce a similar histologic and clinical syndrome but occurs in residents of or travelers to tropical climates; abrupt onset and response to antibiotics suggest an infectious etiology. *Whipple's disease*, due to

the bacillus *Tropheryma whipplei* and histiocytic infiltration of the small-bowel mucosa, is a less common cause of steatorrhea that most typically occurs in young or middle-aged men; it is frequently associated with arthralgias, fever, lymphadenopathy, and extreme fatigue, and it may affect the CNS and endocardium. A similar clinical and histologic picture results from *Mycobacterium avium-intracellulare* infection in patients with AIDS. *Abetalipoproteinemia* is a rare defect of chylomicron formation and fat malabsorption in children, associated with acanthocytic erythrocytes, ataxia, and retinitis pigmentosa. Several other conditions may cause mucosal malabsorption including infections, especially with protozoa such as *Giardia*, numerous medications (e.g., olmesartan, mycophenolate mofetil, colchicine, cholestyramine, neomycin), idiopathic enteropathies, amyloidosis, and chronic ischemia.

**POSTMUCOSAL LYMPHATIC OBSTRUCTION** The pathophysiology of this condition, which is due to the rare *congenital intestinal lymphangiectasia* or to *acquired lymphatic obstruction* secondary to trauma, tumor, cardiac disease, or infection, leads to the unique constellation of fat malabsorption with enteric losses of protein (often causing edema) and lymphocytopenia. Carbohydrate and amino acid absorption are preserved.

**Inflammatory Causes** Inflammatory diarrheas are generally accompanied by pain, fever, bleeding, or other manifestations of inflammation. The mechanism of diarrhea may not only be exudation but, depending on lesion site, may include fat malabsorption, disrupted fluid/electrolyte absorption, and hypersecretion or hypermotility from release of cytokines and other inflammatory mediators. The unifying feature on stool analysis is the presence of leukocytes or leukocyte-derived proteins such as calprotectin. With severe inflammation, exudative protein loss can lead to anasarca (generalized edema). Any middle-aged or older person with chronic inflammatory-type diarrhea, especially with blood, should be carefully evaluated to exclude a colorectal tumor.

**IDIOPATHIC INFLAMMATORY BOWEL DISEASE** The illnesses in this category, which include *Crohn's disease* and *chronic ulcerative colitis*, are among the most common organic causes of chronic diarrhea in adults and range in severity from mild to fulminant and life-threatening. They may be associated with uveitis, polyarthralgias, cholestatic liver disease (primary sclerosing cholangitis), and skin lesions (erythema nodosum, pyoderma gangrenosum). *Microscopic colitis*, including both lymphocytic and *collagenous colitis*, is an increasingly recognized cause of chronic watery diarrhea, especially in middle-aged women and those on NSAIDs, statins, proton pump inhibitors (PPIs), and selective serotonin reuptake inhibitors (SSRIs); biopsy of a normal-appearing colon is required for histologic diagnosis. It may coexist with symptoms suggesting IBS or with celiac sprue or drug-induced enteropathy. It typically responds well to anti-inflammatory drugs (e.g., bismuth), the opioid agonist loperamide, or budesonide.

**PRIMARY OR SECONDARY FORMS OF IMMUNODEFICIENCY** Immunodeficiency may lead to prolonged infectious diarrhea. With selective IgA deficiency or common variable *hypogammaglobulinemia*, diarrhea is particularly prevalent and often the result of giardiasis, bacterial overgrowth, or sprue.

**EOSINOPHILIC GASTROENTERITIS** Eosinophil infiltration of the mucosa, muscularis, or serosa at any level of the GI tract may cause diarrhea, pain, vomiting, or ascites. Affected patients often have an atopic history, Charcot-Leyden crystals due to extruded eosinophil contents may be seen on microscopic inspection of stool, and peripheral eosinophilia is present in 50–75% of patients. While hypersensitivity to certain foods occurs in adults, true food allergy causing chronic diarrhea is rare.

**OTHER CAUSES** Chronic inflammatory diarrhea may be caused by *radiation enterocolitis*, *chronic graft-versus-host disease*, autoimmune

or idiopathic enteropathies, *Behcet's syndrome*, and *Cronkhite-Canada syndrome*, among others.

**Dysmotility Causes** Rapid transit may accompany many diarrheas as a secondary or contributing phenomenon, but primary dysmotility is an unusual etiology of true diarrhea. Stool features often suggest a secretory diarrhea, but mild steatorrhea of up to 14 g of fat per day can be produced by maldigestion from rapid transit alone. *Hyperthyroidism*, *carcinoid syndrome*, and certain drugs (e.g., prostaglandins, prokinetic agents) may produce hypermotility with resultant diarrhea. Primary visceral neuromyopathies or idiopathic acquired intestinal pseudoobstruction may lead to stasis with secondary bacterial overgrowth causing diarrhea. *Diabetic diarrhea*, often accompanied by peripheral and generalized autonomic neuropathies, may occur in part because of intestinal dysmotility.

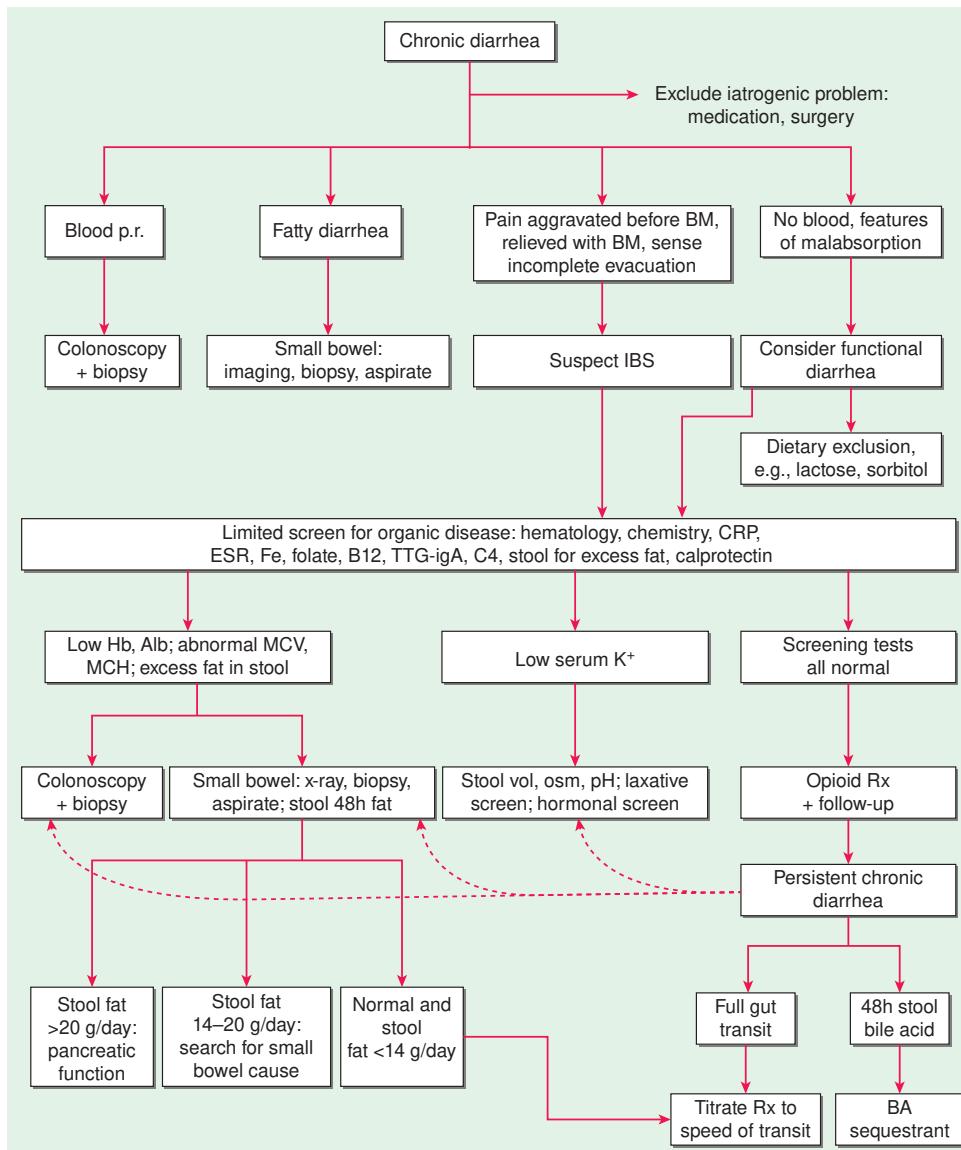
The exceedingly common IBS (10% point prevalence, 1–2% per year incidence) is characterized by disturbed intestinal and colonic motor and sensory responses to various stimuli. Symptoms of stool frequency typically cease at night, alternate with periods of constipation, are accompanied by abdominal pain relieved with defecation, and rarely result in weight loss.

**Factitious Causes** Factitious diarrhea accounts for up to 15% of unexplained diarrheas referred to tertiary care centers. Either as a form of *Munchausen syndrome* (deception or self-injury for secondary gain) or *eating disorders*, some patients covertly self-administer laxatives alone or in combination with other medications (e.g., diuretics) or surreptitiously add water or urine to stool sent for analysis. Such patients are typically women, often with histories of psychiatric illness, and disproportionately from careers in health care. Hypotension and hypokalemia are common co-presenting features. The evaluation of such patients may be difficult: contamination of the stool with water or urine is suggested by very low or high stool osmolarity, respectively. Such patients often deny this possibility when confronted, but they do benefit from psychiatric counseling when they acknowledge their behavior.

## APPROACH TO THE PATIENT

### CHRONIC DIARRHEA

The laboratory tools available to evaluate the very common problem of chronic diarrhea are extensive, and many are costly and invasive. As such, the diagnostic evaluation must be rationally directed by a careful history, including medications, and physical examination (Fig. 46-4). When this strategy is unrevealing, simple triage tests are often warranted to direct the choice of more complex investigations (Fig. 46-4). The history, physical examination (Table 46-4), and routine blood studies should attempt to characterize the mechanism of diarrhea, identify diagnostically helpful associations, and assess the patient's fluid/electrolyte and nutritional status. Patients should be questioned about the onset, duration, pattern, aggravating (especially diet) and relieving factors, and stool characteristics of their diarrhea. The presence or absence of fecal incontinence, fever, weight loss, pain, certain exposures (travel, medications, contacts with diarrhea), and common extraintestinal manifestations (skin changes, arthralgias, oral aphthous ulcers) should be noted. A family history of IBD or celiac disease may indicate those possibilities. Physical findings may offer clues such as a thyroid mass, wheezing, heart murmurs, edema, hepatomegaly, abdominal masses, lymphadenopathy, mucocutaneous abnormalities, perianal fistulas, or anal sphincter laxity. Peripheral blood leukocytosis, elevated sedimentation rate, or C-reactive protein suggests inflammation; anemia reflects blood loss or nutritional deficiencies; or eosinophilia may occur with parasitoses, neoplasia, collagen-vascular disease, allergy, or eosinophilic gastroenteritis. Blood chemistries may demonstrate electrolyte, hepatic, or other metabolic disturbances. Measuring IgA tissue transglutaminase antibodies



**FIGURE 46-4** Algorithm for management of chronic diarrhea. Patients undergo an initial evaluation based on different symptom presentations, leading to selection of patients for imaging, biopsy analysis, and limited screens for organic diseases. Alb, albumin; BA, bile acid; BM, bowel movement; C4, 7 α-hydroxy-4-cholesten-3-one; CRP, C-reactive protein; ESR, erythrocyte sedimentation rate; Hb, hemoglobin; Hx, history; IBS, irritable bowel syndrome; MCH, mean corpuscular hemoglobin; MCV, mean corpuscular volume; osm, osmolality; p.r., per rectum; Rx, treatment; TTG, tissue transglutaminase. (Reproduced with permission from M Camilleri, JH Sellin, KE Barrett: Pathophysiology, evaluation, and management of chronic watery diarrhea. *Gastroenterology* 152:515, 2017.)

**TABLE 46-4** Physical Examination in Patients with Chronic Diarrhea

1. Are there general features to suggest malabsorption or inflammatory bowel disease (IBD) such as anemia, dermatitis herpetiformis, edema, or clubbing?
2. Are there features to suggest underlying autonomic neuropathy or collagen-vascular disease in the pupils, orthostasis, skin, hands, or joints?
3. Is there an abdominal mass or tenderness?
4. Are there any abnormalities of rectal mucosa, rectal defects, or altered anal sphincter functions?
5. Are there any mucocutaneous manifestations of systemic disease such as dermatitis herpetiformis (celiac disease), erythema nodosum (ulcerative colitis), flushing (carcinoid), or oral ulcers for IBD or celiac disease?

may help detect celiac disease. Bile acid diarrhea is confirmed by a scintigraphic radiolabeled bile acid retention test; however, this is not available in many countries. Alternative approaches are a screening blood test (serum C4 or FGF-19), measurement of fecal bile acids, or a therapeutic trial with a bile acid sequestant (e.g., cholestyramine, colestipol or colesevelam).

A therapeutic trial is often appropriate, definitive, and highly cost-effective when a specific diagnosis is suggested on the initial physician encounter. For example, chronic watery diarrhea, which ceases with fasting in an otherwise healthy young adult, may justify a trial of a lactose-restricted diet; bloating and diarrhea persisting since a mountain backpacking trip may warrant a trial of metronidazole for likely giardiasis; and postprandial diarrhea persisting

following resection of terminal ileum might be due to bile acid malabsorption and be treated with cholestyramine, colestipol, or colesvelam before further evaluation. Persistent symptoms require additional investigation.

Certain diagnoses may be suggested on the initial encounter (e.g., idiopathic IBD); however, additional focused evaluations may be necessary to confirm the diagnosis and characterize the severity or extent of disease so that treatment can be best guided. Patients suspected of having IBS should be initially evaluated with flexible sigmoidoscopy with colorectal biopsies to exclude IBD, or particularly microscopic colitis, which is clinically indistinguishable from IBS with diarrhea or functional diarrhea; those with normal findings might be reassured and, as indicated, treated empirically with antispasmodics, antidiarrheals, or antidepressants (e.g., tricyclic agents). Any patient who presents with chronic diarrhea and hematochezia should be evaluated with stool microbiologic studies and colonoscopy.

In an estimated two-thirds of cases, the cause for chronic diarrhea remains unclear after the initial encounter, and further testing is required. Quantitative stool collection and analyses can yield important objective data that may establish a diagnosis or characterize the type of diarrhea as a triage for focused additional studies (Fig. 46-4). If stool weight is >200 g/d, additional stool analyses should be performed that might include electrolyte concentration, pH, occult blood testing, leukocyte inspection (or leukocyte protein assay), fat quantitation, and laxative screens.

For secretory diarrheas (watery, normal osmotic gap), possible medication-related side effects or surreptitious laxative use should be reconsidered. Microbiologic studies should be done including fecal bacterial cultures (including media for *Aeromonas* and *Plesiomonas*), inspection for ova and parasites, and *Giardia* antigen assay (the most sensitive test for giardiasis). Small-bowel bacterial overgrowth can be excluded by intestinal aspirates with quantitative cultures or with glucose or lactulose breath tests involving measurement of breath hydrogen, methane, or other metabolite. However, interpretation of these breath tests may be confounded by disturbances of intestinal transit. Upper endoscopy and colonoscopy with biopsies and small-bowel x-rays (formerly barium, but increasingly CT with enterography or magnetic resonance with enteroclysis) are helpful to rule out structural or occult inflammatory disease. When suggested by history or other findings, screens for peptide hormones should be pursued (e.g., serum gastrin, VIP, calcitonin, thyroid hormone/thyroid-stimulating hormone, urinary 5-hydroxyindolacetic acid, histamine).

Further evaluation of osmotic diarrhea should include tests for lactose intolerance and magnesium ingestion, the two most common causes. Low fecal pH suggests carbohydrate malabsorption; lactose malabsorption can be confirmed by lactose breath testing or by a therapeutic trial with lactose exclusion and observation of the effect of lactose challenge (e.g., a liter of milk). Lactase determination on small-bowel biopsy is not generally available. If fecal magnesium or laxative levels are elevated, inadvertent or surreptitious ingestion should be considered and psychiatric help should be sought.

For those with proven fatty diarrhea, endoscopy with small-bowel biopsy (including aspiration for quantitative cultures, if available) should be performed; if this procedure is unrevealing, a small-bowel radiograph is often an appropriate next step. If small-bowel studies are negative or if pancreatic disease is suspected, pancreatic exocrine insufficiency should be excluded with direct tests, such as the secretin-cholecystokinin stimulation test or a variation that could be performed endoscopically. In general, indirect tests such as assay of fecal elastase or chymotrypsin activity or a bentiromide test have fallen out of favor because of low sensitivity and specificity.

Chronic inflammatory-type diarrheas should be suspected by the presence of blood or leukocytes in the stool. Such findings warrant stool cultures; inspection for ova and parasites; *C. difficile* toxin assay; colonoscopy with biopsies; and, if indicated, small-bowel imaging studies.

## TREATMENT

### Chronic Diarrhea

Treatment of chronic diarrhea depends on the specific etiology and may be curative, suppressive, or empirical. If the cause can be eradicated, treatment is curative as with resection of a colorectal cancer, antibiotic administration for Whipple's disease or tropical sprue, or discontinuation of a drug. For many chronic conditions, diarrhea can be controlled by suppression of the underlying mechanism. Examples include elimination of dietary lactose for lactase deficiency or gluten for celiac sprue, use of glucocorticoids or other anti-inflammatory agents for idiopathic IBDs, bile acid sequestrants for bile acid malabsorption, PPIs for the gastric hypersecretion of gastrinomas, somatostatin analogues such as octreotide for malignant carcinoid syndrome, prostaglandin inhibitors such as indomethacin for medullary carcinoma of the thyroid, and pancreatic enzyme replacement for pancreatic insufficiency. When the specific cause or mechanism of chronic diarrhea evades diagnosis, empirical therapy may be beneficial. Mild opiates, such as diphenoxylate or loperamide, are often helpful in mild or moderate watery diarrhea. For those with more severe diarrhea, codeine or tincture of opium may be beneficial. Such antimotility agents should be avoided with severe IBD, because toxic megacolon may be precipitated. Clonidine, an  $\alpha_2$ -adrenergic agonist, may allow control of diabetic diarrhea, although the medication may be poorly tolerated because it causes postural hypotension. The 5-HT<sub>3</sub> receptor antagonists (e.g., alosetron, ondansetron) may relieve diarrhea and urgency in patients with IBS diarrhea. Other medications approved for the treatment of diarrhea associated with IBS are the nonabsorbed antibiotic, rifaximin, and the mixed  $\mu$ -opioid receptor (OR) and  $\kappa$ -OR agonist and  $\delta$ -OR antagonist, eluxadoline. The latter may induce sphincter of Oddi spasm and subsequent acute pancreatitis, usually in patients with prior cholecystectomy. For all patients with chronic diarrhea, fluid and electrolyte repletion is an important component of management (see "Acute Diarrhea," earlier). Replacement of fat-soluble vitamins may also be necessary in patients with chronic steatorrhea.

## CONSTIPATION

### ■ DEFINITION

Constipation is a common complaint in clinical practice and usually refers to persistent, difficult, infrequent, or seemingly incomplete defecation. Because of the wide range of normal bowel habits, constipation is difficult to define precisely. Most persons have at least three bowel movements per week; however, low stool frequency alone is not the sole criterion for the diagnosis of constipation. Many constipated patients have a normal frequency of defecation but complain of excessive straining, hard stools, lower abdominal fullness, or a sense of incomplete evacuation. The individual patient's symptoms must be analyzed in detail to ascertain what is meant by "constipation" or "difficulty" with defecation.

Stool form and consistency are well correlated with the time elapsed from the preceding defecation. Hard, pellet stools occur with slow transit, whereas loose, watery stools are associated with rapid transit. Both small pellet or very large stools are more difficult to expel than normal stools.

The perception of hard stools or excessive straining is more difficult to assess objectively, and the need for enemas or digital disimpaction is a clinically useful way to corroborate the patient's perceptions of difficult defecation.

Psychosocial or cultural factors may also be important. A person whose parents attached great importance to daily defecation will become greatly concerned when he or she misses a daily bowel movement; some children withhold stool to gain attention or because of fear of pain from anal irritation; and some adults habitually ignore or delay the call to have a bowel movement.

## ■ CAUSES

Pathophysiologically, chronic constipation generally results from inadequate fiber or fluid intake or from disordered colonic transit or anorectal function. These result from neurogastroenterologic disturbance, certain drugs, advancing age, or in association with a large number of systemic diseases that affect the GI tract (Table 46-5). Constipation of recent onset may be a symptom of significant organic disease such as tumor, anorectal irritation, or stricture. In *idiopathic constipation*, a subset of patients exhibits delayed emptying of the ascending and transverse colon with prolongation of transit (often in the proximal colon) and a reduced frequency of propulsive HAPCs. *Outlet obstruction to defecation* (also called *evacuation disorders*) accounts for about a quarter of cases presenting with constipation in tertiary care and may cause delayed colonic transit, which is usually corrected by biofeedback retraining of the disordered defecation. Constipation of any cause may be exacerbated by hospitalization or chronic illnesses that lead to physical or mental impairment and result in inactivity or physical immobility.

## APPROACH TO THE PATIENT

### Constipation

A careful history should explore the patient's symptoms and confirm whether she or he is indeed constipated based on frequency (e.g., fewer than three bowel movements per week), consistency (lumpy/hard), excessive straining, prolonged defecation time, or need to support the perineum or digitate the anorectum to facilitate stool evacuation. These latter items identified in the history suggest the presence of a rectal evacuation disorder. In the vast majority of cases (probably >90%), there is no underlying cause (e.g., cancer, depression, or hypothyroidism), and constipation responds to ample hydration, exercise, and supplementation of dietary fiber (15–25 g/d). A good diet and medication history and attention to psychosocial issues are key. Physical examination and, particularly, rectal examination are mandatory and should exclude fecal impaction and most of the important diseases that present with constipation and possibly indicate features suggesting an evacuation disorder (e.g., high anal sphincter tone, failure of perineal descent, or paradoxical puborectalis contraction or puborectalis tenderness during straining to simulate stool evacuation).

The presence of weight loss, rectal bleeding, or anemia with constipation mandates either flexible sigmoidoscopy plus

barium enema or colonoscopy alone, particularly in patients aged >40 years, to exclude structural diseases such as cancer or strictures. Colonoscopy alone is most cost-effective in this setting because it provides an opportunity to biopsy mucosal lesions, perform polypectomy, or dilate strictures. Barium enema has advantages over colonoscopy in the patient with isolated constipation because it is less costly and identifies colonic dilation and all significant mucosal lesions or strictures that are likely to present with constipation. Melanosis coli, or pigmentation of the colon mucosa, indicates the use of anthraquinone laxatives such as cascara or senna; however, this is usually apparent from a careful history. An unexpected disorder such as megacolon or cathartic colon may also be detected by colonic radiographs. Measurement of serum calcium, potassium, and thyroid-stimulating hormone levels will identify rare patients with metabolic disorders.

Patients with more troublesome constipation may not respond to fiber alone and may be helped by a bowel-training regimen, which involves taking an osmotic laxative (e.g., magnesium salts, lactulose, sorbitol, polyethylene glycol) and evacuating with enema or suppository (e.g., glycerin or bisacodyl) as needed. After breakfast, a distraction-free 15–20 min on the toilet without straining is encouraged. Excessive straining may lead to development of hemorrhoids and, if there is weakness of the pelvic floor or injury to the pudendal nerve, may result in obstructed defecation from descending perineum syndrome several years later. Those few who do not benefit from the simple measures delineated above or require long-term treatment or fail to respond to potent laxatives should undergo further investigation (Fig. 46-5). Novel agents that induce secretion (e.g., lubiprostone, a chloride channel activator, or linaclotide, a guanylate cyclase C agonist that activates chloride secretion) are also available.

## ■ INVESTIGATION OF SEVERE CONSTIPATION

A small minority (probably <5%) of patients have severe or “intractable” constipation; about 25% have evacuation disorders. These are the patients most likely to require evaluation by gastroenterologists or in referral centers. Further observation of the patient may occasionally

TABLE 46-5 Causes of Constipation in Adults

TYPES OF CONSTIPATION AND CAUSES	EXAMPLES
<b>Recent Onset</b>	
Colonic obstruction	Neoplasm; stricture: ischemic, diverticular, inflammatory
Anal sphincter spasm	Anal fissure, painful hemorrhoids
Medications	
<b>Chronic</b>	
Irritable bowel syndrome	Constipation-predominant, alternating
Medications	Ca <sup>2+</sup> blockers, antidepressants
Colonic pseudoobstruction	Slow-transit constipation, megacolon (rare Hirschsprung's, Chagas' diseases)
Disorders of rectal evacuation	Pelvic floor dysfunction; anismus; descending perineum syndrome; rectal mucosal prolapse; rectocele
Endocrinopathies	Hypothyroidism, hypercalcemia, pregnancy
Psychiatric disorders	Depression, eating disorders, drugs
Neurologic disease	Parkinsonism, multiple sclerosis, spinal cord injury
Generalized muscle disease	Progressive systemic sclerosis

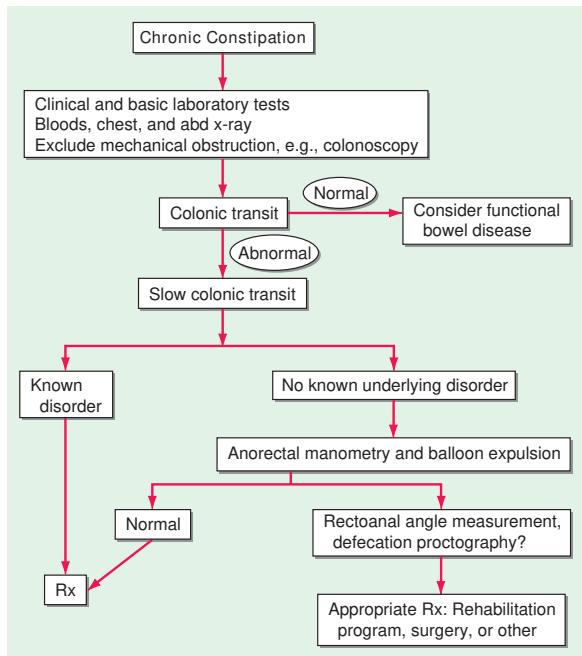


FIGURE 46-5 Algorithm for the management of constipation. abd, abdominal; Rx, treatment.

reveal a previously unrecognized cause, such as an evacuation disorder, laxative abuse, malingering, or psychological disorder. In these patients, evaluations of the physiologic function of the colon and pelvic floor and of psychological status aid in the rational choice of treatment. Even among these highly selected patients with severe constipation, a cause can be identified in only about one-third of tertiary referral patients, with the others being diagnosed with normal transit constipation. Since evacuation disorders also retard colonic transit through the left colon or the entire colon, anorectal and pelvic floor testing should precede transit measurements if there is clinical suspicion of an evacuation disorder. If an evacuation disorder is identified on testing, colonic transit may be unnecessary.

**Measurement of Colonic Transit** Radiopaque marker transit tests are easy, repeatable, generally safe, inexpensive, reliable, and highly applicable in evaluating constipated patients in clinical practice. Several validated methods are very simple. For example, radiopaque markers are ingested; an abdominal flat film taken 5 days later should indicate passage of 80% of the markers out of the colon without the use of laxatives or enemas. This test does not provide useful information about the transit profile of the stomach and small bowel. An alternative approach involves ingestion of 24 radiopaque markers on 3 successive days and an abdominal radiograph on the fourth day. The number of markers counted in the radiograph is an estimate of the colonic transit in hours. The collection of gas in the rectum between the level of the ischial spines and the lower border of the sacroiliac joints may suggest the presence of a rectal evacuation disorder as the cause of constipation.

Radioscintigraphy with a delayed-release capsule containing radiolabeled particles has been used to noninvasively characterize normal, accelerated, or delayed colonic function over 24–48 h with low radiation exposure. This approach simultaneously assesses gastric, small bowel (which may be important in ~20% of patients with delayed colonic transit because they reflect a more generalized GI motility disorder), and colonic transit. The disadvantages are the greater cost and the need for specific materials prepared in a nuclear medicine laboratory.

**Anorectal and Pelvic Floor Tests** Pelvic floor dysfunction is suggested by the inability to evacuate the rectum, a feeling of persistent rectal fullness, rectal pain, the need to extract stool from the rectum digitally, application of pressure on the posterior wall of the vagina, support of the perineum during straining, and excessive straining. These significant symptoms should be contrasted with the simple sense of incomplete rectal evacuation, which is common in IBS.

Formal psychological evaluation may identify eating disorders, “control issues,” depression, or posttraumatic stress disorders that may respond to cognitive or other intervention and may be important in restoring quality of life to patients who might present with chronic constipation.

A simple clinical test in the office to document a nonrelaxing puborectalis muscle is to have the patient strain to expel the index finger during a digital rectal examination. Motion of the puborectalis posteriorly during straining indicates proper coordination of the pelvic floor muscles. Motion anteriorly with paradoxical contraction or limited perineal descent (<1.5 cm) during simulated evacuation indicates pelvic floor dysfunction.

Measurement of perineal descent is relatively easy to gauge clinically by placing the patient in the left decubitus position and watching the perineum to detect inadequate descent (<1.5 cm, a sign of pelvic floor dysfunction) or perineal ballooning during straining relative to bony landmarks (>4 cm, suggesting excessive perineal descent).

A useful overall test of evacuation is the balloon expulsion test. A balloon-tipped urinary catheter is placed and inflated with 50 mL of water. Normally, a patient can expel it while seated on a toilet or in the left lateral decubitus position. In the lateral position, the weight needed to facilitate expulsion of the balloon is determined; normally, expulsion occurs with <200 g added or unaided within 1 minute.

Anorectal manometry, when used in the evaluation of patients with severe constipation, may find an excessively high resting (>80 mmHg) or squeeze anal sphincter tone, suggesting anismus (anal

sphincter spasm). This test also identifies rare syndromes, such as adult Hirschsprung’s disease, by the absence of the rectoanal inhibitory reflex.

Defecography (a dynamic barium enema including lateral views obtained during barium expulsion or a magnetic resonance defecogram) reveals “soft abnormalities” in many patients; the most relevant findings are the measured changes in rectoanal angle, anatomic defects of the rectum such as internal mucosal prolapse, and enteroceles or rectoceles. Surgically remediable conditions are identified in only a few patients. These include severe, whole-thickness intussusception with complete outlet obstruction due to funnel-shaped plugging at the anal canal or an extremely large rectocele that fills preferentially during attempts at defecation instead of expulsion of the barium through the anus. In summary, defecography requires an interested and experienced radiologist, and abnormalities are not pathognomonic for pelvic floor dysfunction. The most common cause of outlet obstruction is failure of the puborectalis muscle to relax; this is not identified by barium defecography but can be demonstrated by magnetic resonance defecography, which provides more information about the structure and function of the pelvic floor, distal colorectum, and anal sphincters.

Neurologic testing (electromyography) is more helpful in the evaluation of patients with incontinence than of those with symptoms suggesting obstructed defecation. The absence of neurologic signs in the lower extremities suggests that any documented denervation of the puborectalis results from pelvic (e.g., obstetric) injury or from stretching of the pudendal nerve by chronic, long-standing straining. Constipation is common among patients with spinal cord injuries, neurologic diseases such as Parkinson’s disease, multiple sclerosis, and diabetic neuropathy.

Spinal-evoked responses during electrical rectal stimulation or stimulation of external anal sphincter contraction by applying magnetic stimulation over the lumbosacral cord identify patients with limited sacral neuropathies with sufficient residual nerve conduction to attempt biofeedback training.

In summary, a balloon expulsion test is an important screening test for anorectal dysfunction. Rarely, an anatomic evaluation of the rectum or anal sphincters and an assessment of pelvic floor relaxation are the tools for evaluating patients in whom obstructed defecation is suspected and is associated with symptoms of rectal mucosal prolapse, pressure of the posterior wall of the vagina to facilitate defecation (suggestive of anterior rectocele), or prior pelvic surgery that may be complicated by enterocele.

## TREATMENT

### Constipation

After the cause of constipation is characterized, a treatment decision can be made. Slow-transit constipation requires aggressive medical or surgical treatment; anismus or pelvic floor dysfunction usually responds to biofeedback management (Fig. 46-5). The remaining ~60% of patients with constipation have normal colonic transit and can be treated symptomatically. Patients with spinal cord injuries or other neurologic disorders require a dedicated bowel regimen that often includes rectal stimulation, enema therapy, and carefully timed laxative therapy.

Patients with constipation are treated with bulk (fiber, psyllium), osmotic (milk of magnesia, lactulose, polyethylene glycol), secretory (lubiprostone, linaclootide, plecanatide, tenapanor), and prokinetic or stimulant laxatives (including diphenyl methanes such as bisacodyl and sodium picosulfate and 5-HT<sub>4</sub> agonists prucalopride and tegaserod). If a 3- to 6-month trial of medical therapies fails, unassociated with obstructed defecation, the patient should be considered for laparoscopic colectomy with ileostomy; however, this should not be undertaken for pain or if there is continued evidence of an evacuation disorder or a generalized GI dysmotility. Referral to a specialized center for further tests of colonic motor function is warranted. The decision to resort to surgery is facilitated by the presence of megacolon and megarectum. The complications after surgery include small-bowel obstruction (11%) and fecal

soiling, particularly at night during the first postoperative year. Frequency of defecation is 3–8 per day during the first year, dropping to 1–3 per day from the second year after surgery.

Patients who have a combined (evacuation and transit/motility) disorder should first pursue pelvic floor retraining (biofeedback and muscle relaxation), psychological counseling, and dietetic advice. If symptoms are intractable despite biofeedback and optimized medical therapy, colectomy and ileorectalostomy could be considered as long as the evacuation disorder is resolved and optimized medical therapy is unsuccessful. In patients with pelvic floor dysfunction alone, biofeedback training has a 70–80% success rate, measured by the acquisition of comfortable stool habits. Attempts to manage pelvic floor dysfunction with operations (internal anal sphincter or puborectalis muscle division) or injections with botulinum toxin have achieved only mediocre success and have been largely abandoned.

## FURTHER READING

- A R et al: Sexually transmitted infections of the anus and rectum. *World J Gastroenterol* 20:15262, 2014.
- B AE, R SS: An update on anorectal disorders for gastroenterologists. *Gastroenterology* 146:37, 2014.
- B AE et al: American Gastroenterological Association technical review on constipation. *Gastroenterology* 144:218, 2013.
- B G et al: Fundamentals of neurogastroenterology: Physiology/motility—sensation. *Gastroenterology* 150:1292, 2016.
- C M et al: Chronic constipation. *Nat Rev Dis Primers* 3:17095, 2017.
- C M et al: Pathophysiology, evaluation, and management of chronic watery diarrhea. *Gastroenterology* 152:515, 2017.
- P AF et al: Burden and cost of gastrointestinal, liver, and pancreatic diseases in the United States: Update 2018. *Gastroenterology* 156:254, 2019.
- R MS et al: ACG Clinical Guideline: Diagnosis, treatment, and prevention of acute diarrheal infections in adults. *Am J Gastroenterol* 111:602, 2016.
- R -T A et al: American College of Gastroenterology. ACG clinical guidelines: Diagnosis and management of celiac disease. *Am J Gastroenterol* 108:656, 2013.
- S W et al: AGA Clinical Practice Guidelines on the laboratory evaluation of functional diarrhea and diarrhea-predominant irritable bowel syndrome in adults (IBS-D). *Gastroenterology* 157:851, 2019.
- U M et al: Gastrointestinal disorders associated with common variable immune deficiency (CVID) and chronic granulomatous disease (CGD). *Curr Gastroenterol Rep* 18:17, 2016.

those with known causes, particularly when the source is neoplastic. Weight loss in older persons is associated with a variety of deleterious effects, including falls and fractures, pressure ulcers, impaired immune function, and decreased functional status. Not surprisingly, significant weight loss is associated with increased mortality, which can range from 9% to as high as 38% within 1–2.5 years in the absence of clinical awareness and attention.

## PHYSIOLOGY OF WEIGHT REGULATION WITH AGING

(See also Chaps. 401 and 476) Among healthy aging people, total body weight peaks in the sixth decade of life and generally remains stable until the ninth decade, after which it gradually falls. In contrast, lean body mass (fat-free mass) begins to decline at a rate of 0.3 kg per year in the third decade, and the rate of decline increases further beginning at age 60 in men and age 65 in women. These changes in lean body mass largely reflect the age-dependent decline in growth hormone secretion and, consequently, circulating levels of insulin-like growth factor type I (IGF-I) that occur with normal aging. Loss of sex steroids, at menopause in women and more gradually in men, also contributes to these changes in body composition. In the healthy elderly, an increase in fat tissue balances the loss in lean body mass until very old age, when loss of both fat and skeletal muscle occurs. Age-dependent changes also occur at the cellular level. Telomeres shorten, and body cell mass—the fat-free portion of cells—declines steadily with aging.

Between ages 20 and 80, mean energy intake is reduced by up to 1200 kcal/d in men and 800 kcal/d in women. Decreased hunger is a reflection of reduced physical activity and loss of lean body mass, producing lower demand for calories and food intake. Several important age-associated physiologic changes also predispose elderly persons to weight loss, such as declining chemosensory function (smell and taste), reduced efficiency of chewing, slowed gastric emptying, and alterations in the neuroendocrine axis, including changes in levels of leptin, cholecystokinin, neuropeptide Y, and other hormones and peptides. These changes are associated with early satiety and a decline in both appetite and the hedonistic appreciation of food. Collectively, they contribute to the “anorexia of aging.” As noted below, these physiologic changes with aging may be accompanied by social isolation, poverty, and immobility, further contributing to undernutrition.

## CAUSES OF UNINTENTIONAL WEIGHT LOSS

Most causes of UWL belong to one of four categories: (1) malignant neoplasms, (2) chronic inflammatory or infectious diseases, (3) metabolic disorders (e.g., hyperthyroidism and diabetes), or (4) psychiatric disorders (Table 47-1). Not infrequently, more than one of these causes can be responsible for UWL. Depending upon patient populations, UWL is caused by malignant disease in a quarter of patients and by organic disease in one-third, with the remainder due to psychiatric disease, medications, or uncertain causes. Risk factors for undiagnosed cancer include a history of smoking, particularly for men, localizing symptoms, and abnormal laboratory tests.

The most common malignant causes of UWL are gastrointestinal, hepatobiliary, hematologic, lung, breast, genitourinary, ovarian, and prostate. Half of all patients with cancer lose some body weight; one-third lose more than 5% of their original body weight, and up to 20% of all cancer deaths are caused directly by cachexia (through immobility and/or cardiac/respiratory failure). The greatest incidence of weight loss is seen among patients with solid tumors. Malignancy that reveals itself through significant weight loss usually has a very poor prognosis.

In addition to malignancies, gastrointestinal diseases are among the most prominent causes of UWL. Peptic ulcer disease, inflammatory bowel disease, dysmotility syndromes, chronic pancreatitis, celiac disease, constipation, and atrophic gastritis are some of the more common entities. Oral and dental problems are easily overlooked and may manifest with halitosis, poor oral hygiene, xerostomia, inability to chew, reduced masticatory force, nonocclusion, temporomandibular joint syndrome, edentulousness, and pain due to caries or abscesses.

Tuberculosis, fungal diseases, parasites, subacute bacterial endocarditis, and HIV are well-documented causes of UWL. Cardiovascular

# 47

## Unintentional Weight Loss

J. Larry Jameson

Involuntary or unintentional weight loss (UWL) is frequently insidious and can have important implications, often serving as a harbinger of serious underlying disease. Clinically important weight loss is defined as the loss of 10 pounds (4.5 kg) or >5% of one's body weight over a period of 6–12 months. UWL is encountered in up to 8% of all adult outpatients and 27% of frail persons aged ≥65 years. There is no identifiable cause in up to one-quarter of patients despite extensive investigation. Conversely, up to half of people who claim to have lost weight have no documented evidence of weight loss. People with no known cause of weight loss generally have a better prognosis than do

TABLE 47-1 Causes of Involuntary Weight Loss

Cancer	Medications
Colon	Sedatives
Hepatobiliary	Antibiotics
Hematologic	Nonsteroidal anti-inflammatory drugs
Lung	Serotonin reuptake inhibitors
Breast	Metformin
Genitourinary	Levodopa
Ovarian	Angiotensin-converting enzyme inhibitors
Prostate	Other drugs
Gastrointestinal disorders	Disorders of the mouth and teeth
Difficulty swallowing	Caries
Malabsorption	Dysgeusia
Peptic ulcer	Age-related factors
Inflammatory bowel disease	Physiologic changes
Pancreatitis	Visual impairment
Obstruction/constipation	Decreased taste and smell
Pernicious anemia	Functional disabilities
Endocrine and metabolic	Neurologic
Hyperthyroidism	Stroke
Diabetes mellitus	Parkinson's disease
Pheochromocytoma	Neuromuscular disorders
Adrenal insufficiency	Dementia
Cardiac disorders	Social
Chronic ischemia	Isolation
Chronic congestive heart failure	Poverty
Respiratory disorders	Psychiatric and behavioral
Emphysema	Depression
Chronic obstructive pulmonary disease	Anxiety
Renal insufficiency	Paranoia
Rheumatologic disease	Bereavement
Infections	Alcoholism
HIV	Eating disorders
Tuberculosis	Increased activity or exercise
Parasitic infection	Idiopathic
Subacute bacterial endocarditis	

and pulmonary diseases cause UWL through increased metabolic demand and decreased appetite and caloric intake. Repeated surgeries may lead to weight loss because of reduced caloric intake and increased metabolic demands resulting from a systemic inflammatory response. Uremia produces nausea, anorexia, and vomiting. Connective tissue diseases may increase metabolic demand and disrupt nutritional balance. As the incidence of diabetes mellitus increases with aging, the associated glucosuria can contribute to weight loss. Hyperthyroidism in the elderly may have less prominent sympathomimetic features and may present as “apathetic hyperthyroidism” or  $T_3$  toxicosis (Chap. 382).

Neurologic injuries such as stroke, quadriplegia, and multiple sclerosis may lead to visceral and autonomic dysfunction that can impair caloric intake. Dysphagia from these neurologic insults is a common mechanism. Functional disability that compromises activities of daily living (ADLs) is a common cause of undernutrition in the elderly. Visual impairment from ophthalmic or central nervous system disorders such as a tremor can limit the ability of people to prepare and eat meals. UWL may be one of the earliest manifestations of Alzheimer’s dementia.

Isolation and depression are significant causes of UWL that may manifest as an inability to care for oneself, including nutritional needs. A cytokine-mediated inflammatory metabolic cascade can be both a cause of and a manifestation of depression. Bereavement can be a cause of UWL and, when present, is often more pronounced in men. More intense forms of mental illness such as paranoid disorders may

lead to delusions about food and cause weight loss. Alcoholism can be a significant source of weight loss and malnutrition.

Elderly persons living in poverty may have to choose whether to purchase food or use the money for other expenses, including medications. Screening questions can probe whether patients have run out of food or whether they routinely purchase less than they need. Institutionalization is an independent risk factor, as up to 30–50% of nursing home patients have inadequate food intake.

Medications can cause anorexia, nausea, vomiting, gastrointestinal distress, diarrhea, dry mouth, and changes in taste. This is particularly an issue in the elderly, many of whom take five or more medications.

## ASSESSMENT

The four major manifestations of UWL are (1) anorexia (loss of appetite), (2) sarcopenia (loss of muscle mass), (3) cachexia (a syndrome that combines weight loss, loss of muscle and adipose tissue, anorexia, and weakness), and (4) dehydration. The current obesity epidemic adds complexity, as excess adipose tissue can mask the development of sarcopenia and delay awareness of the development of cachexia. If it is not possible to measure weight directly, a change in clothing size, corroboration of weight loss by a relative or friend, and a numeric estimate of weight loss provided by the patient are suggestive of true weight loss.

Initial assessment includes a comprehensive history and physical, a complete blood count, tests of liver enzyme levels, C-reactive protein, erythrocyte sedimentation rate, renal function studies, thyroid function tests, chest radiography, and an abdominal ultrasound (Table 47-2). Age-, sex-, and risk factor-specific cancer screening tests, such as mammography and colonoscopy, should be performed (Chap. 70). Patients at risk should have HIV testing. All elderly patients with weight loss should undergo screening for dementia and depression by using instruments such as the Mini-Mental State Examination and the Geriatric Depression Scale, respectively (Chap. 477). The Mini Nutritional Assessment ([www.mna-elderly.com](http://www.mna-elderly.com)) and the Nutrition Screening Initiative (<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1694757/>) are also available for the nutritional assessment of elderly patients. Almost all patients with a malignancy and >90% of those with other organic diseases have at least one laboratory abnormality. In patients presenting with substantial UWL, major organic and malignant diseases are unlikely when

TABLE 47-2 Assessment and Testing for Involuntary Weight Loss

Indications	Laboratory
5% weight loss in 30 d	Complete blood count
10% weight loss in 180 d	Comprehensive electrolyte and metabolic panel, including liver and renal function tests
Body mass index <21	Thyroid function tests
25% of food left uneaten after 7 d	Erythrocyte sedimentation rate
Change in fit of clothing	C-reactive protein
Change in appetite, smell, or taste	Ferritin
Abdominal pain, nausea, vomiting, diarrhea, constipation, dysphagia	HIV testing, if indicated
Assessment	Radiology
Complete physical examination, including dental evaluation	Chest x-ray Abdominal ultrasound
Medication review	
Recommended cancer screening	
Mini-Mental State Examination <sup>a</sup>	
Mini-Nutritional Assessment <sup>a</sup>	
Nutrition Screening Initiative <sup>a</sup>	
Simplified Nutritional Assessment Questionnaire <sup>a</sup>	
Observation of eating <sup>a</sup>	
Activities of daily living <sup>a</sup>	
Instrumental activities of daily living <sup>a</sup>	

<sup>a</sup>May be more specific to assess weight loss in the elderly.

a baseline evaluation is completely normal. Careful follow-up rather than undirected testing is advised because the prognosis of weight loss of undetermined cause is generally favorable.

## TREATMENT

### Unintentional Weight Loss

The first priority in managing weight loss is to identify and treat the underlying causes. Treatment of underlying metabolic, psychiatric, infectious, or other systemic disorders may be sufficient to restore weight and functional status gradually. Medications that cause nausea or anorexia should be withdrawn or changed, if possible. For those with unexplained UWL, oral nutritional supplements such as high-energy drinks sometimes reverse weight loss. Advising patients to consume supplements between meals rather than with a meal may help minimize appetite suppression and facilitate increased overall intake. Orexigenic, anabolic, and anticytokine agents are under investigation. In selected patients, the antidepressant mirtazapine results in a significant increase in body weight, body fat mass, and leptin concentration. Patients with wasting conditions who can comply with an appropriate exercise program gain muscle protein mass, strength, and endurance and may be more capable of performing ADLs.

A

*The author is grateful to Russell G. Robertson, MD, for contributions to this chapter in prior editions.*

### FURTHER READING

- A SM et al: An approach to the management of unintentional weight loss in elderly people. *CMAJ* 172:773, 2005.
- G HL, H K: Unintentional weight loss in older adults. *Am Fam Physician* 89:718, 2014.
- M M J et al: Investigation and management of unintentional weight loss in older adults. *BMJ* 342:d1732, 2011.
- N BD et al: Prioritising primary care patients with unexpected weight loss for cancer investigation. *BMJ* 370:m2651, 2020.
- V S et al: The diagnostic spectrum of unintentional weight loss. *Eur J Intern Med* 16:160, 2005.
- W CJ: Involuntary weight loss. *Med Clin North Am* 98:625, 2014.

## SOURCES OF GASTROINTESTINAL BLEEDING

**Upper Gastrointestinal Sources of Bleeding • PEPTIC ULCERS** Peptic ulcers are the most common cause of upper GIB (UGIB), accounting for ~50% of UGIB hospitalizations. Features of an ulcer at endoscopy provide important prognostic information that guides subsequent management decisions (Fig. 48-1). Approximately 20% of patients with bleeding ulcers have the highest-risk findings of active bleeding or a nonbleeding visible vessel; one-third of such patients have further bleeding that requires urgent surgery if they are treated conservatively. These patients benefit from endoscopic therapy such as bipolar electrocoagulation, heater probe, injection therapy (e.g., absolute alcohol, 1:10,000 epinephrine), and/or clips with reductions in bleeding, hospital stay, mortality, and costs. In contrast, patients with clean-based ulcers have rates of serious recurrent bleeding approaching zero. If stable with no other reason for hospitalization, such patients may be discharged home after endoscopy.

Randomized controlled trials document that high-dose, constant-infusion IV proton pump inhibitor (PPI) (80-mg bolus and 8-mg/h infusion), designed to sustain intragastric pH >6 and enhance clot stability, decreases further bleeding and mortality in patients with high-risk ulcers (active bleeding, nonbleeding visible vessel, adherent clot) when given after endoscopic therapy. Meta-analysis of randomized trials indicates that high-dose intermittent PPIs are noninferior to constant-infusion PPI therapy and thus may be substituted. Patients with lower-risk findings (flat pigmented spot or clean base) do not require endoscopic therapy and receive standard doses of oral PPI.

Approximately 10–50% of patients with bleeding ulcers rebleed within the next year if no preventive strategies are employed. Prevention of recurrent bleeding focuses on the three main factors in ulcer pathogenesis, *Helicobacter pylori*, nonsteroidal anti-inflammatory drugs (NSAIDs), and acid. Eradication of *H. pylori* in patients with bleeding ulcers decreases rebleeding rates to <5%. If a bleeding ulcer develops in a patient taking NSAIDs, the NSAIDs should be discontinued. If NSAIDs must be given, a cyclooxygenase (COX)-2 selective NSAID plus a PPI is recommended, based on results of a randomized trial. Patients with established cardiovascular disease who develop bleeding ulcers while taking low-dose aspirin for secondary prevention should restart aspirin as soon as possible after their bleeding episode (1–7 days). A randomized trial showed that immediate reinstitution of aspirin was associated with a lower 8-week mortality compared to not restarting aspirin (1% vs 13%; hazard ratio, 0.2; 95% CI, 0.1–0.6). In contrast, aspirin probably should be discontinued in most patients taking aspirin for primary prevention of cardiovascular events who develop UGIB. Patients with bleeding ulcers unrelated to *H. pylori* or NSAIDs should remain on PPI therapy indefinitely given a 42% incidence of rebleeding at 7 years without protective therapy. **Peptic ulcers are discussed in Chap. 324.**

**MALLORY WEISS TEARS** Mallory-Weiss tears account for ~2–10% of UGIB hospitalizations. The classic history is vomiting, retching, or coughing preceding hematemesis, especially in an alcoholic patient. Bleeding from these tears, which are usually on the gastric side of the gastroesophageal junction, stops spontaneously in ~80–90% of patients and recurs in only 0–10%. Endoscopic therapy is indicated for actively bleeding Mallory-Weiss tears. **Mallory-Weiss tears are discussed in Chap. 323.**

**ESOPHAGEAL VARICES** The proportion of UGIB hospitalizations due to varices varies widely, from ~2–40%, depending on the population. Patients with variceal hemorrhage have poorer outcomes than patients with other sources of UGIB. Esophageal varices are treated with endoscopic ligation and an IV vasoactive medication (octreotide, somatostatin, vaptoreotide, terlipressin) for 2–5 days. Combination of endoscopic and medical therapy is superior to either therapy alone in decreasing rebleeding. Over the long term, treatment with nonselective beta blockers plus endoscopic ligation is recommended because the combination is more effective than either alone in reduction of recurrent esophageal variceal bleeding. Transjugular intrahepatic portosystemic shunt (TIPS) is recommended in patients who have persistent or

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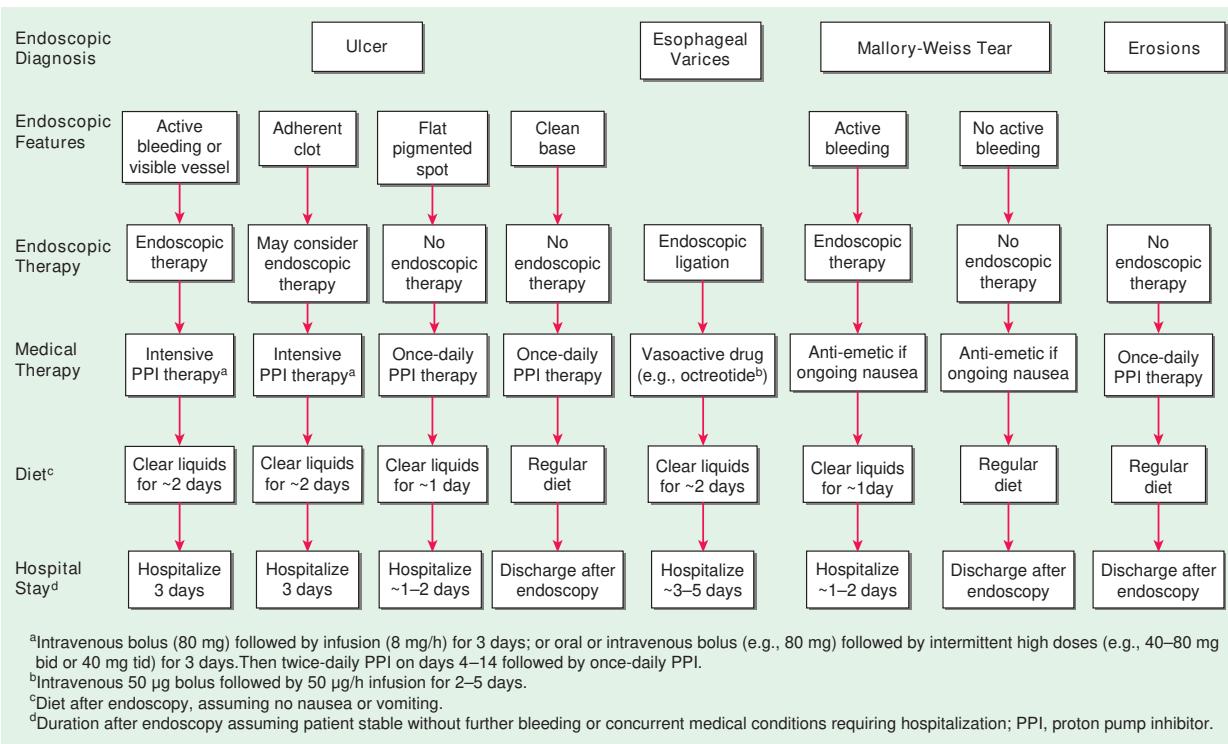
### Gastrointestinal Bleeding

Loren Laine

Gastrointestinal bleeding (GIB) presents as either overt or occult bleeding. **Overt GIB** is manifested by *hematemesis*, vomitus of red blood or “coffee-grounds” material; *melena*, black, tarry stool; and/or *hematochezia*, passage of red or maroon blood from the rectum. In the absence of overt bleeding, **occult GIB** may present with *symptoms of blood loss or anemia* such as lightheadedness, syncope, angina, or dyspnea; with iron-deficiency anemia; or a positive fecal occult blood test on colorectal cancer screening. GIB is also categorized by the site of bleeding as upper, from the esophagus, stomach, or duodenum; lower, from the colon; small intestinal; or obscure GIB if the source is unclear.

GIB is the most common gastrointestinal condition leading to hospitalization in the United States, accounting for ~513,000 admissions and \$5 billion in direct costs annually. The case fatality of patients hospitalized with GIB is ~2% in the United States. Patients generally die from decompensation of other underlying illnesses rather than exsanguination.





<sup>a</sup>Intravenous bolus (80 mg) followed by infusion (8 mg/h) for 3 days; or oral or intravenous bolus (e.g., 80 mg) followed by intermittent high doses (e.g., 40–80 mg bid or 40 mg tid) for 3 days. Then twice-daily PPI on days 4–14 followed by once-daily PPI.

<sup>b</sup>Intravenous 50 µg bolus followed by 50 µg/h infusion for 2–5 days.

<sup>c</sup>Diet after endoscopy, assuming no nausea or vomiting.

<sup>d</sup>Duration after endoscopy assuming patient stable without further bleeding or concurrent medical conditions requiring hospitalization; PPI, proton pump inhibitor.

FIGURE 48-1 Suggested algorithm for patients with acute upper gastrointestinal bleeding based on endoscopic findings.

recurrent bleeding despite endoscopic and medical therapy. TIPS also should be considered in the first 1–2 days of hospitalization for acute variceal bleeding in patients with advanced liver disease (Child-Pugh class B, Child-Pugh class C with score 10–13), because randomized trials show significant decreases in rebleeding and mortality compared with standard endoscopic and medical therapy.

Portal hypertension is also responsible for bleeding from gastric varices, varices in the small and large intestine, and portal hypertensive gastropathy and enterocolopathy. Bleeding gastric varices are treated with endoscopic injection of tissue adhesive (e.g., *n*-butyl cyanoacrylate), if available; if not, TIPS is performed.

**EROSIVE DISEASE** Erosions are endoscopically visualized breaks that are confined to the mucosa and do not cause major bleeding because arteries and veins are not present in the mucosa. Erosions in the esophagus, stomach, or duodenum commonly cause mild UGIB, with erosive gastritis and duodenitis accounting for perhaps ~10–15% and erosive esophagitis (primarily due to gastroesophageal reflux disease) accounting for ~1–10% of UGIB hospitalizations. The most important cause of gastric and duodenal erosions is NSAID use: ~50% of patients who chronically ingest NSAIDs may have gastric erosions. Other potential causes of gastric erosions include alcohol intake, *H. pylori* infection, and stress-related mucosal injury.

Stress-related gastric mucosal injury occurs only in extremely sick patients, such as those with serious trauma, major surgery, burns covering more than one-third of the body surface area, major intracranial disease, or severe medical illness (e.g., ventilator dependence, coagulopathy). Severe bleeding should not develop unless ulceration occurs. The mortality rate in these patients is high because of their serious underlying illnesses.

The incidence of bleeding from stress-related gastric mucosal injury has decreased dramatically in recent years, most likely due to better care of critically ill patients. A recent double-blind placebo-controlled randomized trial in 3282 intensive care patients with risk factors for GIB showed a small benefit of PPI in clinically important bleeding (2.5% vs 4.2%) without a difference in mortality or infections (e.g.,

*Clostridium difficile*, pneumonia). Thus, pharmacologic prophylaxis for bleeding has limited benefit but may be considered in the high-risk patients mentioned above. Meta-analyses of randomized trials suggest PPIs are more effective than H<sub>2</sub>-receptor antagonists in reduction of overt and clinically important UGIB without differences in mortality or nosocomial pneumonia.

**OTHER CAUSES** Less common causes of UGIB include neoplasms, vascular ectasias (including hereditary hemorrhagic telangiectasias [Osler-Weber-Rendu] and gastric antral vascular ectasia ["watermelon stomach"]), Dieulafoy's lesion (in which an aberrant vessel in the mucosa bleeds from a pinpoint mucosal defect), prolapse gastropathy (prolapse of proximal stomach into esophagus with retching, especially in alcoholics), aortoenteric fistulas, and hemobilia or hemosuccus pancreaticus (bleeding from the bile duct or pancreatic duct).

**Small-Intestinal Sources of Bleeding** Patients without a source of GIB identified on upper endoscopy and colonoscopy were previously labeled as having obscure GIB. With the advent of improved diagnostic modalities, ~75% of GIB previously labeled obscure is now estimated to originate in the small intestine beyond the extent of a standard upper endoscopic exam. Small-intestinal GIB may account for ~5% of GIB cases. The most common causes in adults include vascular ectasias, neoplasm (e.g., gastrointestinal stromal tumor, carcinoid, adenocarcinoma, lymphoma, metastases), and NSAID-induced erosions and ulcers. Meckel's diverticulum is the most common cause of significant small-intestinal GIB in children, decreasing in frequency as a cause of bleeding with age. Other less common causes of small-intestinal GIB include Crohn's disease, infection, ischemia, vasculitis, small-bowel varices, diverticula, intussusception, Dieulafoy's lesions, aortoenteric fistulas, and duplication cysts.

Small-intestinal vascular ectasias are treated with endoscopic therapy, if possible, based on observational studies suggesting initial efficacy. However, rebleeding is common: 45% over a mean follow-up of 26 months in a systematic review. Estrogen/progesterone compounds are not recommended because a multicenter double-blind trial found no benefit in prevention of recurrent bleeding. Octreotide is used,

based on positive results from case series but no randomized trials. A randomized trial reported significant benefit of thalidomide and awaits further confirmation. Other isolated lesions, such as tumors, generally require surgical resection.

**Colonic Sources of Bleeding** Hemorrhoids are probably the most common cause of lower GIB (LGIB); anal fissures also cause minor bleeding and pain. If these local anal processes, which rarely require hospitalization, are excluded, the most common cause of LGIB in adults is diverticulosis. Other causes include vascular ectasias (especially in the proximal colon of patients >70 years), neoplasms (primarily adenocarcinoma), colitis (ischemic, infectious, Crohn's or ulcerative colitis, NSAID-induced colitis or ulcers), postpolypectomy bleeding, and radiation proctopathy. Rarer causes include solitary rectal ulcer syndrome, varices (most commonly rectal), lymphoid nodular hyperplasia, vasculitis, trauma, and aortocolic fistulas. In children and adolescents, the most common colonic causes of significant GIB are inflammatory bowel disease and juvenile polyps.

Diverticular bleeding is abrupt in onset, usually painless, sometimes massive, and often from the right colon; chronic or occult bleeding is not characteristic. Case series from the United States and Europe suggest colonic diverticula stop bleeding spontaneously in ~90% of patients, with rebleeding on long-term follow-up as low as ~15% over 4–5 years. Rebleeding is substantially higher in reports from Asia. Case series suggest endoscopic therapy may decrease recurrent bleeding in the uncommon case when colonoscopy identifies the specific bleeding diverticulum. When diverticular bleeding is found at angiography, transcatheter arterial embolization by superselective technique stops bleeding in a majority of patients. Segmental surgical resection is recommended for persistent or refractory diverticular bleeding.

Bleeding from colonic vascular ectasias may be overt or occult; it tends to be chronic and only occasionally hemodynamically significant. Endoscopic hemostatic therapy may be used in the treatment of vascular ectasias, as well as discrete bleeding ulcers and post-polypectomy bleeding. Transcatheter arterial embolization also may be attempted for persistent bleeding from vascular ectasias and other discrete lesions. Surgical therapy is generally required for major persistent or recurrent bleeding from colonic sources that cannot be treated medically, endoscopically, or angiographically. Patients with Heyde's syndrome (bleeding vascular ectasias and aortic stenosis) appear to benefit from aortic valve replacement.

## APPROACH TO THE PATIENT

### Gastrointestinal Bleeding

#### INITIAL ASSESSMENT

Measurement of the heart rate and blood pressure is the best way to initially assess a patient with GIB. Clinically significant bleeding leads to postural changes in heart rate or blood pressure, tachycardia, and, finally, recumbent hypotension. In contrast, hemoglobin does not fall immediately with acute GIB, due to proportionate reductions in plasma and red cell volumes ("people bleed whole blood"). Thus, hemoglobin may be normal or only minimally decreased at initial presentation of a severe bleeding episode. As extravascular fluid enters the vascular space to restore volume, the hemoglobin falls, but this process may take up to 72 h. Transfusion is recommended when the hemoglobin drops below 7 g/dL, based on a large randomized trial showing this restrictive transfusion strategy decreases rebleeding and death in acute UGIB compared with a transfusion threshold of 9 g/dL. Patients with slow, chronic GIB may have very low hemoglobin values despite normal blood pressure and heart rate. With the development of iron-deficiency anemia, the mean corpuscular volume is low and red blood cell distribution width is increased.

#### DIFFERENTIATION OF UGIB FROM LGIB

Hematemesis indicates an UGIB source. Melena indicates blood has been present in the gastrointestinal (GI) tract for ≥14 h and as

long as 3–5 days. The more proximal the bleeding site, the more likely melena will occur. Hematochezia usually represents a lower GI source of bleeding, although an upper GI lesion may bleed so briskly that blood transits the bowel before melena develops. When hematochezia is the presenting symptom of UGIB, it is associated with hemodynamic instability and dropping hemoglobin. Bleeding lesions of the small bowel may present as melena or hematochezia. Other clues to UGIB include hyperactive bowel sounds and an elevated blood urea nitrogen (due to volume depletion and blood proteins absorbed in the small intestine).

A nonbloody nasogastric aspirate may be seen in ~15% of patients with UGIB who present with clinically serious hematochezia. A bile-stained appearance does not exclude UGIB because reports of bile in the aspirate are incorrect in ~50% of cases. Testing of aspirates that are not grossly bloody for occult blood is not useful.

#### EVALUATION AND MANAGEMENT OF UGIB (FIG. 48-1)

**Initial Risk Assessment** Baseline characteristics predictive of rebleeding and death include hemodynamic compromise (tachycardia or hypotension), increasing age, and comorbidities. Risk assessment tools may be used to identify patients with very low risk. Discharge from the emergency room with outpatient management has been suggested for patients with a Glasgow-Blatchford score (possible range 0–23, Table 48-1) of 0–1 because only ~1% of patients who require transfusion, require hemostatic intervention, or die have a score of 0–1.

**Pre-Endoscopic Medications** PPI infusion may be considered at presentation; it decreases high-risk ulcer stigmata (e.g., active bleeding) and need for endoscopic therapy but does not improve clinical outcomes such as further bleeding, surgery, or death. The promotility agent erythromycin, 250 mg intravenously ~30–90 min before endoscopy, is suggested to improve visualization at endoscopy, thereby reducing the need for repeat endoscopy and hospital stay. Cirrhotic patients presenting with UGIB should be given an antibiotic (e.g., ceftriaxone) and IV vasoactive medication (e.g., octreotide) upon presentation. Antibiotics decrease bacterial infections, rebleeding, and mortality, and vasoactive medications may improve control of bleeding in the 12 h after presentation.

**Endoscopy** Upper endoscopy should be performed within 24 h in most patients hospitalized with UGIB whether they have clinical features predicting low risk or high risk of further bleeding

TABLE 48-1 Glasgow-Blatchford Score

RISK FACTORS AT ADMISSION	SCORE
Blood urea nitrogen (mg/dL)	
18.2 to <22.4	2
22.4 to <28.0	3
28.0 to <70.0	4
≥70.0	6
Hemoglobin (g/dL)	
12.0 to <13.0 (men); 10.0 to <12.0 (women)	1
10.0 to <12.0 (men)	3
<10.0	6
Systolic blood pressure (mmHg)	
100–109	1
90–99	2
<90	3
Heart rate (beats per minute)	
≥100	1
Melena	1
Syncope	2
Hepatic disease	2
Cardiac failure	2

and death. Even in high-risk patients, more urgent endoscopy (performed within 6 h of gastroenterology consultation) does not improve clinical outcomes. Early endoscopy in low-risk patients (e.g., hemodynamically stable without severe comorbidities) identifies low-risk findings (e.g., clean-based ulcers, erosions, nonbleeding Mallory-Weiss tears) that allow discharge in  $\geq 40\%$  of patients, thereby reducing hospital stay and costs. Patients with high-risk endoscopic findings (e.g., varices, ulcers with active bleeding or a visible vessel) benefit from hemostatic therapy at endoscopy.

#### EVALUATION AND MANAGEMENT OF LGIB (FIG. 48-2)

Patients with hematochezia and hemodynamic instability should have upper endoscopy to rule out an upper GI source before evaluation of the lower GI tract.

Colonoscopy after an oral lavage solution is the procedure of choice in most patients admitted with LGIB unless bleeding is too massive, in which case angiography is recommended. Computed tomography (CT) angiography is often suggested prior to angiography to document evidence and location of active bleeding. Sigmoidoscopy is used primarily in patients  $<40$  years old with minor bleeding. In patients with no source identified on colonoscopy, imaging studies may be employed.  $^{99m}\text{Tc}$ -labeled red cell scan allows repeated imaging for up to 24 h and may identify the general location of bleeding. However, CT angiography is increasingly used instead because it is likely superior and more readily available. In active LGIB, angiography can detect the site of bleeding (extravasation of contrast into the gut) and permits treatment with transcatheter arterial embolization.

#### EVALUATION AND MANAGEMENT OF SMALL-INTESTINAL OR OBSCURE GIB

In patients with massive bleeding suspected to be from the small intestine, current guidelines suggest angiography as the initial test, with CT angiography or  $^{99m}\text{Tc}$ -labeled red cell scan prior to

angiography if the patient's clinical status permits. For others, repeat upper and lower endoscopy may be considered as the initial evaluation because second-look procedures identify a source in up to  $\sim 25\%$  of upper endoscopies and colonoscopies; a push enteroscopy, usually performed with a pediatric colonoscope to inspect the entire duodenum and proximal jejunum, may be substituted for a repeat standard upper endoscopy. If second-look procedures are negative, evaluation of the entire small intestine is performed, usually with video capsule endoscopy. A systematic review of comparative studies showed the yield of "clinically significant findings" to be greater with capsule than push enteroscopy (56% vs 26%) or small bowel barium radiography (42% vs 6%). However, capsule endoscopy does not allow full visualization of the small intestine, tissue sampling, or application of therapy.

CT enterography may be used initially instead of video capsule in patients with possible small bowel narrowing (e.g., stricture, prior surgery or radiation, Crohn's disease) and may follow a negative video capsule for suspected small-intestinal GIB, given its higher sensitivity for small-intestinal masses.

If capsule endoscopy is positive, management is dictated by the finding. If capsule endoscopy is negative, clinically stable patients may be observed and treated with iron if iron deficiency is present, while those with ongoing bleeding (e.g., need for transfusions) undergo further testing. A second capsule endoscopy may be considered because it is reported to identify a source in up to  $\sim 50\%$  of cases. "Deep" enteroscopy (double-balloon, single-balloon, or spiral enteroscopy) is commonly the next test after capsule endoscopy for clinically important GIB documented or suspected to be from the small intestine because it allows the endoscopist to examine, obtain specimens from, and provide therapy to much or all of the small intestine. Other imaging techniques sometimes used in evaluation of obscure GIB include  $^{99m}\text{Tc}$ -labeled red blood cell scintigraphy, CT angiography, angiography, and  $^{99m}\text{Tc}$ -pertechnetate scintigraphy for Meckel's

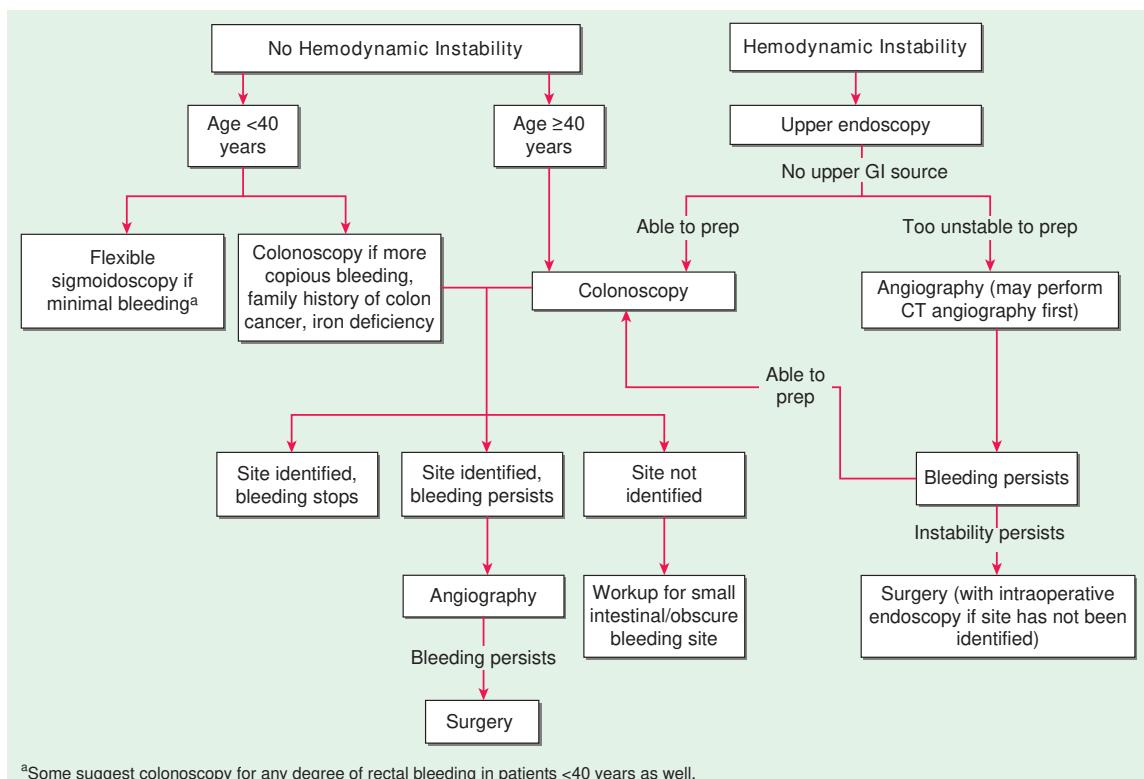


FIGURE 48-2 Suggested algorithm for patients with acute lower gastrointestinal bleeding.

diverticulum (especially in young patients). If all tests are unrevealing, intraoperative endoscopy is indicated in patients with severe recurrent or persistent bleeding requiring repeated transfusions.

#### POSITIVE FECAL OCULT BLOOD TEST

Fecal occult blood testing is recommended only for colorectal cancer screening, beginning at age 45–50 years in average-risk adults. A positive test necessitates colonoscopy. If evaluation of the colon is negative, further workup is not recommended unless iron-deficiency anemia or GI symptoms are present.

#### ■ FURTHER READING

- G -T G et al: Portal hypertensive bleeding in cirrhosis: Risk stratification, diagnosis, and management: 2016 practice guidance by the American Association for the Study of Liver Diseases. *Hepatology* 65:310, 2017.
- G SR et al: The role of endoscopy in the management of suspected small-bowel bleeding. *Gastrointest Endosc* 85:22, 2017.
- K M et al: Pantoprazole in patients at risk for gastrointestinal bleeding in the ICU. *N Engl J Med* 379:2199, 2018.
- L L et al: ACG clinical guideline: Upper gastrointestinal and ulcer bleeding. *Am J Gastroenterol* 116:899, 2021.
- L JYW et al: Timing of endoscopy for acute upper gastrointestinal bleeding. *N Engl J Med* 382:1299, 2020.
- P AF et al: Burden and cost of gastrointestinal, liver, and pancreatic diseases in the United States: Update 2018. *Gastroenterology* 156:254, 2019.
- S AJ, L L: Management of acute upper gastrointestinal bleeding. *BMJ* 364:i536, 2019.
- S LL, G KM: ACG clinical guideline: Management of patients with acute lower gastrointestinal bleeding. *Am J Gastroenterol* 111:459, 2016.
- V C et al: Transfusion strategies for acute upper gastrointestinal bleeding. *N Engl J Med* 368:11, 2013.

oranges that contain carotene. In jaundice, the yellow coloration of the skin is uniformly distributed over the body, whereas in carotenoderma, the pigment is concentrated on the palms, soles, forehead, and nasolabial folds. Carotenoderma can be distinguished from jaundice by the sparing of the sclerae. Quinacrine causes a yellow discoloration of the skin in 4–37% of patients treated with it. It has also been reported with the use of tyrosine kinase inhibitors sunitinib and sorafenib.

Another sensitive indicator of increased serum bilirubin is darkening of the urine, which is due to the renal excretion of conjugated bilirubin. Patients often describe their urine as tea- or cola-colored. Bilirubin indicates an elevation of the direct serum bilirubin fraction and, therefore, the presence of liver or biliary disease.

Serum bilirubin levels increase when an imbalance exists between bilirubin production and clearance. A logical evaluation of the patient who is jaundiced requires an understanding of bilirubin production and metabolism.

#### ■ PRODUCTION AND METABOLISM OF BILIRUBIN

(See Chap. 338) Bilirubin, a tetrapyrrole pigment, is a breakdown product of heme (ferroprotoporphyrin IX). About 80–85% of the 4 mg/kg body weight of bilirubin produced each day is derived from the breakdown of hemoglobin in senescent red blood cells. The remainder comes from prematurely destroyed erythroid cells in bone marrow and from the turnover of hemoproteins such as myoglobin and cytochromes found in tissues throughout the body.

The formation of bilirubin occurs in reticuloendothelial cells, primarily in the spleen and liver. The first reaction, catalyzed by the microsomal enzyme heme oxygenase, oxidatively cleaves the  $\alpha$  bridge of the porphyrin group and opens the heme ring. The end products of this reaction are biliverdin, carbon monoxide, and iron. The second reaction, catalyzed by the cytosolic enzyme biliverdin reductase, reduces the central methylene bridge of biliverdin and converts it to bilirubin. Bilirubin formed in the reticuloendothelial cells is virtually insoluble in water due to tight internal hydrogen bonding between the water-soluble moieties of bilirubin—that is, the bonding of the propionic acid carboxyl groups of one dipyrrolic half of the molecule with the imino and lactam groups of the opposite half. This configuration blocks solvent access to the polar residues of bilirubin and places the hydrophobic residues on the outside. To be transported in blood, bilirubin must be solubilized. Solubilization is accomplished by the reversible, noncovalent binding of bilirubin to albumin. Unconjugated bilirubin bound to albumin is transported to the liver. There, the bilirubin—but not the albumin—is taken up by hepatocytes via a process that at least partly involves carrier-mediated membrane transport. No specific bilirubin transporter has yet been identified (Chap. 338, Fig. 338-1).

After entering the hepatocyte, unconjugated bilirubin is bound in the cytosol to several proteins including proteins in the glutathione-S-transferase superfamily. These proteins serve both to reduce efflux of bilirubin back into the serum and to present the bilirubin for conjugation. In the endoplasmic reticulum, bilirubin is made aqueous soluble by conjugation to glucuronic acid, a process that disrupts the hydrophobic internal hydrogen bonds and yields bilirubin monoglucuronide and diglucuronide. The conjugation of glucuronic acid to bilirubin is catalyzed by bilirubin uridine diphosphate-glucuronosyl transferase (UDPGT). The now-hydrophilic bilirubin conjugates diffuse from the endoplasmic reticulum to the canalicular membrane, where bilirubin monoglucuronide and diglucuronide are actively transported into canalicular bile by an energy-dependent mechanism involving the multidrug resistance-associated protein 2 (MRP2). A portion of bilirubin glucuronides is transported into the sinusoids and portal circulation by MRP3 and is subjected to reuptake into the hepatocyte by the sinusoidal organic anion transport protein 1B1 (OATP1B1) and OATP1B3. The conjugated bilirubin excreted into bile drains into the duodenum and passes unchanged through the proximal small bowel. Conjugated bilirubin is not reabsorbed by the intestinal mucosa due to its hydrophilicity and increased molecular size. When the conjugated bilirubin reaches the distal ileum and colon, it is hydrolyzed to unconjugated bilirubin by bacterial  $\beta$ -glucuronidases.

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## Jaundice

Savio John, Daniel S. Pratt



Jaundice is a yellowish discoloration of body tissues resulting from the deposition of bilirubin. Tissue deposition of bilirubin occurs only in the presence of serum hyperbilirubinemia and is a sign of either liver disease or, less often, a hemolytic disorder or disorder of bilirubin metabolism. The degree of serum bilirubin elevation can be estimated by physical examination. Slight increases in serum bilirubin level are best detected by examining the sclerae for icterus. Sclerae have a particular affinity for bilirubin due to their high elastin content, and the presence of scleral icterus indicates a serum bilirubin level of at least 51  $\mu$ mol/L (3 mg/dL). The ability to detect scleral icterus is made more difficult if the examining room has fluorescent lighting. If the examiner suspects scleral icterus, a second site to examine is underneath the tongue. As serum bilirubin levels rise, the skin will eventually become yellow in light-skinned patients and even green if the process is long-standing; the green color is produced by oxidation of bilirubin to biliverdin.

The differential diagnosis for yellowing of the skin is limited. In addition to jaundice, it includes carotenoderma; the use of drugs including quinacrine, sunitinib, and sorafenib; and excessive exposure to phenols. Carotenoderma, a yellow coloring of the skin, is associated with diabetes, hypothyroidism, and anorexia nervosa, but most commonly, it is caused by the ingestion of an excessive amounts of vegetables and fruits such as carrots, leafy vegetables, squash, peaches, and

The unconjugated bilirubin is reduced by normal gut bacteria to form a group of colorless tetrapyrroles called *urobilinogens* and other products, the nature and relative amounts of which depend on the bacterial flora. About 80–90% of these products are excreted in feces, either unchanged or oxidized to orange derivatives called *urobilins*. The remaining 10–20% of the urobilinogens undergo enterohepatic cycling. A small fraction (usually <3 mg/dL) escapes hepatic uptake, filters across the renal glomerulus, and is excreted in urine. Increased urinary excretion of urobilinogen can be due to increased bilirubin production, increased hepatic reabsorption of urobilinogen from the colon, or decreased hepatic clearance of urobilinogen.

### MEASUREMENT OF SERUM BILIRUBIN

The terms *direct* and *indirect* bilirubin—that is, conjugated and unconjugated bilirubin, respectively—are based on the original van den Bergh reaction. This assay, or a variation of it, is still used in most clinical chemistry laboratories to determine the serum bilirubin level. In this assay, bilirubin is exposed to diazotized sulfanilic acid and splits into two relatively stable dipyrromethene azopigments that absorb maximally at 540 nm, allowing photometric analysis. The direct fraction is that which reacts with diazotized sulfanilic acid in the absence of an accelerator substance such as alcohol. The direct fraction provides an approximation of the conjugated bilirubin level in serum. The *total* serum bilirubin is the amount that reacts after the addition of alcohol. The indirect fraction is the difference between the total and the direct bilirubin levels and provides an estimate of the unconjugated bilirubin in serum. Unconjugated bilirubin also reacts with diazo reagents, albeit slowly, even when the accelerator is absent. Thus, the calculated indirect bilirubin may underestimate the true amount of unconjugated bilirubin in circulation.

With the van den Bergh method, the normal serum bilirubin concentration usually is between 17 and 26  $\mu\text{mol/L}$  (1 and 1.5 mg/dL). Total serum bilirubin concentrations are between 3.4 and 15.4  $\mu\text{mol/L}$  (0.2 and 0.9 mg/dL) in 95% of a normal population. Unconjugated hyperbilirubinemia is present when the direct fraction is <15% of the total serum bilirubin. The presence of even limited amounts of true conjugated bilirubin in serum suggests significant hepatobiliary pathology. As conjugated hyperbilirubinemia is always associated with bilirubinuria (except in the presence of delta bilirubin in prolonged cholestasis when jaundice is overt), detection of bilirubin in urine via dipstick test is extremely helpful to confirm the presence of conjugated hyperbilirubinemia in a patient with mildly elevated direct fraction.

Several new techniques, although less convenient to perform, have added considerably to our understanding of bilirubin metabolism. First, studies using these methods demonstrate that, in normal persons or those with Gilbert's syndrome, almost 100% of the serum bilirubin is unconjugated; <3% is monoconjugated bilirubin. Second, in jaundiced patients with hepatobiliary disease, the total serum bilirubin concentration measured by these new, more accurate methods is lower than the values found with diazo methods. This finding suggests that there are diazo-positive compounds distinct from bilirubin in the serum of patients with hepatobiliary disease. Third, these studies indicate that, in jaundiced patients with hepatobiliary disease, monoglucuronides of bilirubin predominate over diglucuronides. Fourth, part of the direct-reacting bilirubin fraction includes conjugated bilirubin that is covalently linked to albumin. This albumin-linked fraction of conjugated bilirubin (*delta fraction*, *delta bilirubin*, or *biliprotein*) represents an important fraction of total serum bilirubin in patients with cholestasis and hepatobiliary disorders. The delta bilirubin is formed in serum when hepatic excretion of bilirubin glucuronides is impaired and the glucuronides accumulate in serum. By virtue of its tight binding to albumin, the clearance rate of delta bilirubin from serum approximates the half-life of albumin (12–14 days) rather than the short half-life of bilirubin (about 4 h).

The prolonged half-life of albumin-bound conjugated bilirubin accounts for two previously unexplained enigmas in jaundiced patients with liver disease: (1) that some patients with conjugated hyperbilirubinemia do not exhibit bilirubinuria during the recovery phase of their

disease because the delta bilirubin, although conjugated, is covalently bound to albumin and therefore not filtered by the renal glomeruli, and (2) that the elevated serum bilirubin level declines more slowly than expected in some patients who otherwise appear to be recovering satisfactorily. Late in the recovery phase of hepatobiliary disorders, all the conjugated bilirubin may be in the albumin-linked form.

### MEASUREMENT OF URINE BILIRUBIN

Unconjugated bilirubin is always bound to albumin in the serum, is not filtered by the kidney, and is not found in the urine. Conjugated bilirubin is filtered at the glomerulus, and the majority is reabsorbed by the proximal tubules; a small fraction is excreted in the urine. Any bilirubin found in the urine is conjugated bilirubin. The presence of bilirubinuria on urine dipstick test (Ictotest) indicates an elevation of the conjugated bilirubin fraction that cannot be excreted from the liver and implies the presence of hepatobiliary disease. A false-negative result is possible in patients with prolonged cholestasis due to the predominance of delta bilirubin, which is covalently bound to albumin and therefore not filtered by the renal glomeruli.

## APPROACH TO THE PATIENT

### Jaundice

The goal of this chapter is not to provide an encyclopedic review of every condition that causes jaundice. Rather, the chapter is intended to offer a framework that helps a physician to evaluate the patient with jaundice in a logical way (Fig. 49-1).

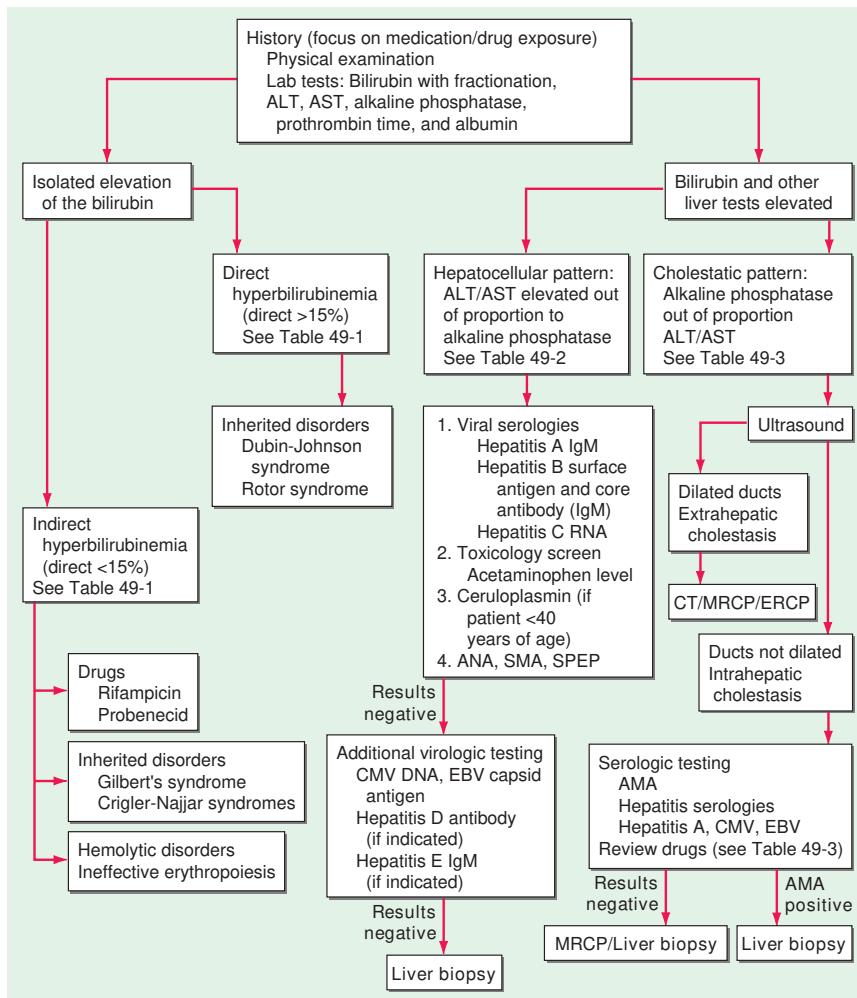
The initial step is to perform appropriate blood tests in order to determine whether the patient has an isolated elevation of serum bilirubin. If so, is the bilirubin elevation due to an increased unconjugated or conjugated fraction? If the hyperbilirubinemia is accompanied by other liver test abnormalities, is the disorder hepatocellular or cholestatic? If cholestatic, is it intra- or extrahepatic? These questions can all be answered with a thoughtful history, physical examination, and interpretation of laboratory and radiologic tests and procedures.

The bilirubin present in serum represents a balance between input from the production of bilirubin and hepatic/biliary removal of the pigment. Hyperbilirubinemia may result from (1) overproduction of bilirubin; (2) impaired uptake, conjugation, or excretion of bilirubin; or (3) regurgitation of unconjugated or conjugated bilirubin from damaged hepatocytes or bile ducts. An increase in unconjugated bilirubin in serum results from overproduction, impaired uptake, or conjugation of bilirubin. An increase in conjugated bilirubin is due to decreased excretion into the bile ductules or backward leakage of the pigment. The initial steps in evaluating the patient with jaundice are to determine (1) whether the hyperbilirubinemia is predominantly conjugated or unconjugated in nature and (2) whether other biochemical liver tests are abnormal. The thoughtful interpretation of limited data permits a rational evaluation of the patient (Fig. 49-1). The following discussion will focus solely on the evaluation of the adult patient with jaundice.

### ISOLATED ELEVATION OF SERUM BILIRUBIN

**Unconjugated Hyperbilirubinemia.** The differential diagnosis of isolated unconjugated hyperbilirubinemia is limited (Table 49-1). The critical determination is whether the patient is suffering from a hemolytic process resulting in an overproduction of bilirubin (hemolytic disorders and ineffective erythropoiesis) or from impaired hepatic uptake/conjugation of bilirubin (drug effect or genetic disorders).

Hemolytic disorders that cause excessive heme production may be either inherited or acquired. Inherited disorders include spherocytosis, sickle cell anemia, thalassemia, and deficiency of red cell enzymes such as pyruvate kinase and glucose-6-phosphate dehydrogenase. In these conditions, the serum bilirubin level rarely exceeds 86  $\mu\text{mol/L}$  (5 mg/dL). Higher levels may occur when there



**FIGURE 49-1** Evaluation of the patient with jaundice. ALT, alanine aminotransferase; AMA, antimitochondrial antibody; ANA, antinuclear antibody; AST, aspartate aminotransferase; CMV, cytomegalovirus; EBV, Epstein-Barr virus; ERCP, endoscopic retrograde cholangiopancreatography; LKM, liver-kidney microsomal antibody; MRCP, magnetic resonance cholangiopancreatography; SMA, smooth-muscle antibody; SPEP, serum protein electrophoresis.

**TABLE 49-1** Causes of Isolated Hyperbilirubinemia

- I. Indirect hyperbilirubinemia
  - A. Hemolytic disorders
  - B. Ineffective erythropoiesis
  - C. Increased bilirubin production
    - 1. Massive blood transfusion
    - 2. Resorption of hematoma
  - D. Drugs
    - 1. Rifampin
    - 2. Probenecid
    - 3. Antibiotics—cephalosporins and penicillins
  - E. Inherited conditions
    - 1. Crigler-Najjar types I and II
    - 2. Gilbert's syndrome
- II. Direct hyperbilirubinemia (inherited conditions)
  - A. Dubin-Johnson syndrome
  - B. Rotor syndrome

is coexistent renal or hepatocellular dysfunction or in acute hemolysis, such as a sickle cell crisis. In evaluating jaundice in patients with chronic hemolysis, it is important to remember the high incidence of pigmented (calcium bilirubinate) gallstones found in these patients, which increases the likelihood of choledocholithiasis as an alternative explanation for hyperbilirubinemia.

Acquired hemolytic disorders include microangiopathic hemolytic anemia (e.g., hemolytic-uremic syndrome), paroxysmal nocturnal hemoglobinuria, spur cell anemia, immune hemolysis, and parasitic infections (e.g., malaria and babesiosis). Ineffective erythropoiesis occurs in cobalamin, folate, and iron deficiencies. Resorption of hematomas and massive blood transfusions both can result in increased hemoglobin release and overproduction of bilirubin.

In the absence of hemolysis, the physician should consider a problem with the hepatic uptake or conjugation of bilirubin. Certain drugs, including rifampin and probenecid, may cause unconjugated hyperbilirubinemia by diminishing hepatic uptake

of bilirubin. Impaired bilirubin conjugation occurs in three genetic conditions: Crigler-Najjar syndrome types I and II and Gilbert's syndrome. *Crigler-Najjar type I* is an exceptionally rare condition found in neonates and characterized by severe jaundice (bilirubin  $>342 \mu\text{mol/L}$  [ $>20 \text{ mg/dL}$ ]) and neurologic impairment due to kernicterus, frequently leading to death in infancy or childhood. These patients have a complete absence of bilirubin UDPGT activity; are totally unable to conjugate bilirubin; and hence cannot excrete it.

*Crigler-Najjar type II* is somewhat more common than type I. Patients live into adulthood with serum bilirubin levels of 103–428  $\mu\text{mol/L}$  (6–25  $\text{mg/dL}$ ). In these patients, mutations in the bilirubin UDPGT gene cause the reduction—typically  $\leq 10\%$ —of the enzyme's activity. Bilirubin UDPGT activity can be induced by the administration of phenobarbital, which can reduce serum bilirubin levels in these patients. Despite marked jaundice, these patients usually survive into adulthood, although they may be susceptible to kernicterus under the stress of concurrent illness or surgery.

*Gilbert's syndrome* is also marked by the impaired conjugation of bilirubin due to reduced bilirubin UDPGT activity (typically 10–35% of normal). Patients with Gilbert's syndrome have mild unconjugated hyperbilirubinemia, with serum levels almost always  $<103 \mu\text{mol/L}$  (6  $\text{mg/dL}$ ). The serum levels may fluctuate, and jaundice is often identified only during periods of stress, concurrent illness, alcohol use, or fasting. Unlike both Crigler-Najjar syndromes, Gilbert's syndrome is very common. The reported incidence is 3–7% of the population, with males predominating over females by a ratio of 1.5–7:1.

**Conjugated Hyperbilirubinemia** Elevated conjugated hyperbilirubinemia is found in two rare inherited conditions: *Dubin-Johnson syndrome* and *Rotor syndrome* (Table 49-1). Patients with either condition present with asymptomatic jaundice. The defect in Dubin-Johnson syndrome is the presence of mutations in the gene for MRP2. These patients have altered excretion of bilirubin into the bile ducts. Rotor syndrome may represent a deficiency of the major hepatic drug reuptake transporters OATP1B1 and OATP1B3. Differentiating between these syndromes is possible but is clinically unnecessary due to their benign nature.

#### ELEVATION OF SERUM BILIRUBIN WITH OTHER LIVER TEST ABNORMALITIES

The remainder of this chapter will focus on the evaluation of patients with conjugated hyperbilirubinemia in the setting of other liver test abnormalities. This group of patients can be divided into those with a primary hepatocellular process and those with intra- or extrahepatic cholestasis. This distinction, which is based on the history and physical examination as well as the pattern of liver test abnormalities, guides the clinician's evaluation (Fig. 49-1).

**History** A complete medical history is perhaps the single most important part of the evaluation of the patient with unexplained jaundice. Important considerations include the use of or exposure to any chemical or medication, whether physician-prescribed, over-the-counter, complementary, or alternative medicines (e.g., herbal and vitamin preparations) or other drugs such as anabolic steroids. The patient should be carefully questioned about possible parenteral exposures, including transfusions, intravenous and intranasal drug use, tattooing, and sexual activity. Other important points include recent travel history; exposure to people with jaundice; exposure to possibly contaminated foods; occupational exposure to hepatotoxins; alcohol consumption; the duration of jaundice; and the presence of any accompanying signs and symptoms, such as arthralgias, myalgias, rash, anorexia, weight loss, abdominal pain, fever, pruritus, and changes in the urine and stool. While none of the latter manifestations is specific for any one condition, any of them can suggest a diagnosis. A history of arthralgias and myalgias predating jaundice suggests hepatitis, either viral or drug related. Jaundice associated with the sudden onset of severe right-upper-quadrant

pain and shaking chills suggests choledocholithiasis and ascending cholangitis.

**Physical Examination** The general assessment should include evaluation of the patient's nutritional status. Temporal and proximal muscle wasting suggests long-standing disease such as pancreatic cancer or cirrhosis. Stigmata of chronic liver disease, including spider nevi, palmar erythema, gynecomastia, caput medusae, Dupuytren's contractures, parotid gland enlargement, and testicular atrophy, are commonly seen in advanced alcohol-related cirrhosis and occasionally in other types of cirrhosis. An enlarged left suprACLAVICULAR node (Virchow's node) or a periumbilical nodule (Sister Mary Joseph's nodule) suggests an abdominal malignancy. Jugular venous distention, a sign of right-sided heart failure, suggests hepatic congestion. Right pleural effusion even in the absence of clinically apparent ascites may be seen in advanced cirrhosis.

The abdominal examination should focus on the size and consistency of the liver, on whether the spleen is palpable and hence enlarged, and on whether ascites is present. Patients with cirrhosis may have an enlarged left lobe of the liver, which is felt below the xiphoid, and an enlarged spleen. A grossly enlarged nodular liver or an obvious abdominal mass suggests malignancy. An enlarged tender liver could signify viral or alcoholic hepatitis; an infiltrative process such as amyloidosis; or, less often, an acutely congested liver secondary to right-sided heart failure. Severe right-upper-quadrant tenderness with respiratory arrest on inspiration (Murphy's sign) suggests cholecystitis. Ascites in the presence of jaundice suggests either cirrhosis or malignancy with peritoneal spread.

**Laboratory Tests** A battery of tests are helpful in the initial evaluation of a patient with unexplained jaundice. These include total and direct serum bilirubin measurement with fractionation; determination of serum aminotransferase, alkaline phosphatase, and albumin concentrations; and prothrombin time tests. Enzyme tests (alanine aminotransferase [ALT], aspartate aminotransferase [AST], and alkaline phosphatase [ALP]) are helpful in differentiating between a hepatocellular process and a cholestatic process (Table 337-1; Fig. 49-1)—a critical step in determining what additional workup is indicated. Patients with a hepatocellular process generally have a rise in the aminotransferases that is disproportionate to that in ALP, whereas patients with a cholestatic process have a rise in ALP that is disproportionate to that of the aminotransferases. The serum bilirubin can be prominently elevated in both hepatocellular and cholestatic conditions and therefore is not necessarily helpful in differentiating between the two.

In addition to enzyme tests, all jaundiced patients should have additional blood tests—specifically, an albumin level and a prothrombin time—to assess liver function. A low albumin level suggests a chronic process such as cirrhosis or cancer. A normal albumin level is suggestive of a more acute process such as viral hepatitis or choledocholithiasis. An elevated prothrombin time indicates either vitamin K deficiency due to prolonged jaundice and malabsorption of vitamin K or significant hepatocellular dysfunction. The failure of the prothrombin time to correct with parenteral administration of vitamin K indicates severe hepatocellular injury.

The results of the bilirubin, enzyme, albumin, and prothrombin time tests will usually indicate whether a jaundiced patient has a hepatocellular or a cholestatic disease and offer some indication of the duration and severity of the disease. The causes and evaluations of hepatocellular and cholestatic diseases are quite different.

**Hepatocellular Conditions** Hepatocellular diseases that can cause jaundice include viral hepatitis, drug or environmental toxicity, alcohol, and end-stage cirrhosis from any cause (Table 49-2). Wilson's disease occurs primarily in young adults. Autoimmune hepatitis is typically seen in young to middle-aged women but may affect men and women of any age. Alcoholic hepatitis can be differentiated from viral and toxin-related hepatitis by the pattern of the aminotransferases: patients with alcoholic hepatitis typically have

TABLE 49-2 Hepatocellular Conditions That May Produce Jaundice

Viral hepatitis
Hepatitis A, B, C, D, and E
Epstein-Barr virus
Cytomegalovirus
Herpes simplex virus
Alcoholic hepatitis
Chronic liver disease and cirrhosis
Drug toxicity
Predictable, dose-dependent (e.g., acetaminophen)
Unpredictable, idiosyncratic (e.g., isoniazid)
Environmental toxins
Vinyl chloride
Jamaica bush tea—pyrrolizidine alkaloids
Kava kava
Wild mushrooms— <i>Amanita phalloides</i> , <i>A. verna</i>
Wilson's disease
Autoimmune hepatitis

an AST-to-ALT ratio of at least 2:1, and the AST level rarely exceeds 300 U/L. Patients with acute viral hepatitis and toxin-related injury severe enough to produce jaundice typically have aminotransferase levels >500 U/L, with the ALT greater than or equal to the AST. While ALT and AST values <8 times normal may be seen in either hepatocellular or cholestatic liver disease, values 25 times normal or higher are seen primarily in acute hepatocellular diseases. Patients with jaundice from cirrhosis can have normal or only slightly elevated aminotransferase levels.

When the clinician determines that a patient has a hepatocellular disease, appropriate testing for acute viral hepatitis includes a hepatitis A IgM antibody assay, a hepatitis B surface antigen and core IgM antibody assay, a hepatitis C viral RNA test, and, depending on the circumstances, a hepatitis E IgM antibody assay. The hepatitis C antibody can take up to 6 weeks to become detectable, making it an unreliable test if acute hepatitis C is suspected. Studies for hepatitis D, Epstein-Barr virus (EBV), and cytomegalovirus (CMV) may also be indicated. Ceruloplasmin is the initial screening test for Wilson's disease. Testing for autoimmune hepatitis usually includes antinuclear antibody and anti-smooth muscle antibody assays and measurement of specific immunoglobulins.

Drug-induced hepatocellular injury can be classified as either predictable or unpredictable. Predictable drug reactions are dose-dependent and affect all patients who ingest a toxic dose of the drug in question. The classic example is acetaminophen hepatotoxicity. Unpredictable or idiosyncratic drug reactions are not dose-dependent and occur in a minority of patients. A great number of drugs can cause idiosyncratic hepatic injury. Environmental toxins are also an important cause of hepatocellular injury. Examples include industrial chemicals such as vinyl chloride, herbal preparations containing pyrrolizidine alkaloids (Jamaica bush tea) or kava, and the mushrooms *Amanita phalloides* and *A. verna*, which contain highly hepatotoxic amatoxins.

**Cholestatic Conditions** When the pattern of the liver tests suggests a cholestatic disorder, the first step is to determine whether it is intra- or extrahepatic cholestasis (Fig. 49-1). Distinguishing intrahepatic from extrahepatic cholestasis may be difficult. History, physical examination, and laboratory tests often are not helpful. The next appropriate test is an ultrasound. The ultrasound is inexpensive, does not expose the patient to ionizing radiation, and can detect dilation of the intra- and extrahepatic biliary tree with a high degree of sensitivity and specificity. The absence of biliary dilation suggests intrahepatic cholestasis, while its presence indicates extrahepatic cholestasis. False-negative results occur in patients with

partial obstruction of the common bile duct or in patients with cirrhosis or primary sclerosing cholangitis (PSC), in which scarring prevents the intrahepatic ducts from dilating.

Although ultrasonography may indicate extrahepatic cholestasis, it rarely identifies the site or cause of obstruction. The distal common bile duct is a particularly difficult area to visualize by ultrasound because of overlying bowel gas. Appropriate next tests include computed tomography (CT), magnetic resonance cholangiopancreatography (MRCP), endoscopic retrograde cholangiopancreatography (ERCP), percutaneous transhepatic cholangiography (PTC), and endoscopic ultrasound (EUS). CT and MRCP are better than ultrasonography for assessing the head of the pancreas and for identifying choledocholithiasis in the distal common bile duct, particularly when the ducts are not dilated. ERCP is the "gold standard" for identifying choledocholithiasis. Beyond its diagnostic capabilities, ERCP allows therapeutic interventions, including the removal of common bile duct stones and the placement of stents. PTC can provide the same information as ERCP and it also allows for intervention in patients in whom ERCP is unsuccessful due to proximal biliary obstruction or altered gastrointestinal anatomy. MRCP has replaced ERCP as the initial diagnostic test in most cases. EUS displays sensitivity and specificity comparable to that of MRCP in the detection of bile duct obstruction and allows biopsy of suspected malignant lesions.

In patients with apparent *intrahepatic cholestasis*, the diagnosis is often made by serologic testing in combination with a liver biopsy. The list of possible causes of intrahepatic cholestasis is long and varied (Table 49-3). A number of conditions that typically cause a hepatocellular pattern of injury can also present as a cholestatic variant. Both hepatitis B and C viruses can cause cholestatic hepatitis (fibrosing cholestatic hepatitis). This disease variant has been reported in patients who have undergone solid organ transplantation. Hepatitis A and E, alcoholic hepatitis, and EBV or CMV infections may also present as cholestatic liver disease.

Drugs may cause intrahepatic cholestasis that is usually reversible after discontinuation of the offending agent, although it may take many months for cholestasis to resolve. Drugs most commonly associated with cholestasis are the anabolic and contraceptive steroids. Cholestatic hepatitis has been reported with chlorpromazine, imipramine, tolbutamide, sulindac, cimetidine, and erythromycin estolate. It also occurs in patients taking trimethoprim-sulfamethoxazole; and penicillin-based antibiotics such as ampicillin, dicloxacillin, and clavulanic acid. Rarely, cholestasis may be chronic and associated with progressive fibrosis despite early discontinuation of the offending drug. Chronic cholestasis has been associated with chlorpromazine and prochlorperazine.

*Primary biliary cholangitis* is an autoimmune disease predominantly affecting women and characterized by progressive destruction of interlobular bile ducts. The diagnosis is made by the detection of antimitochondrial antibody, which is found in 95% of patients. *Primary sclerosing cholangitis* is characterized by the destruction and fibrosis of larger bile ducts. The diagnosis of PSC is made with cholangiography (either MRCP or ERCP), which demonstrates the pathognomonic segmental strictures. Approximately 75% of patients with PSC also have inflammatory bowel disease.

The *vanishing bile duct syndrome* and *adult bile ductopenia* are rare conditions in which a decreased number of bile ducts are seen in liver biopsy specimens. This histologic picture is also seen in patients who develop chronic rejection after liver transplantation and in those who develop graft-versus-host disease after bone marrow transplantation. Vanishing bile duct syndrome also occurs in rare cases of sarcoidosis, in patients taking certain drugs (including chlorpromazine), and idiopathically.

There are also familial forms of intrahepatic cholestasis. The familial intrahepatic cholestatic syndromes include *progressive familial intrahepatic cholestasis* (PFIC) types 1–3 and *benign recurrent intrahepatic cholestasis* (BRIC) types 1 and 2. BRIC is characterized

TABLE 49-3 Cholestatic Conditions That May Produce Jaundice

I. Intrahepatic
A. Viral hepatitis
1. Fibrosing cholestatic hepatitis—hepatitis B and C
2. Hepatitis A, Epstein-Barr virus infection, cytomegalovirus infection
B. Alcoholic hepatitis
C. Drug toxicity
1. Pure cholestasis—anabolic and contraceptive steroids
2. Cholestatic hepatitis—chlorpromazine, erythromycin estolate
3. Chronic cholestasis—chlorpromazine and prochlorperazine
D. Primary biliary cholangitis
E. Primary sclerosing cholangitis
F. Vanishing bile duct syndrome
1. Chronic rejection of liver transplants
2. Sarcoidosis
3. Drugs
G. Congestive hepatopathy and ischemic hepatitis
H. Inherited conditions
1. Progressive familial intrahepatic cholestasis
2. Benign recurrent intrahepatic cholestasis
I. Cholestasis of pregnancy
J. Total parenteral nutrition
K. Nonhepatobiliary sepsis
L. Benign postoperative cholestasis
M. Paraneoplastic syndrome
N. Veno-occlusive disease
O. Graft-versus-host disease
P. Infiltrative disease
1. Tuberculosis
2. Lymphoma
3. Amyloidosis
Q. Infections
1. Malaria
2. Leptospirosis
II. Extrahepatic
A. Malignant
1. Cholangiocarcinoma
2. Pancreatic cancer
3. Gallbladder cancer
4. Ampullary cancer
5. Malignant involvement of the porta hepatis lymph nodes
B. Benign
1. Choledocholithiasis
2. Postoperative biliary strictures
3. Primary sclerosing cholangitis
4. Chronic pancreatitis
5. AIDS cholangiopathy
6. Mirizzi's syndrome
7. Parasitic disease (ascariasis)

by episodic attacks of pruritus, cholestasis, and jaundice beginning at any age, which can be debilitating but does not lead to chronic liver disease. Serum bile acids are elevated during episodes, but serum  $\gamma$ -glutamyltransferase ( $\gamma$ -GT) activity is normal. PFIC disorders begin at childhood and are progressive in nature. All three types of PFIC are associated with progressive cholestasis, elevated levels of serum bile acids, and similar phenotypes but different genetic mutations. Only type 3 PFIC is associated with high levels of  $\gamma$ -GT. *Cholestasis of pregnancy* occurs in the second and third trimesters and resolves after delivery. Its cause is unknown, but the

condition is probably inherited, and cholestasis can be triggered by estrogen administration.

Other causes of intrahepatic cholestasis include total parenteral nutrition (TPN); nonhepatobiliary sepsis; benign postoperative cholestasis; and a paraneoplastic syndrome associated with a number of different malignancies, including Hodgkin's disease, medullary thyroid cancer, renal cell cancer, renal sarcoma, T-cell lymphoma, prostate cancer, and several gastrointestinal malignancies. The term *Stauffer's syndrome* has been used for intrahepatic cholestasis specifically associated with renal cell cancer. In patients developing cholestasis in the intensive care unit, the major considerations should be sepsis, ischemic hepatitis ("shock liver"), and TPN-related jaundice. Jaundice occurring after bone marrow transplantation is most likely due to veno-occlusive disease or graft-versus-host disease. In addition to hemolysis, sickle cell disease may cause intrahepatic and extrahepatic cholestasis. Jaundice is a late finding in heart failure caused by hepatic congestion and hepatocellular hypoxia. Ischemic hepatitis is a distinct entity of acute hypoperfusion characterized by an acute and dramatic elevation in the serum aminotransferases followed by a gradual peak in serum bilirubin.

Jaundice with associated liver dysfunction can be seen in severe cases of *Plasmodium falciparum* malaria. The jaundice in these cases is due to a combination of indirect hyperbilirubinemia from hemolysis and both cholestatic and hepatocellular jaundice. Weil's disease, a severe presentation of leptospirosis, is marked by jaundice with renal failure, fever, headache, and muscle pain.

Causes of *extrahepatic cholestasis* can be split into malignant and benign (Table 49-3). Malignant causes include pancreatic, gallbladder, and ampullary cancers as well as cholangiocarcinoma. This last malignancy is most commonly associated with PSC and is exceptionally difficult to diagnose because its appearance is often identical to that of PSC. Pancreatic and gallbladder tumors as well as cholangiocarcinoma are rarely resectable and have poor prognoses. Ampullary carcinoma has the highest surgical cure rate of all the tumors that present as painless jaundice. Hilar lymphadenopathy due to metastases from other cancers may cause obstruction of the extrahepatic biliary tree.

*Choledocholithiasis* is the most common cause of extrahepatic cholestasis. The clinical presentation can range from mild right-upper-quadrant discomfort with only minimal elevations of enzyme test values to ascending cholangitis with jaundice, sepsis, and circulatory collapse. PSC may occur with clinically important strictures limited to the extrahepatic biliary tree. IgG4-associated cholangitis is marked by stricturing of the biliary tree. It is critical that the clinician differentiate this condition from PSC as it is responsive to glucocorticoid therapy. In rare instances, chronic pancreatitis causes strictures of the distal common bile duct, where it passes through the head of the pancreas. AIDS cholangiopathy is a condition that is usually due to infection of the bile duct epithelium with CMV or cryptosporidia and has a cholangiographic appearance similar to that of PSC. The affected patients usually present with greatly elevated serum alkaline phosphatase levels (mean, 800 IU/L), but the bilirubin level is often near normal. These patients do not typically present with jaundice.

## ■ GLOBAL CONSIDERATIONS

While extrahepatic biliary obstruction and drugs are common causes of new-onset jaundice in developed countries, infections remain the leading cause in developing countries. Liver involvement and jaundice are observed with numerous infections, particularly malaria, babesiosis, severe leptospirosis, infections due to *Mycobacterium tuberculosis* and the *Mycobacterium avium* complex, typhoid fever, infection with hepatitis viruses A–E, EBV, CMV, viral hemorrhagic fevers including Ebola virus, late phases of yellow fever, dengue fever, schistosomiasis, fascioliasis, clonorchiasis, opisthorchiasis, ascariasis, echinococcosis, hepatosplenic candidiasis, disseminated histoplasmosis, cryptococcosis, coccidioidomycosis, ehrlichiosis, chronic Q fever, yersiniosis,

brucellosis, syphilis, and leprosy. Bacterial infections that do not necessarily involve the liver and bile ducts may also lead to jaundice, as in cholestasis of sepsis. The presence of fever or abdominal pain suggests concurrent infection, sepsis, or complications from gallstones. The development of encephalopathy and coagulopathy in a jaundiced patient with no preexisting liver disease signifies acute liver failure, which warrants urgent liver transplant evaluation.

## A

*This chapter is a revised version of chapters that have appeared in prior editions of Harrison's in which Marshall M. Kaplan was a co-author with Daniel Pratt.*

### ■ FURTHER READING

- E S et al: Inherited disorders of bilirubin transport and conjugation: New insights into molecular mechanisms and consequences. *Gastroenterology* 146:1625, 2014.  
W AW et al: Bilirubin metabolism and jaundice, in *Schiff's Diseases of the Liver*, 11th ed, Schiff ER et al (eds). Oxford, UK, John Wiley & Sons, Ltd, 2012, pp 120–150.

coordination between diaphragmatic contraction and anterior abdominal wall relaxation, a response in some cases to intraluminal bowel stimuli; dietary alterations, manipulation of the intestinal microbiota, or biofeedback may be effective therapy. Occasionally, increased lumbar lordosis accounts for apparent abdominal distention.

**Fat** Weight gain with an increase in abdominal fat can result in an increase in abdominal girth and can be perceived as abdominal swelling. Abdominal fat may be caused by an imbalance between caloric intake and energy expenditure associated with a poor diet and sedentary lifestyle; it also can be a manifestation of certain diseases, such as Cushing's syndrome. Excess abdominal fat has been associated with an increased risk of insulin resistance and cardiovascular disease.

**Fluid** The accumulation of fluid within the abdominal cavity (ascites) often results in abdominal distention and is discussed in detail below. Grade 1 ascites is detectable only by ultrasonography; grade 2 ascites is detectable by physical examination; and grade 3 ascites results in marked abdominal distention.

**Fetus** Pregnancy results in increased abdominal girth. Typically, an increase in abdominal size is first noted at 12–14 weeks of gestation, when the uterus moves from the pelvis into the abdomen. Abdominal distention may be seen before this point as a result of fluid retention and relaxation of the abdominal muscles.

**Feces** In the setting of severe constipation or intestinal obstruction, increased stool in the colon leads to increased abdominal girth. These conditions are often accompanied by abdominal discomfort or pain, nausea, and vomiting and can be diagnosed by imaging studies.

**Fatal Growth** An abdominal mass can result in abdominal swelling. Neoplasms, abscesses, or cysts can grow to sizes that lead to increased abdominal girth. Enlargement of the intraabdominal organs, specifically the liver (hepatomegaly) or spleen (splenomegaly), or an abdominal aortic aneurysm can result in abdominal distention. Bladder distention also may result in abdominal swelling.

# 50

## Abdominal Swelling and Ascites

Lawrence S. Friedman



### ABDOMINAL SWELLING

Abdominal swelling is a manifestation of numerous diseases. Patients may complain of bloating or abdominal fullness and may note increasing abdominal girth on the basis of increased clothing or belt size. Abdominal discomfort is often reported, but pain is less frequent. When abdominal pain does accompany swelling, it is frequently the result of an intraabdominal infection, peritonitis, or pancreatitis. Patients with abdominal distention from *ascites* (fluid in the abdomen) may report the new onset of an inguinal or umbilical hernia. Dyspnea may result from pressure against the diaphragm and the inability to expand the lungs fully.

### ■ CAUSES

The causes of abdominal swelling can be remembered conveniently as the *six Fs*: flatus, fat, fluid, fetus, feces, or a “fatal growth” (often a neoplasm).

**Flatus** Abdominal swelling may be the result of increased intestinal gas. The normal small intestine contains ~200 mL of gas made up of nitrogen, oxygen, carbon dioxide, hydrogen, and methane. Nitrogen and oxygen are consumed (swallowed), whereas carbon dioxide, hydrogen, and methane are produced intraluminally by bacterial fermentation. Increased intestinal gas can occur in a number of conditions. *Aerophagia*, the swallowing of air, can result in increased amounts of oxygen and nitrogen in the small intestine and lead to abdominal swelling. Aerophagia typically results from gulping food; chewing gum; smoking; or as a response to anxiety, which can lead to repetitive belching. In some cases, increased intestinal gas is the consequence of bacterial metabolism of excess fermentable substances such as lactose and other oligosaccharides, which can lead to production of hydrogen, carbon dioxide, or methane. In many cases, the precise cause of abdominal distention cannot be determined. In some persons, particularly those with irritable bowel syndrome and bloating, the subjective sense of abdominal pressure is attributable to impaired intestinal transit of gas rather than increased gas volume. Abdominal distention—an objective increase in girth—is the result of a lack of

### APPROACH TO THE PATIENT

#### Abdominal Swelling

##### HISTORY

Determining the etiology of abdominal swelling begins with history-taking and a physical examination. Patients should be questioned regarding symptoms suggestive of malignancy, including weight loss, night sweats, and anorexia. Inability to pass stool or flatus together with nausea or vomiting suggests bowel obstruction, severe constipation, or an ileus (lack of peristalsis). Increased eructation and flatus may point toward aerophagia or increased intestinal production of gas. Patients should be questioned about risk factors for or symptoms of chronic liver disease, including excessive alcohol use and jaundice, which suggest ascites. Patients should also be asked about symptoms of other medical conditions, including heart failure and tuberculosis, which may cause ascites.

##### PHYSICAL EXAMINATION

Physical examination should include an assessment for signs of systemic disease. The presence of lymphadenopathy, especially supraclavicular lymphadenopathy (*Virchow's node*), suggests metastatic abdominal malignancy. Care should be taken during the cardiac examination to evaluate for elevation of jugular venous pressure (JVP); *Kussmaul's sign* (elevation of the JVP during inspiration); a pericardial knock, which may be seen in heart failure or constrictive pericarditis; or a murmur of tricuspid regurgitation. Spider angiomas, palmar erythema, dilated superficial veins around the umbilicus (*caput medusae*), and gynecomastia suggest liver disease.

The abdominal examination should begin with inspection for the presence of uneven distention or an obvious mass. Auscultation should follow. The absence of bowel sounds or the presence

of high-pitched localized bowel sounds points toward an ileus or intestinal obstruction. An umbilical venous hum may suggest the presence of portal hypertension, and a harsh bruit over the liver is heard rarely in patients with hepatocellular carcinoma or alcohol-associated hepatitis. Abdominal swelling caused by intestinal gas can be differentiated from swelling caused by fluid or a solid mass by percussion; an abdomen filled with gas is tympanic, whereas an abdomen containing a mass or fluid is dull to percussion. The absence of abdominal dullness, however, does not exclude ascites, because a minimum of 1500 mL of ascitic fluid is required for detection on physical examination. Finally, the abdomen should be palpated to assess for tenderness, a mass, enlargement of the spleen or liver, or presence of a nodular liver suggesting cirrhosis or tumor. Light palpation of the liver may detect pulsations suggesting retrograde vascular flow from the heart in patients with right-sided heart failure, particularly tricuspid regurgitation.

### IMAGING AND LABORATORY EVALUATION

Abdominal x-rays can be used to detect dilated loops of bowel suggesting intestinal obstruction or ileus. Abdominal ultrasonography can detect as little as 100 mL of ascitic fluid, hepatosplenomegaly, a nodular liver, or a mass. Ultrasonography is often inadequate to detect retroperitoneal lymphadenopathy or a pancreatic lesion because of overlying bowel gas. If malignancy or pancreatic disease is suspected, CT can be performed. CT may also detect changes associated with advanced cirrhosis and portal hypertension (Fig. 50-1).

Laboratory evaluation should include liver biochemical testing, serum albumin level measurement, and prothrombin time determination (international normalized ratio) to assess hepatic function as well as a complete blood count to evaluate for the presence of cytopenias that may result from portal hypertension or of leukocytosis, anemia, and thrombocytosis that may result from systemic infection. Serum amylase and lipase levels should be checked to evaluate the patient for acute pancreatitis. Urinary protein quantitation is indicated when nephrotic syndrome, which may cause ascites, is suspected. Hydrogen and methane absorbed from the intestine are not metabolized by the host and are excreted in expired air, and detection of increased amounts of these gases in expired breath is the basis for tests used to



FIGURE 50-1 CT of a patient with a cirrhotic, nodular liver (white arrow), splenomegaly (yellow arrow), and ascites (arrowheads).

diagnose carbohydrate (e.g., lactose) malabsorption and small intestinal bacterial overgrowth.

In selected cases, the hepatic venous pressure gradient (pressure across the liver between the portal and hepatic veins) can be measured via cannulation of the hepatic vein to confirm that ascites is caused by cirrhosis (Chap. 344). In some cases, a liver biopsy may be necessary to confirm cirrhosis.

### ASCITES

#### PATHOGENESIS IN THE PRESENCE OF CIRRHOSIS

Ascites in patients with cirrhosis is the result of portal hypertension and renal salt and water retention. Similar mechanisms contribute to ascites formation in heart failure. Portal hypertension signifies elevation of the pressure within the portal vein. According to Ohm's law, pressure is the product of resistance and flow. Increased hepatic resistance occurs by several mechanisms. First, the development of hepatic fibrosis, which defines cirrhosis, disrupts the normal architecture of the hepatic sinusoids and impedes normal blood flow through the liver. Second, activation of hepatic stellate cells, which mediate fibrogenesis, leads to smooth-muscle contraction and fibrosis. Finally, cirrhosis is associated with a decrease in endothelial nitric oxide synthetase (eNOS) production, which results in decreased nitric oxide production and increased intrahepatic vasoconstriction.

The development of cirrhosis is also associated with increased systemic circulating levels of nitric oxide (in contrast to the decrease seen intrahepatically), as well as increased levels of vascular endothelial growth factor and tumor necrosis factor, that result in splanchnic arterial vasodilation. Vasodilation of the splanchnic circulation results in pooling of blood and a decrease in the effective circulating volume, which is perceived by the kidneys as hypovolemia. Compensatory vasoconstriction via release of antidiuretic hormone ensues; the consequences are free water retention and activation of the sympathetic nervous system and the renin-angiotensin-aldosterone system, which lead in turn to renal sodium and water retention.

#### PATHOGENESIS IN THE ABSENCE OF CIRRHOSIS

Ascites in the absence of cirrhosis generally results from peritoneal carcinomatosis, peritoneal infection, or pancreatic disease. Peritoneal carcinomatosis can result from primary peritoneal malignancies such as mesothelioma or sarcoma, abdominal malignancies such as gastric or colonic adenocarcinoma, or metastatic disease from breast or lung carcinoma or melanoma (Fig. 50-2). The tumor cells lining the

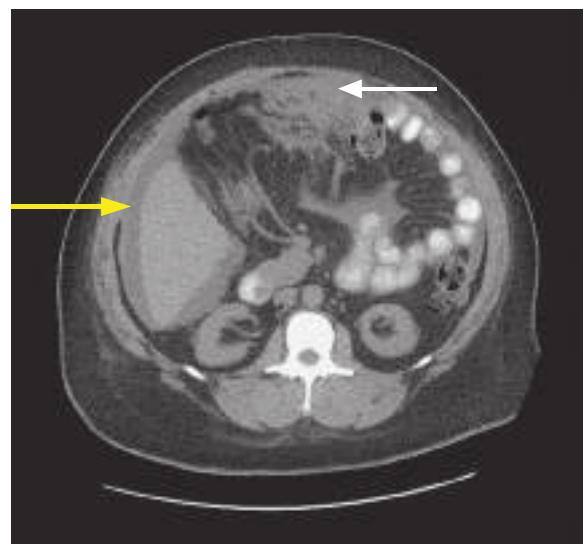


FIGURE 50-2 CT of a patient with peritoneal carcinomatosis (white arrow) and ascites (yellow arrow).

peritoneum produce a protein-rich fluid that contributes to the development of ascites. Fluid from the extracellular space is drawn into the peritoneum, further contributing to the development of ascites. Tuberculous peritonitis causes ascites via a similar mechanism; tubercles deposited on the peritoneum exude a proteinaceous fluid. Pancreatic ascites results from leakage of pancreatic enzymes into the peritoneum.

## ■ CAUSES

Cirrhosis accounts for 84% of cases of ascites. Cardiac ascites, peritoneal carcinomatosis, and “mixed” ascites resulting from cirrhosis and a second disease account for 10–15% of cases. Less common causes of ascites include massive hepatic metastasis, infection (tuberculosis, *Chlamydia* infection), pancreatitis, and renal disease (nephrotic syndrome). Rare causes of ascites include hypothyroidism and familial Mediterranean fever.

## ■ EVALUATION

Once the presence of ascites has been confirmed, the etiology of the ascites is best determined by *paracentesis*, a bedside procedure in which a needle or small catheter is passed transcutaneously to extract ascitic fluid from the peritoneum. The lower quadrants are the most frequent sites for paracentesis. The left lower quadrant is preferred because of the greater depth of ascites and the thinner abdominal wall. Paracentesis is a safe procedure even in patients with coagulopathy; complications, including abdominal wall hematomas, hypotension, hepatorenal syndrome, and infection, are infrequent.

Once ascitic fluid has been extracted, its gross appearance should be examined. Turbid fluid can result from the presence of infection or tumor cells. White, milky fluid indicates a triglyceride level >200 mg/dL (and often >1000 mg/dL), which is the hallmark of *chylous ascites*. Chylous ascites results from lymphatic disruption that may occur with trauma, cirrhosis, tumor, tuberculosis, or certain congenital abnormalities. Dark brown fluid can reflect a high bilirubin concentration and indicates biliary tract perforation. Black fluid may indicate the presence of pancreatic necrosis or metastatic melanoma.

The ascitic fluid should be sent for measurement of albumin and total protein levels, cell and differential counts, and, if infection is suspected, Gram's stain and culture, with inoculation into blood culture bottles at the patient's bedside to maximize the yield. A serum albumin level should be measured simultaneously to permit calculation of the *serum-ascites albumin gradient* (SAAG).

The SAAG is useful for distinguishing ascites caused by portal hypertension from nonportal hypertensive ascites (Fig. 50-3). The SAAG reflects the pressure within the hepatic sinusoids and correlates with the hepatic venous pressure gradient. The SAAG is calculated by subtracting the ascitic albumin concentration from the serum albumin level and does not change with diuresis. A SAAG ≥1 g/dL reflects the presence of portal hypertension and indicates that the ascites is due to increased pressure in the hepatic sinusoids. According to Starling's law, a high SAAG reflects the oncotic pressure that counterbalances the portal pressure. Possible causes include cirrhosis, cardiac ascites,

hepatic vein thrombosis (Budd-Chiari syndrome), sinusoidal obstruction syndrome (veno-occlusive disease), or massive liver metastases. A SAAG <1.1 g/dL indicates that the ascites is not related to portal hypertension, as in tuberculous peritonitis, peritoneal carcinomatosis, or pancreatic ascites.

For high-SAAG (≥1.1) ascites, the ascitic protein level can provide further clues to the etiology (Fig. 50-3). An ascitic protein level of ≥2.5 g/dL indicates that the hepatic sinusoids are normal and are allowing passage of protein into the ascites, as occurs in cardiac ascites, early Budd-Chiari syndrome, or sinusoidal obstruction syndrome. An ascitic protein level <2.5 g/dL indicates that the hepatic sinusoids have been damaged and scarred and no longer allow passage of protein, as occurs with cirrhosis, late Budd-Chiari syndrome, or massive liver metastases. Pro-brain-type natriuretic peptide (BNP) is a natriuretic hormone released by the heart as a result of increased volume and ventricular wall stretch. High levels of BNP in serum occur in heart failure and may be useful in identifying heart failure as the cause of high-SAAG ascites.

Further tests are indicated only in specific clinical circumstances. When secondary peritonitis resulting from a perforated hollow viscus is suspected, ascitic glucose and lactate dehydrogenase (LDH) levels can be measured. In contrast to “spontaneous” bacterial peritonitis, which may complicate cirrhotic ascites (see “Complications,” below), secondary peritonitis is suggested by an ascitic glucose level <50 mg/dL, an ascitic LDH level higher than the serum LDH level, and the detection of multiple pathogens on ascitic fluid culture. When pancreatic ascites is suspected, the ascitic amylase level should be measured and is typically >1000 mg/dL. Cytology can be useful in the diagnosis of peritoneal carcinomatosis. At least 50 mL of fluid should be obtained and sent for immediate processing. Tuberculous peritonitis is typically associated with ascitic fluid lymphocytosis but can be difficult to diagnose by paracentesis. A smear for acid-fast bacilli has a diagnostic sensitivity of only 0–3%; a culture increases the sensitivity to 35–50%. In patients without cirrhosis, an elevated ascitic adenosine deaminase level has a sensitivity of >90% for tuberculous ascites when a cut-off value of 30–45 U/L is used. When the cause of ascites remains uncertain, laparotomy or laparoscopy with peritoneal biopsies for histology and culture remains the gold standard.

## TREATMENT

### Ascites

The initial treatment for cirrhotic ascites is restriction of sodium intake to 2 g/d. When sodium restriction alone is inadequate to control ascites, oral diuretics—typically the combination of spironolactone and furosemide—are used to increase urinary sodium excretion. Spironolactone is an aldosterone antagonist that inhibits sodium resorption in the distal convoluted tubule of the kidney. Use of spironolactone may be limited by hyponatremia, hyperkalemia, and painful gynecomastia. If the gynecomastia is

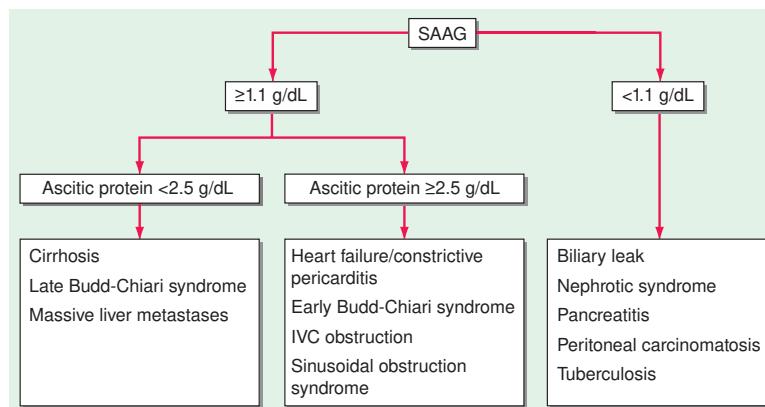


FIGURE 50-3 Algorithm for the diagnosis of ascites according to the serum-ascites albumin gradient (SAAG). IVC, inferior vena cava.

distressing, amiloride (5–40 mg/d) may be substituted for spironolactone. Furosemide is a loop diuretic that is generally combined with spironolactone in a ratio of 40:100; maximal daily doses of spironolactone and furosemide are 400 mg and 160 mg, respectively. Fluid intake may be restricted in patients with hyponatremia.

Refractory cirrhotic ascites is defined by the persistence of ascites despite sodium restriction and maximal (or maximally tolerated) diuretic use. Pharmacologic therapy for refractory ascites includes the addition of midodrine, an  $\alpha_1$ -adrenergic agonist, or clonidine, an  $\alpha_2$ -adrenergic agonist, to diuretic therapy. These agents act as vasoconstrictors, counteracting splanchnic vasodilation. Midodrine alone or in combination with clonidine improves systemic hemodynamics and control of ascites over that obtained with diuretics alone. Although  $\beta$ -adrenergic blocking agents (beta blockers) are often prescribed to prevent variceal hemorrhage in patients with cirrhosis, the use of beta blockers in patients with refractory ascites may be associated with decreased survival rates.

When medical therapy alone is insufficient, refractory cirrhotic ascites can be managed by repeated large-volume paracentesis (LVP) or a transjugular intrahepatic peritoneal shunt (TIPS)—a radiologically placed portosystemic shunt that decompresses the hepatic sinusoids. Intravenous (IV) infusion of albumin accompanying LVP decreases the risk of “postparacentesis circulatory dysfunction” and death. Patients undergoing LVP should receive IV albumin infusions of 6–8 g/L of ascitic fluid removed. TIPS placement is superior to LVP in reducing the reaccumulation of ascites but is associated with an increased frequency of hepatic encephalopathy, with no difference in mortality rates. The Alfapump system, which consists of an automated pump and tunneled peritoneal catheter that transports ascites from the peritoneal cavity to the urinary bladder, has shown promise in the management of refractory ascites but is associated with a higher frequency of technical difficulties and renal dysfunction.

Malignant ascites does not respond to sodium restriction or diuretics. Patients must undergo serial LVPs, transcutaneous drainage catheter placement, or, rarely, creation of a peritoneovenous shunt (a shunt from the abdominal cavity to the vena cava) or placement of the Alfapump system, if available.

Ascites caused by tuberculous peritonitis is treated with standard antituberculosis therapy. Noncirrhotic ascites of other causes is treated by correction of the precipitating condition.

## COMPLICATIONS

*Spontaneous bacterial peritonitis* (SBP; Chap. 132) is a common and potentially lethal complication of cirrhotic ascites. Occasionally, SBP also complicates ascites caused by nephrotic syndrome, heart failure, acute hepatitis, and acute liver failure but is rare in malignant ascites. Patients with SBP generally note an increase in abdominal girth; however, abdominal tenderness is found in only 40% of patients, and rebound tenderness is uncommon. Patients may present with fever, nausea, vomiting, or the new onset or an exacerbation of preexisting hepatic encephalopathy.

In hospitalized patients with ascites, paracentesis within 12 hours of admission reduces mortality because of early detection of SBP. SBP is defined by a polymorphonuclear neutrophil (PMN) count of  $\geq 250/\mu\text{L}$  in the ascitic fluid. Cultures of ascitic fluid should be performed in blood culture bottles and typically reveal one bacterial pathogen. The presence of multiple pathogens in the setting of an elevated ascitic PMN count suggests *secondary peritonitis* from a ruptured viscus or abscess (Chap. 132). The presence of multiple pathogens without an elevated PMN count suggests bowel perforation from the paracentesis needle. SBP is generally the result of enteric bacteria that have translocated across an edematous bowel wall. The most common pathogens are gram-negative rods, including *Escherichia coli* and *Klebsiella*, as well as streptococci and enterococci.

Treatment of SBP with an antibiotic such as IV cefotaxime is generally effective against gram-negative and gram-positive aerobes. A

5-day course of treatment is sufficient if the patient improves clinically. Nosocomial or health care–acquired SBP is frequently caused by multi-drug-resistant bacteria, and initial antibiotic therapy should be guided by the local bacterial epidemiology.

Cirrhotic patients with a history of SBP, an ascitic fluid total protein concentration  $<1 \text{ g/dL}$ , or active gastrointestinal bleeding should receive prophylactic antibiotics to prevent SBP; oral daily ciprofloxacin or, where available, norfloxacin is commonly used. IV ceftriaxone may be used in hospitalized patients. Diuresis increases the activity of ascitic fluid protein opsonins and may decrease the risk of SBP.

*Hepatic hydrothorax* occurs when ascites, often caused by cirrhosis, migrates via fenestrae in the diaphragm into the pleural space. This condition can result in shortness of breath, hypoxia, and infection. Treatment is similar to that for cirrhotic ascites and includes sodium restriction, diuretics, and, if needed, thoracentesis or TIPS placement. Chest tube placement should be avoided.

## A

The author thanks Dr. Kathleen E. Corey for contributions to this chapter in prior editions of the textbook.

## FURTHER READING

- A D et al: Refractory ascites in liver cirrhosis. *Am J Gastroenterol* 114:40, 2019.
- B E et al: Correction of abdominal distention by biofeedback-guided control of abdominothoracic muscular activity in a randomized, placebo-controlled trial. *Clin Gastroenterol Hepatol* 15:1922, 2017.
- B M et al: Albumin infusion in patients undergoing large-volume paracentesis: A meta-analysis of randomized trials. *Hepatology* 55:1172, 2012.
- E A S L :EASL Clinical Practice Guidelines for the management of patients with decompensated cirrhosis. *J Hepatol* 69:406, 2018.
- F AQ et al: Serum B-type natriuretic peptide in the initial workup of patients with new onset ascites: A diagnostic accuracy study. *Hepatology* 59:1043, 2014.
- F J et al: Prevalence and risk factors of infections by multiresistant bacteria in cirrhosis: A prospective study. *Hepatology* 55:1551, 2012.
- G PS, R BA: Role of plasma BNP in patients with ascites: Advantages and pitfalls. *Hepatology* 59:751, 2014.
- J S, F LS: Portal hypertensive ascites: Current status. *Curr Hepatol Rep* 19:226, 2020.
- J S, T PJ: Hyponatremia in cirrhosis: Pathophysiology and management. *World J Gastroenterol* 21:3197, 2015.
- L B et al: Review article: the diagnostic approach and current management of chylous ascites. *Aliment Pharmacol Ther* 46:816, 2017.
- M JR et al: Bloating and abdominal distension: Old misconceptions and current knowledge. *Am J Gastroenterol* 112:1221, 2017.
- O ES et al: Paracentesis is associated with reduced mortality in patients hospitalized with cirrhosis and ascites. *Clin Gastroenterol Hepatol* 12:496, 2014.
- R BA: Introduction to the revised American Association for the Study of Liver Diseases Practice Guideline management of adult patients with ascites due to cirrhosis 2012. *Hepatology* 57:165, 2013.
- R BA et al: The serum-ascites albumin gradient is superior to the exudate-transudate concept in the differential diagnosis of ascites. *Ann Intern Med* 117:215, 1992.
- S P et al: Effect of intravenous albumin on renal impairment and mortality in patients with cirrhosis and spontaneous bacterial peritonitis. *N Engl J Med* 341:403, 1999.
- W JW J , S DL: The rational clinical examination. Does this patient have ascites? How to divine fluid in the abdomen. *JAMA* 267:2645, 1992.

## Section 7 Alterations in Renal and Urinary Tract Function

51

### Interstitial Cystitis/ Bladder Pain Syndrome

R. Christopher Doiron, J. Curtis Nickel



#### DEFINITION

A condition associated with bladder inflammation and pain, with what were thought to be discrete bladder ulcerations, was first described in 1887. The description of the classic bladder-wall ulcer—now referred to as a *Hunner lesion*—became known as *interstitial cystitis* (IC). The first generally accepted definition of IC was derived from a National Institute for Diabetes and Digestive and Kidney Diseases (NIDDK) consensus of experts in the field in 1998. The NIDDK criteria used to define IC included typical cystoscopic findings such as glomerulations (submucosal petechial hemorrhages of the urothelium) or Hunner lesions. However, over time, the syndrome experienced by patients, including bladder and/or pelvic pain with associated urinary storage symptoms of urinary frequency and urgency, negative urine cultures, and no specific identifiable causes, became known as *interstitial cystitis/bladder pain syndrome* (IC/BPS).

The nomenclature and definitions have evolved, but the contemporary definitions accepted by the American Urological Association, the Canadian Urological Association, the International Continence Society, the Society for Urodynamics and Female Urology, and the European Society for the Study of IC/BPS, although they all differ somewhat in language and specifics, generally reflect several fundamental concepts common in the disease: (1) it is chronic in nature; (2) it causes pain perceived to be attributable to the bladder; (3) this pain occurs in the presence of lower urinary tract symptoms (LUTS); and (4) pain outside the bladder—in the pelvis, perineum, genitals, abdomen, and beyond—is common.

The following definition incorporates the major descriptions by all international groups interested in the diagnosis and management of IC/BPS: an unpleasant sensation (pain, pressure, discomfort) perceived to be related to the urinary bladder, associated with LUTS of >6 weeks' duration, in the absence of infection or other identifiable causes.

A generalized urologic chronic pelvic pain syndrome (UCPPS) is referenced in the literature and is thought to encompass two distinct urologic chronic pain disorders: IC/BPS, which may be present in men and women, and chronic prostatitis/chronic pelvic pain syndrome (CP/CPPS), which is present only in men. The latter refers to a urologic pain disorder with pain localized to the perineum and/or male genitals, with or without LUTS. IC/BPS can exist independent of CP/CPPS in men. In reality, the urologic chronic pain disorders often have overlapping symptom presentations and may share common etiologic and pathophysiological origins, but the focus of the current chapter will be on IC/BPS.

#### ETIOLOGY AND PATHOGENESIS

Pinning a single etiology to a diagnosis of IC/BPS has been an endeavor fraught with uncertainty that ultimately has failed thus far. Instead, it is much more likely and widely accepted that IC/BPS represents a syndrome or constellation of interrelated disease processes that manifest in a spectrum of disease that reaches beyond the bladder. While the search for a single etiology soldiers on, we will review here a collection of proposed theories.

#### ■ INFECTION AND THE URINARY MICROBIOTA

Bacterial infection of the urothelium has long been regarded as a major suspect in the etiology of IC/BPS but has never been definitively shown to cause the disease. It is not uncommon for patients presenting with IC/BPS to describe a long history of “urinary tract infections” (UTIs); these patients often have undergone multiple courses of treatment with one or multiple antibiotics prescribed by their physicians. Often, however, in patients with IC/BPS, the benefit of antibiotic treatment is short-lived, urine culture results are negative, and the return of symptoms is inevitable.

Although studies examining the role of microbiologic organisms in this patient population are numerous and the results conflicting, far more studies have yielded negative results rather than positive findings. Furthermore, our understanding of the urinary microbiota continues to expand, rendering older studies using outdated and insensitive cultivation techniques less relevant.

Using state-of-the-art, culture-independent techniques for microorganism identification, investigators observe subtle differences between the urinary microbiota of IC/BPS patients and that of healthy controls and between IC/BPS patients experiencing symptom flares and IC/BPS patients not in flare. The clinical relevance of these findings is still not fully understood. As the study of the urinary microbiota continues to unfold, researchers and clinicians believe that although a single causative microbe is unlikely, dysbiosis or disturbance in the microbial ecology of the lower urinary tract may be responsible for flares or symptom patterns experienced by IC/BPS patients.

#### ■ AUTOIMMUNITY

The consideration of IC/BPS as a disorder of the immune system stems from the observation of a significant prevalence of autoimmune disorders in IC/BPS patients; several historical studies have identified anti-urothelial antibodies within the bladder mucosa of IC/BPS patients. Furthermore, although IC/BPS is not a pathologic diagnosis, there are widely accepted, recognizable patterns of inflammatory infiltration in the bladder mucosa of this patient population, including lymphoplasmacytic infiltrates, stromal edema and fibrosis, urothelial denudation, and detrusor mastocytosis. Thus, although it is likely that immune disturbances cause the condition in a subset of patients (for example, in those with associated Sjögren's syndrome), researchers and clinicians have been unable to leverage this knowledge into a clear description, and its clinical relevance is not fully understood.

#### ■ INFLAMMATION

It is well established that a subset of patients suffering from IC/BPS clearly have associated bladder inflammation of unknown etiology. The best described of these patients are those with Hunner lesions—discrete inflammatory lesions, previously believed to be ulcers, that have a well-characterized inflammatory profile on histologic and pathologic analysis. While Hunner lesions are easily identified under direct vision by cystoscopy, a spectrum of other, less obvious inflammatory patterns in the bladder is associated with infiltration of acute and chronic inflammatory cells and mast cells. This inflammation observed on histologic analysis can be so subtle that it cannot be recognized under direct visual examination of the bladder with cystoscopy.

Investigators in the Multidisciplinary Approach to the Study of Chronic Pelvic Pain (MAPP) Research Network have found that, among patients with UCPPS, women exhibit more robust inflammatory responses to stimulation of Toll-like receptor 2 (TLR2) and TLR4. Furthermore, an increased response to stimulation of TLR4 predicts more severe symptoms, widespread pain (vs pelvic/bladder pain only), and a higher number of chronic overlapping pain conditions (COPCs). Further studies aimed at a better understanding of these findings are under way.

#### ■ UROTHELIAL DYSFUNCTION

**Urothelial Permeability and the Glycosaminoglycan Layer** The stratified epithelium of the bladder—the urothelium—is composed of basal precursor cells, intermediate cells, and a layer of

specialized, superficial epithelial cells called *umbrella cells*. Collectively, these layers are responsible for the various functions of the bladder lining. One important function of the urothelium is to provide a robust barrier layer. This function is fulfilled by the dense layering of glycosaminoglycans (GAGs) on the luminal surface of the urothelium along with a complex arrangement of numerous intercellular tight junctions among urothelial cells that protects the underlying bladder interstitium from the constituents of the urine resting in the bladder.

Defects in this barrier function—either disruptions in the GAG layer or disruptions in the epithelial layer itself or its cellular junctions—have been proposed as a possible mechanism for bladder pain in IC/BPS patients. This theory, while still popular, lacks definitive evidence supporting it as the etiology of this disease.

**Antiproliferative Factor** The discovery that urothelial cells from IC/BPS patients appear to grow far more slowly than urothelial cells from a healthy control population led to the identification of antiproliferative factor (APF). Although APF initially showed promise as a sensitive and specific urine biomarker for IC/BPS, this idea has not been widely adopted, and the etiologic role of APF is not yet fully understood.

### ■ PELVIC ORGAN CROSSTALK

The observation of dysfunction and symptoms in multiple organ systems, including gastrointestinal, gynecologic, and genital organs, in patients with IC/BPS is so common that it might be considered the norm. Mechanisms of neural sensitization in patients with chronic pain have been reported, and abnormalities in the autonomic nervous system have been observed among IC/BPS patients. Again, although these observations apply in a subset of patients, their broader application to the heterogeneous IC/BPS patient population as a clear cause of disease is not warranted.

### ■ NEUROBIOLOGIC CONTRIBUTIONS AND CENTRAL SENSITIZATION

One breakthrough by the MAPP Research Network is an investigation of the role of structural and functional alterations in the brains of patients with UCPPS. The network's innovative methods of correlating clinical and deep phenotyping data with functional MRI data identified such structural and functional differences. These differences were later shown to successfully predict the progression of symptoms in a cohort of 52 patients with UCPPS. Although the relevant study did not differentiate between IC/BPS and CP/CPPS patients, the findings are nevertheless informative, and further longitudinal studies are ongoing.

In addition to the novel MAPP-led findings using neuroimaging, quantitative sensory testing (QST) methods have been used to investigate the sensory processing mechanisms in UCPPS patients. The findings—generalized pain hypersensitivity and altered endogenous inhibitory pain control systems among UCPPS patients—further support a hypothesis of a central sensitization phenotype in urologic chronic pelvic pain. The clinical implications of observed neural alterations and multisensory hypersensitivity remain under investigation.

Although a single etiology for this clinically heterogeneous pain syndrome may never be identified, efforts to do so have revealed much about its pathogenesis in subsets of patients and have provided valuable insight into specific patient phenotypes. The challenge for researchers and clinicians moving forward will be to unify clinical phenotypes with these proposed underlying mechanisms of disease and to integrate this knowledge into clinically actionable interventions that may provide meaningful outcomes.

### EPIDEMIOLOGY

The prevalence of IC/BPS has been difficult to determine because definitions and diagnostic criteria (in the absence of a definitive diagnostic test or biomarker) are constantly evolving. In addition, the various methods used in attempting to describe the syndrome's epidemiology (patient self-reports, symptom-based surveys, physician visits, population-based databases) have been problematic and have made comparisons of results challenging. Many studies have historically been performed only in female populations. Currently, it is estimated that

2.7–6.5% of North American women experience symptoms consistent with a diagnosis of IC/BPS. Fewer than 10% of women who experience these symptoms actually have a diagnosis of IC/BPS. The syndrome does occur in men, with a reported 10:1 female-to-male ratio, but it is thought that the condition is dramatically underreported in men.

Some predictors of the development of IC/BPS have been suggested through an analysis of retrospective observational studies of childhood disorders and adverse childhood experiences (ACEs), including childhood UTI, childhood bowel and bladder dysfunction, and childhood sexual trauma. Furthermore, it has been well established that IC/BPS patients exhibit a remarkable prevalence of COPCs such as fibromyalgia, irritable bowel syndrome (IBS), chronic back pain, and chronic fatigue syndrome (CFS). Recent MAPP-led studies have shown that more than one-third of IC/BPS patients have one COPC (IBS, fibromyalgia, or CFS), while up to 10% have multiple COPCs. Thus, these conditions might be considered risk factors for the development of IC/BPS.

### CLINICAL MANIFESTATIONS

Patients with IC/BPS, both female and male, present with varying degrees of discomfort and/or pain perceived to be related to the bladder and associated with urinary storage symptoms, including daytime and nighttime urinary frequency and urinary urgency. For some patients, urinary symptoms (the most common complaint after bladder pain) are the most bothersome, while for most patients, bladder pain causes the most distress and most significantly affects quality of life. Unfortunately, the majority of patients with IC/BPS present with both types of symptoms, as patients void frequently to relieve pain (or because of fear of bladder pain). Typically, this combination of bladder pain and urinary frequency severely impacts patients' quality of life, social interactions, and physical activities.

Pain-mapping studies have been used to identify different pain phenotypes within the disease. Nickel and colleagues first described a bladder-only phenotype present in 20% of a cohort of female IC/BPS patients, whereas up to 80% of patients described pain in the pelvis and at least one site beyond. Common associated conditions include IBS (40%), pelvic floor dysfunctional pain syndrome (40–60%), vulvodynia (17%), fibromyalgia (36%), CFS (10%), and chronic back pain (47%). As described above, these multiorgan symptoms may be due to central nervous system sensitization and associated spinal crosstalk, which may promote phenotypic progression as patients with one pain syndrome slowly progress to another. Subsequent MAPP-led studies among a more heterogeneous UCPPS cohort of men and women have supported this concept of specific pain phenotypes, reporting a pelvic-pain-only phenotype in 25% of participants and pain in the pelvis and beyond in up to 75%.

Another important finding from the MAPP investigations is their identification of not just a pelvic-pain-only phenotype but also of a bladder-focused phenotype. The latter phenotype was identified by patients' responses to two RAND Interstitial Cystitis Epidemiology (RICE) survey questions: whether they had "painful bladder filling" and/or "painful urinary urgency." Most female UCPPS patients (88%) responded "yes" to at least one of these questions. The bladder-focused phenotype was associated with more severe urologic symptoms and worse quality of life.

Patients present with unique pain trajectories. Some initially have mild discomfort that progresses over many years to pain with bladder filling and finally to chronic unremitting pelvic pain with only short periods of relief with urination. Other patients begin with UTI-like symptoms and acute bladder and urethral pain with urinary frequency and urgency; these manifestations persist as a chronic cystitis-like syndrome despite negative cultures and no benefit from antimicrobial therapy. Still other patients report a waxing and waning of pain over time, with flares exacerbated by diet, anxiety/stress, infection, or hormone cycle (typically with increased pain prior to menses). In a longitudinal study of UCPPS patients followed over a 12-month period during routine care for their disease, MAPP investigators described 60% of patients' symptoms as stable, 20% as improved, and 20% as worsened.

**TABLE 51-1** Workup of Patients by a Primary Care Practitioner or General Internist

STEPS IN WORKUP	SPECIFICS
History/physical examination	Conduct a pelvic exam (recommended). Categorize symptoms as bladder/pelvis focused and/or extending beyond the pelvis.
Urinalysis	Perform a urine culture. If the culture is positive, conduct sensitivity testing.
Consideration of patient-centered treatment options if satisfied with diagnosis <sup>a</sup>	Begin with conservative measures. Introduce further symptom-specific treatments as needed.
Referral to an appropriate specialist under certain conditions	Referral should follow if: <ul style="list-style-type: none"> <li>the diagnosis is unclear</li> <li>microscopic or gross hematuria is present</li> <li>the condition is refractory to treatment</li> <li>symptoms are severe</li> <li>the presentation is complex</li> </ul>

<sup>a</sup>See text.

## APPROACH TO THE PATIENT

### Interstitial Cystitis/Bladder Pain Syndrome

Patients with IC/BPS present to their family physician or internist with pelvic pain that typically increases in severity with bladder filling, other associated pain, and various degrees of urinary symptomatology. The course that should be followed by primary care practitioners or general internists during the patient's workup and before referral to a specialist is outlined in *Table 51-1*. Most of these physicians will not move beyond a suspected diagnosis and conservative advice; that is acceptable. Patients with IC/BPS can often represent diagnostic challenges, and referral to an appropriate subspecialist is warranted if any diagnostic uncertainty remains.

A diagnosis of IC/BPS is often missed and delayed for many years because physicians tend to silo patients into various medical-specialty streams on the basis of the predominant or most bothersome symptom. For example, patients presenting with pelvic pain in which flares are associated with monthly menstrual cycles may be referred to gynecologists. Patients with abdominal/pelvic pain associated with diarrhea and/or constipation tend to be referred to gastroenterologists, while those with generalized muscle and joint pain, perhaps associated with fatigue, are referred to rheumatologists. Patients with urinary symptoms and bladder pain are treated for UTIs (even with negative urine cultures) or overactive bladder—a common bladder condition associated with urinary frequency and urgency, but not pain.

It would be simple if the approach to patients presenting with pelvic pain was only to determine the actual pelvic organ and/or disease causing the symptoms. However, spinal crosstalk, phenotype progression over time, central sensitization, and COPCs complicate the picture. Since only ~20–25% of patients eventually diagnosed with IC/BPS have bladder-only disease, one must not be bladder-centric in approach but rather must consider the entire patient. The provider must determine the patient's "clinical picture"—that is, the patient's unique presenting clinical phenotype.

Urologists have adapted a system of clinical symptom categorization for patients with UC/PPS. UPOINT, which includes documenting the contribution of six distinct domains—*Urinary, Psychosocial, Organ-specific, Infection, Neurologic, and Tenderness* (as in pelvic floor muscle tenderness)—has helped categorize patient symptoms and allows the practitioner to focus their management on the most bothersome domain, while helping to avoid neglecting domains that are often forgotten. While used by many urologists managing this condition, UPOINT is not as effective in IC/BPS as it is in male CP/CPPS, probably because all IC/BPS patients would be categorized, by definition, in the U and O domains.

A further simplified clinical approach to the assessment of patients with symptoms of IC/BPS is to classify patients with perceived bladder pain (a mandatory criterion for diagnosis) into one of two categories: (1) a "pelvic-pain-only" category, which would include the "bladder-pain-only," pelvic floor dysfunctional pain, and associated gynecologic pain groups; or (2) a "pelvic pain and beyond" category, which would include patients with associated COPCs (such as IBS and fibromyalgia). This approach has been supported by recent observations from the MAPP investigators.

The contribution of psychosocial parameters, such as depression, catastrophizing, anxiety, and stress, and their impact on pain and disability cannot be overlooked and are important to ascertain in all cases. This approach to clinical phenotyping will let the physician tailor a unique treatment plan for each individual patient, using combinations of local bladder, pelvic floor, or more general systemic therapies.

## DIAGNOSIS

IC/BPS is a clinically heterogeneous condition whose lack of a clear etiopathogenesis presents difficulties in diagnosis. In making a diagnosis of exclusion, clinicians must rule out other confusable diseases and identify to the best of their ability the phenotypic presentation of the presenting patient. Although attempts have been made to establish a set of diagnostic criteria in the past, the specified criteria have proven overly stringent and too exclusive to be clinically useful. Furthermore, although several guidelines exist to aide in decision making in diagnostic investigations, most investigations serve merely to rule out other pathology. In contrast, history and physical examination, along with some simple laboratory testing, are the most reliable tools with which to establish a diagnosis of IC/BPS. Details of relevant investigations, some of which may be beyond the scope of the general practitioner or internist, are presented here. *Table 51-1* offers an approach for the general practitioner, and *Table 51-2* provides a more complete summary of diagnostic recommendations.

### HISTORY AND PHYSICAL INCLUDING FREQUENCY/VOLUME CHARTS

A thorough history and physical examination are of utmost importance in diagnosing IC/BPS. A history of the patient's pain symptoms is a logical place to start. The nature, intensity, and timing of the pain are all significant factors. Some patients will be less explicit than others in describing their pain and may instead describe a sense of pressure, burning, or vague fullness in the pelvis or bladder area.

All aspects of the patient's pain should be explored, as many patients' pain will not be limited to the pelvis or bladder but will be associated with the genitals, anus or rectum, perineum, abdomen, and beyond. Furthermore, although pain is commonly experienced with bladder filling, patients may also have suprapubic tenderness or pressure with voiding or burning or pain in the bladder, urethra, or perineum, with radiation into the vagina for women or the prostate, penis, and testicles.

**TABLE 51-2** Recommendations for Investigations in Patients with Suspected Interstitial Cystitis/Bladder Pain Syndrome

MANDATORY	RECOMMENDED	OPTIONAL	NOT RECOMMENDED
History	Frequency/volume chart	Ultrasound/pelvic imaging	Potassium sensitivity test
Physical examination	Urinalysis	Postvoid residual	Urodynamics
	Urine culture	Urine cytology	Bladder biopsy
	Symptom scores	Intravesical anesthetic bladder challenge	
	Cystoscopy	Hydrodistension	

*Source:* Adapted from A Cox et al: CUA guideline: Diagnosis and treatment of interstitial cystitis/bladder pain syndrome. *Can Urol Assoc J* 10:E136, 2016.

for men. In male patients, distinguishing IC/BPS from CP/CPPS can be challenging. Physicians must assess for more widespread pain locations outside the pelvis; screening for COPCs, particularly IBS, fibromyalgia, CFS, back pain, and headache, is important in adequately addressing the clinical impact of IC/BPS.

Eliciting and understanding associated LUTS—specifically urinary frequency, urgency, and nocturia—should be another focus of the history. While several confusable diseases can present with LUTS, the manifestation of IC/BPS as voiding dysfunction can help guide treatment decisions and is often a significant focus of bother for the patient. Having patients complete frequency/volume charts, noting the time and volume of each urination over a 24-hour period, can help provide objective evidence of a LUTS history and facilitate follow-up during and after treatment.

Physical examination should focus on the abdomen, pelvis, genitals, and pelvic floor. The degree of pelvic floor relaxation (i.e., degree of muscle tension and/or spasm) during examination is important to note. Trigger points in the pelvic floor musculature and any areas of localized spasticity should be identified. In women, an examination of the vulva, vaginal mucosa, and urethral meatus is essential to identify the presence of vulvodynia (vulvar mucosal pain with no identifiable cause) or any signs of genitourinary syndrome of menopause. In men, an examination of the external genitalia and a digital rectal (prostate) examination as well as a similar pelvic floor examination should be included to rule out related pathology.

### SYMPOTM SCORES

The quality of a history can be elevated by an accompanying validated, objective measurement of the patient's symptoms. Although several relevant tools exist, the Interstitial Cystitis Symptom Index (ICSI) and the Interstitial Cystitis Problem Index (ICPI) are the most widely used, are commonly employed in research trials as outcome measures, and are straightforward enough for the practitioner to perform in an outpatient setting. These short questionnaires document pain severity, urinary frequency, urgency, and nocturia as well as the bother experienced from each of these symptoms.

More recently, MAPP investigators have suggested that pain and urinary symptoms should be assessed independently using two separate questionnaires: the Genitourinary Pain Index (GUPI) to assess pain and the ICSI to separately assess urinary symptoms. This suggestion is based on their finding of variable effects of urologic pain versus urinary symptoms on quality of life and mental health. Although symptom scores should not be relied on as diagnostic tools, their utility in establishing objective baseline measures to monitor response to treatment and symptoms over time can be valuable to the patient and the practitioner.

### URINE STUDIES

Urine studies (urinalysis, culture, sensitivity, and cytology) should be included in the workup of a patient in whom IC/BPS is suspected. However, their role is mostly in ruling out other confusable disease rather than in aiding in the diagnosis of IC/BPS. A microscopic examination of the urine can reveal abnormalities attributable to the kidney that may warrant referral to a nephrologist; microscopic hematuria may trigger cystoscopic examination and referral to a urologist. The presenting symptoms of IC/BPS often mimic those of UTI, which must be ruled out by urine cultures. It is important to recognize that IC/BPS patients are subject to at least as great a risk of UTIs as the general population and that UTI should be considered when a flare in symptoms is reported. Finally, urine cytology should be considered if a diagnosis of bladder cancer is suspected or if there is a history of hematuria.

### IMAGING, CYSTOSCOPY, AND URODYNAMICS

More intensive investigations and imaging studies should be considered in specific scenarios but need not be routinely performed. Abdominal and pelvic imaging studies in selected patients can help identify anatomic abnormalities of the upper or lower urinary tracts, diagnose urolithiasis or masses in the upper urinary tract, and rule out hydronephrosis, which may suggest obstructive uropathy. Furthermore,

brain imaging with functional MRI and quantitative sensory testing may prove beneficial in establishing a central sensitization phenotype; however, this is an emerging field of investigation, and routine brain imaging and sensory testing are currently not recommended.

Cystoscopy is used to rule out bladder pathology—most importantly, bladder cancer. Moreover, cystoscopy plays an important role in phenotyping IC/BPS and is required for identification of Hunner lesions. Although a broad consensus is lacking, the authors and others advocate for routine cystoscopic evaluation when IC/BPS is suspected, given the potential therapeutic implications and the ability of this measure to make phenotype-directed therapies possible. Finally, urodynamics testing should be reserved for specific scenarios—for example, cases in which complex voiding dysfunction may be contributing to the presentation.

### INTRAVESICAL ANESTHETIC BLADDER CHALLENGE AND HYDRODISTENSION

An intravesical anesthetic bladder challenge (using intravesical lidocaine) can be done in the outpatient setting and can help distinguish bladder-focused pain from pelvic pain of other causes. It can further be harnessed as a therapeutic strategy if the patient experiences an improvement in symptoms. Similarly, hydrodistension, which requires a general or regional anesthetic, can play a diagnostic or therapeutic role. Bladder capacities of <400 mL under general anesthesia have correlated with worse pain and poor prognosis. The diagnostic role of post-hydrodistension inspection for bladder glomerulations has been suggested as a possible important clinical differentiation, although the utility of identifying and grading glomerulations is debated.

## TREATMENT

### Clinical Phenotyping

The UPOINT phenotyping tool introduced in 2009 was the first clinical tool to recognize that patients presenting with pelvic pain syndromes are a heterogeneous population with disease of unclear etiology that makes it difficult to predict outcomes in individuals with standard therapies. UPOINT is based on a patient-centered approach: individualized treatments are matched to patient evaluations by phenotyping of patients using six distinct clinical domains—urinary, psychosocial, organ-specific, infectious, neurologic, and tenderness. Since its initial publication, follow-up phenotyping studies have indicated that UPOINT is likely better than other methods in establishing phenotypic pain patterns in the clinic setting as local (bladder specific or pelvic pain only) or widespread (pelvic pain and beyond). Similarly, identifying inflammatory subtypes (e.g., Hunner lesion patients) and psychological parameters can help organize a patient's management plan and make it more likely that interventions will be successful. Applying an individualized multimodal treatment approach has proven beneficial in clinical practice. A collection of treatment options that might be directed at different domains of disease is presented in Fig. 51-1.

Although many of these treatments would be considered outside the scope of a general practitioner or general internist, it is important for the practitioner to be aware of them. In general, treatment should begin with more conservative measures, moving on to oral regimens or more invasive procedures if the patient's condition does not improve. A patient-centered approach is paramount in considering treatment escalation. The American Urological Association's IC/BPS guidelines provide a measure of overall efficacy of each individual therapy and a suggested order of implementation (tiered approach), but, because of the inability to predict the response to specific therapies, it is more clinically pragmatic to choose a multimodal approach based on the individual patient's presenting clinical phenotype or "clinical picture." Physicians are better positioned to implement this approach than are surgeons (urologists and gynecologists), who tend to be more organ- and surgery-focused when treating IC/BPS patients.

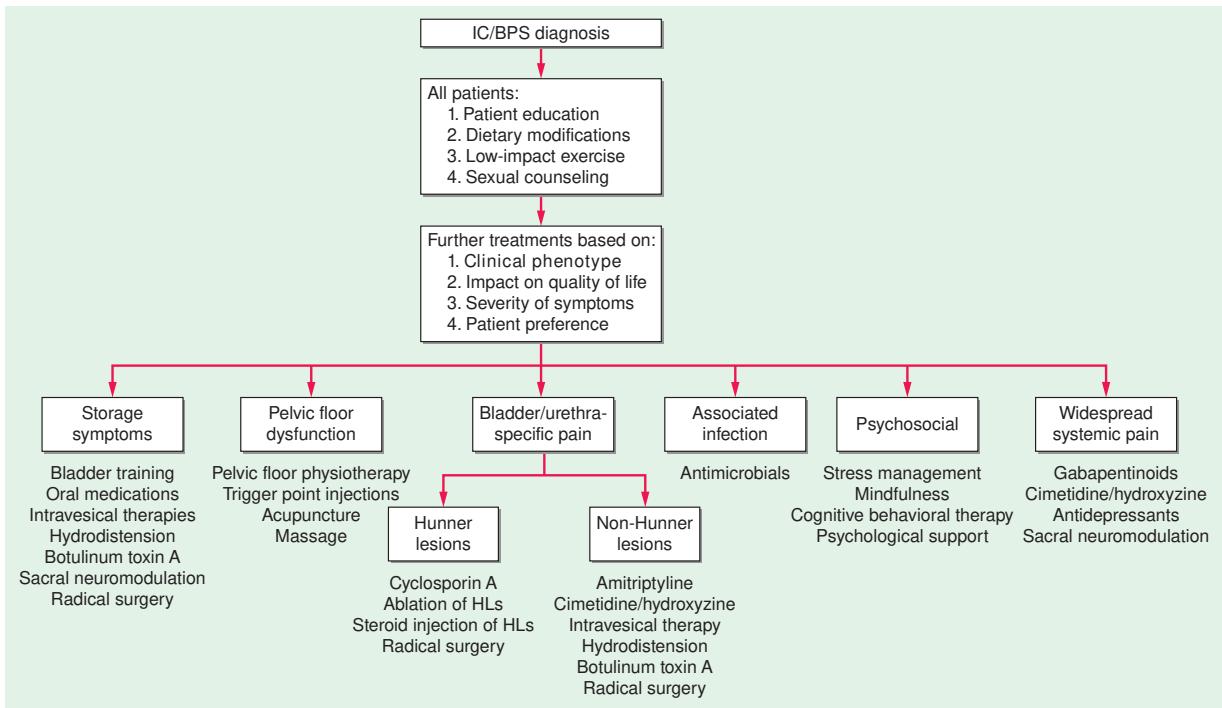


FIGURE 51-1 Proposed management paradigm for the treatment of interstitial cystitis (IC)/bladder pain syndrome (BPS). HLs, Hunner lesions.

## ■ CONSERVATIVE MEASURES

Conservative measures should be implemented for all patients with a diagnosis of IC/BPS. These therapies tend to be simple and inexpensive to introduce, pose little risk of significant side effects, and can be intensified or abandoned on the basis of the patient's response.

**Patient Education** Patient education and empowerment are paramount in this chronic pain disorder. Patients have often seen multiple practitioners prior to their diagnosis of IC/BPS. Acknowledging their suffering while educating them about their disease can go a long way in terms of relieving stress and anxiety related to an unknown and poorly understood problem. This acknowledgement also helps to develop a therapeutic patient–provider relationship. Setting realistic expectations and understanding that cure is not the goal constitute an important first step. Several resources are available for patients to explore at their own leisure.

**Dietary Modifications** Although limited evidence supports the role of dietary modifications, it has long been recognized that certain foods can trigger flares in IC/BPS patients and that simple dietary modifications can result in meaningful improvements in symptoms. Common dietary triggers include acidic and spicy foods and/or drinks, caffeinated or alcoholic beverages, artificial sweeteners, and/or gluten products; this list is by no means exhaustive, and dietary modifications should be made on an individual basis.

**Pelvic Floor Physiotherapy** Involvement of the pelvic floor in the pain syndrome can be ascertained on physical examination. Randomized studies have shown that, for patients who are found to have dysfunctional pelvic floors—muscle spasm, trigger points, or tenderness—contributing to their pain syndrome, pelvic floor physiotherapy may be beneficial. The musculoskeletal anatomy of the pelvic floor is complex; finding a provider with training specifically on the pelvic floor can be difficult but is crucial. Because accessing this resource may be financially burdensome for the patient, working together to find a way to obtain this helpful adjunctive therapy is important.

**Psychological Interventions** Mental health and psychosocial factors have long been identified as significantly prevalent in the IC/BPS

population and can impact disease and quality-of-life outcomes. There is some indication that, in IC/BPS and other related chronic pain conditions, mindfulness and cognitive behavioral therapy may improve outcomes. Challenges in accessing these therapies are a major barrier, and there is a general lack of consensus on which specific interventions are best suited to individual patients.

## ■ MEDICAL THERAPIES

Only two medications are currently approved by the U.S. Food and Drug Administration (FDA) for the treatment of IC/BPS: pentosan polysulfate sodium (PPS) given orally and dimethyl sulfoxide (DMSO) given intravesically. However, a collection of medications, administered orally or intravesically, are commonly used (albeit off-label) for this purpose.

**Oral Therapies** • PPS The only FDA-approved oral medication for IC/BPS has recently come under scrutiny because of reports regarding its association with vision-threatening maculopathy. Although causation has yet to be established, given its marginal benefit in the treatment of IC/BPS, the authors recommend against the long-term use of this medication. For patients currently taking PPS, the risks and benefits of treatment must be weighed. Consideration of a trial of weaning off the medication may be in the best interest of the patient. Any patients experiencing vision-related complaints while taking PPS should undergo immediate ophthalmologic assessment.

**ANTIBIOTICS** IC/BPS is not an infectious condition, and thus, antibiotics should have no role in treatment. Furthermore, the overwhelming majority of IC/BPS patients will have received at least one course, if not several courses, of antibiotics at some point in the course of their disease. Nevertheless, it is not unreasonable to administer a single course of antibiotics (after obtaining a sample for urine culture and sensitivity testing) if the patient has never previously received such therapy.

**AMITRIPTYLINE** Amitriptyline's pharmacologic activity is attributable primarily to its anticholinergic properties, its serotonin and norepinephrine uptake-inhibiting activity, and its sedative effects, which may include an antihistaminic pathway. Amitriptyline has been used to treat IC/BPS and other chronic pain syndromes. Studies support

the use of amitriptyline in IC/BPS patients while recognizing that the benefits can be marginal and associated with significant side effects.

**CIMETIDINE AND HYDROXYZINE** Early nonrandomized studies of hydroxyzine in the treatment of IC/BPS yielded promising results. As with amitriptyline, hydroxyzine's mechanism of action in treating IC/BPS is not fully understood and is likely multifactorial, owing largely to its antihistaminic effect via H<sub>1</sub>-receptor antagonism but perhaps also its anticholinergic properties, its anxiolytic and sedative effects, and its inhibition of mast cell secretion and activation. An underpowered randomized study found no significant difference in symptom improvement between hydroxyzine and placebo.

After the modest success reported for hydroxyzine, cimetidine—an H<sub>2</sub>-receptor antagonist—was investigated as another possible IC/BPS treatment. Only two observational studies and a single, small randomized clinical trial were completed and showed improvement in suprapubic pain and LUTS, particularly urinary frequency.

**GABAPENTINOIDs** Although no randomized studies of gabapentinoids have been performed in the IC/BPS population, these agents have been shown to improve symptoms in related chronic pain conditions. Furthermore, observational studies have shown some efficacy in IC/BPS. In properly selected patients in whom neuropathic pain is suspected, this medication class may have some success.

**CYCLOSPORIN A** Despite its significant side effect profile, cyclosporin A has been investigated as treatment for IC/BPS refractory to other, more standard therapies. Because of its potent anti-inflammatory properties (it is used extensively in organ transplant recipients), this drug is particularly effective in IC/BPS patients with Hunner lesions, although the improvement in symptoms is modest. Side effects, including hypertension and nephrotoxicity, must be carefully monitored for, and the medication is typically reserved for patients in whom standard therapies have failed.

**Intravesical Therapies** Intravesical instillations remain a mainstay in the management of bladder-specific pain. Although this treatment modality typically requires an office visit, able and motivated patients can be trained to administer the medication at home. Patients' responses are variable, and the treatment is not curative, but it can significantly change the trajectory of disease in some patients and can rescue those experiencing symptom flares. Intravesical instillations can be administered as induction therapy; maintenance strategies have been proposed and can be effective for properly selected patients. A plethora of agents—most of them used off-label for this indication—have been investigated. The best-studied options are reviewed here.

**DMSO** DMSO, a solvent with anti-inflammatory properties, has been used in intravesical treatment for IC/BPS for several years. Despite a lack of high-quality evidence (with efficacy documented in only one placebo-controlled randomized clinical trial), DMSO remains the only FDA-approved intravesical medication for IC/BPS treatment. Its use has fallen out of favor, however, largely because of its unpleasant side effect of halitosis (its elimination via the lungs is associated with a garlic-like odor). Although the degree of improvement in symptoms is highly variable (60–95%), DMSO remains in the armamentarium of intravesical therapies.

**HEPARIN** Heparin, a glycosaminoglycan, was first investigated as a treatment for IC/BPS in light of the glycosaminoglycan layer deficiency theory of IC/BPS etiology; in animal models, heparin was shown to restore areas of damaged urothelium. Although there are no randomized clinical trials showing its efficacy, several observational studies have suggested benefit. Furthermore, in current practice, heparin is commonly administered with other medications as part of an intravesical "cocktail." Systemic absorption is minimal and appears not to affect coagulation parameters.

**LIDOCAINE** Lidocaine is commonly used as a local anesthetic and has been investigated as an option for intravesical treatment for IC/BPS. This agent works by blocking sensory nerves in the urothelium. Its

absorption and efficacy increase by alkalinization, commonly through coadministration with sodium bicarbonate.

**HYALURONIC ACID AND CHONDROITIN SULFATE** Hyaluronic acid and, more recently, chondroitin sulfate have been targeted as potential intravesical therapies because of their potentially restorative impact on the glycosaminoglycan layer. As is the case with most intravesical therapies, the quality of evidence is low, but there appears to be a modest benefit, with few side effects. Thus, these agents remain as options for patients whose disease is refractory to more standard therapies.

**Trigger Point Injection** Injection of a local anesthetic into myofascial trigger points in the pelvic floor (identified on physical examination) is a minimally invasive, practical therapy that can be administered during an office visit and can provide relief in properly selected patients. As with all therapies for this chronic pain condition, patient selection is paramount. The evidence supporting this treatment is largely anecdotal and based on expert opinion. A small nonblinded observational trial found a 72% success rate among women diagnosed with chronic pelvic pain and trigger points on physical examination; 33% of women were completely pain free after the injection. Although robust prospective trials are needed, this modality adds to the clinician's armamentarium in the treatment of IC/BPS.

## SURGICAL THERAPIES

**Treatment of Hunner Lesions** A unique subset of IC/BPS patients have Hunner lesions. Direct treatment of these lesions through ablation with cauterization or laser treatment or, alternatively, injection of the lesion with a glucocorticoid improves symptoms in 70–90% of these patients. Hunner lesions tend to be recurrent, however; thus, treated patients still require follow-up, with consideration of a multimodal approach to their disease.

**Hydrodistension** Recent reports confirm that one of the oldest therapies for IC/BPS, hydrodistension under general anesthesia, provides some benefit in up to 54% of patients. Short- and long-term adverse effects (including bladder perforation and long-term bladder wall fibrosis) and the temporary nature of the benefit (with symptoms typically recurring within 3–12 months) mean that repeated bladder distension may not be an ideal long-term management strategy.

**Onabotulinum Toxin A** Onabotulinum toxin A (i.e., Botox) has been used to treat IC/BPS. There has, however, never been a randomized, placebo-controlled study evaluating onabotulinum toxin A injection into the detrusor muscle as monotherapy in this disease. Several randomized studies have evaluated this agent's efficacy and have shown improvements in symptoms; unfortunately, these trials often use onabotulinum toxin A in combination with hydrodistension, lack a placebo arm, and do not control for LUTS. Attributing benefit to this treatment is thus challenging. Furthermore, the side effect of acute urinary retention can be catastrophic in IC/BPS patients, whose pain is often secondary to bladder filling.

**Sacral Neuromodulation** In properly selected patients, sacral neuromodulation (SNM) can provide symptom relief in IC/BPS. Its use for this purpose is off-label, and it is not FDA approved for pain therapy. Nevertheless, SNM is FDA approved for treatment of bladder overactivity—a common symptom in IC/BPS patients—that is refractory to standard therapies. Although studies evaluating improvements in pain have shown variable results, a recent meta-analysis examining 17 observational trials (but no randomized clinical trials) of the use of SNM for IC/BPS does support its efficacy, with a statistically significant pooled treatment success rate of up to 84%. Side effects related to SNM must be considered, and the procedure carries with it a high rate of revision surgery, which is needed in up to half of patients undergoing this treatment.

**Radical Surgery** Radical surgery for the treatment of IC/BPS is reserved as a modality of desperation for the most refractory patients.



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Options range from substitution cystoplasty to cystectomy with urinary diversion. Although improved symptoms and quality of life may result, such surgery is a potentially morbid operation and patient selection must be very specific.

## COMPLICATIONS AND PROGNOSIS

IC/BPS is not unlike other chronic pain conditions in that, although a clear link has not been established with higher mortality, this condition is certainly associated with significant disability, decreased quality of life, and significant mental health morbidity. The economic impact of the disability associated with IC/BPS is similar to that of fibromyalgia, low back pain, rheumatoid arthritis, and peripheral neuropathy. Suicidal ideation is a reality in this patient population, with a reported prevalence as high as 11–23%.

For most patients, IC/BPS onset is subacute, with continuous development of the classic symptom complex over a short time and rapid (within 5 years) progression to its final stage. Symptoms then continue to wax and wane without significant overall change in symptomatology for the majority of patients. However, spontaneous improvement and/or resolution occurs in some patients, while a small subset experience subsequent deterioration to a small-capacity, fibrotic, noncompliant bladder (“end-stage bladder”). A multimodal approach to therapy, interdisciplinary involvement in patient care, particular attention to psychosocial parameters, and check-ins on mental health are important aspects of ongoing care.

## GLOBAL CONSIDERATIONS

Significant challenges have been encountered in confirming the prevalence of IC/BPS, particularly globally. Prevalence estimates have ranged widely from as low as 3.5 per 100,000 women in a study of a Japanese population to as high as 20,000 per 100,000 in a self-report questionnaire study of a U.S. population. Despite these challenges, it has been recognized that IC/BPS is not simply a disease of the global West. Although robust epidemiologic studies outside North America, Europe, and some regions of Asia are lacking, it is presumed that this disease occurs at similar rates globally. This presumption may be extrapolated from epidemiologic studies of a related population and its male counterpart: CP/CPPS. These studies have shown rates of CP/CPPS in African and Asian populations that are similar to rates in North American populations.

There is no evidence to suggest that IC/BPS is phenotypically distinct in various geographic regions. Thus, this condition should be diagnosed and treated in the same ways globally. Given that its diagnosis of exclusion is based largely on history and physical examination and its treatment is based on a minimally invasive algorithm, with the focus on the patient's clinical phenotype and the initial implementation of conservative therapeutic measures, IC/BPS can be well managed even in resource-poor settings. As with many poorly understood and difficult-to-treat conditions, the greatest barrier to its diagnosis and treatment may perhaps be its recognition.

## FURTHER READING

- C JQ et al: Urologic chronic pelvic pain syndrome: Insights from the MAPP Research Network. *Nat Rev Urol* 16:187, 2019.
- C A et al: CUA guideline: Diagnosis and treatment of interstitial cystitis/bladder pain syndrome. *Can Urol Assoc J* 10:E136, 2016.
- H PM et al: AUA guideline for the diagnosis and treatment of interstitial cystitis/bladder pain syndrome. *J Urol* 185:2162, 2011.
- H P et al: Incontinence, in *International Consultation on Incontinence, September 2016*, vol 2, 6th ed, P Abrams et al (eds). Tokyo, ICUD ICS, 2017, pp 2203–2301.
- M JP et al: Diagnostic criteria, classification, and nomenclature for painful bladder syndrome/interstitial cystitis: An ESSIC proposal. *Eur Urol* 53:60, 2008.

Normal kidney functions occur through numerous cellular processes to maintain body homeostasis. Disturbances in any of these functions can lead to abnormalities that may be detrimental to survival. Clinical manifestations of these disorders depend on the pathophysiology of renal injury and often are identified as a complex of symptoms, abnormal physical findings, and laboratory changes that constitute specific syndromes. These renal syndromes (Table 52-1) may arise from systemic illness or as primary renal disease. Nephrologic syndromes usually consist of several elements that reflect the underlying pathologic processes, typically including one or more of the following: (1) reduction in glomerular filtration rate (GFR), (2) abnormalities of urine sediment (red blood cells [RBCs], white blood cells [WBCs], casts, and crystals), (3) abnormal urinary excretion of serum proteins (proteinuria), (4) disturbances in urine volume (oliguria, anuria, polyuria), (5) presence of hypertension and/or expanded total body fluid volume (edema), (6) electrolyte abnormalities, and (7) in some syndromes, fever/pain. The specific combination of these findings should permit identification of one of the major nephrologic syndromes (Table 52-1) and allow differential diagnoses to be narrowed so that the appropriate diagnostic and therapeutic course can be determined. All these syndromes and their associated diseases are discussed in more detail in subsequent chapters. This chapter focuses on several aspects of renal abnormalities that are critically important for distinguishing among those processes: (1) reduction in GFR, (2) alterations of the urinary sediment and/or protein excretion, and (3) abnormalities of urinary volume.

## AZOTEMIA

### ASSESSMENT OF GFR

Monitoring the GFR is important in both hospital and outpatient settings, and several different methodologies are available. GFR is the primary metric for kidney “function,” and its direct measurement involves administration of a radioactive isotope (such as inulin or iothalamate) that is filtered at the glomerulus into the urinary space but is neither reabsorbed nor secreted throughout the tubule. GFR—i.e., the clearance of inulin or iothalamate in milliliters per minute—is calculated from the rate of appearance of the isotope in the urine over several hours. In most clinical circumstances, direct GFR measurement is not feasible, and the plasma creatinine level is used as a surrogate to estimate GFR. Plasma creatinine ( $P_{Cr}$ ) is the most widely used marker for GFR, which is related directly to urine creatinine ( $U_{Cr}$ ) excretion and inversely to  $P_{Cr}$ . On the basis of this relationship (with some important caveats, as discussed below), GFR will fall in roughly inverse proportion to the rise in  $P_{Cr}$ . Failure to account for GFR reductions in drug dosing can lead to significant morbidity and death from drug toxicities (e.g., digoxin, imipenem). In the outpatient setting,  $P_{Cr}$  serves as an estimate for GFR (although much less accurate; see below). In patients with chronic progressive renal disease, there is an approximately linear relationship between  $1/P_{Cr}$  (y axis) and time (x axis). The slope of that line will remain constant for an individual; when values deviate, an investigation for a superimposed acute process (e.g., volume depletion, drug reaction) should be initiated. Signs and symptoms of uremia, the clinical symptom complex associated with renal failure, develop at significantly different levels of  $P_{Cr}$ , depending on the patient (size, age, and sex), underlying renal disease, existence of concurrent diseases, and true GFR. Generally, patients do not develop symptomatic uremia until renal insufficiency is severe (GFR <15 mL/min).

A significantly reduced GFR (either acute or chronic) is usually reflected in a rise in  $P_{Cr}$ , leading to retention of nitrogenous waste products (defined as azotemia) such as urea. Azotemia may result from

TABLE 52-1 Initial Clinical and Laboratory Database for Defining Major Syndromes in Nephrology

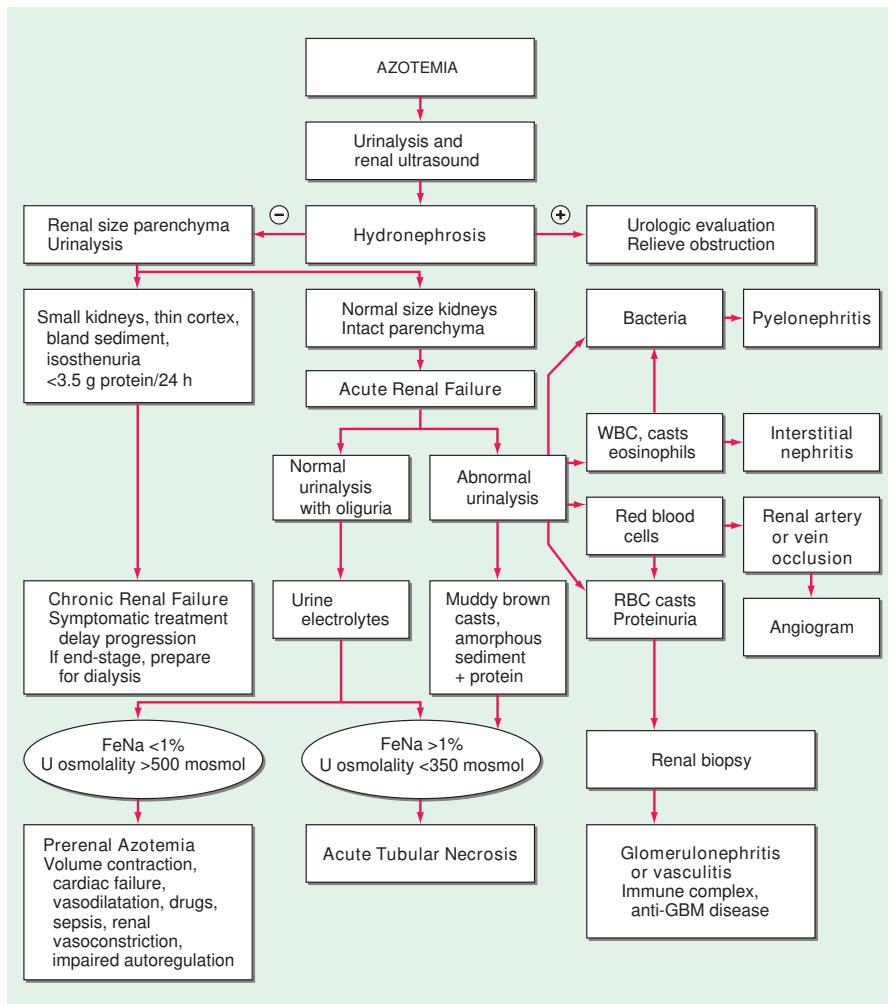
SYNDROME	IMPORTANT CLUES TO DIAGNOSIS	COMMON FINDINGS	CHAP(S), DISCUSSING DISEASE-CAUING SYNDROME
Acute or rapidly progressive renal failure	Anuria	Hypertension, hematuria	310, 314, 316, 319
	Oliguria	Proteinuria, pyuria	
	Documented recent decline in GFR	Casts, edema	
Acute nephritis	Hematuria, RBC casts	Proteinuria	314
	Azotemia, reduced GFR, oliguria	Pyuria	
	Edema, hypertension	Circulatory congestion	
Chronic renal failure	Azotemia for >3 months	Proteinuria, casts	311
	Symptoms or signs of uremia, (late manifestation), casts	Hypocalcemia, hyperphosphatemia, hyperparathyroidism	
	Symptoms or signs of renal osteodystrophy	Polyuria, nocturia	
	Kidneys reduced in size bilaterally	Edema, hypertension	
	Broad casts in urinary sediment	Hyperkalemia, metabolic acidosis	
Nephrotic syndrome	Proteinuria, with >3.5 g/24 h per 1.73 m <sup>2</sup>	Casts	314
	Hypoalbuminemia	Lipiduria	
	Edema	Hypercoagulable state	
	Hyperlipidemia		
Asymptomatic urinary abnormalities	Hematuria		314
	Proteinuria (below nephrotic range)		
	Sterile pyuria, casts		
Urinary tract infection/pyelonephritis	Bacteriuria, with >10 <sup>5</sup> cfu/mL	Hematuria	135
	Other infectious agent documented in urine	Mild azotemia and reduced GFR	
	Pyuria, leukocyte casts	Mild proteinuria	
	Frequency, urgency	Fever	
	Bladder tenderness, flank tenderness		
Renal tubular defects	Electrolyte disorders	Hematuria	315, 316
	Polyuria, nocturia	"Tubular" proteinuria (<1 g/24 h)	
	Renal calcification	Enuresis	
	Large kidneys	Electrolyte and/or acid-base abnormalities	
	Renal transport defects	Other electrolyte issues, e.g., hypomagnesemia	
Hypertension	Systolic/diastolic hypertension	Proteinuria	277, 317
		Casts	
		Azotemia	
Nephrolithiasis	Previous history of stone passage or removal	Hematuria	318
	Previous history of stone seen by x-ray	Pyuria	
	Renal colic	Frequency, urgency	
Urinary tract obstruction	Azotemia, oliguria, anuria	Hematuria	319
	Polyuria, nocturia, urinary retention	Pyuria	
	Slowing of urinary stream	Enuresis, dysuria	
	Large prostate, large kidneys		
	Flank tenderness, full bladder after voiding		

Abbreviations: cfu, colony-forming units; GFR, glomerular filtration rate; RBC, red blood cell.

reduced renal perfusion, intrinsic renal disease, or postrenal processes (ureteral obstruction; see below and Fig. 52-1). Precise determination of GFR is problematic, as both commonly measured indices (urea and creatinine) have characteristics that affect their accuracy as markers of clearance. Urea clearance may underestimate GFR significantly because of urea reabsorption by the tubule. In contrast, creatinine is derived from muscle metabolism of creatine, and its generation varies little from day to day.

Creatinine clearance (CrCl), an approximation of GFR, is measured from plasma and urinary creatinine excretion rates for a defined period (usually 24 h) and is expressed in milliliters per minute: CrCl =  $(U_{\text{vol}} \times U_{\text{Cr}}) / (P_{\text{Cr}} \times T_{\text{min}})$ . The "adequacy" or "completeness" of the urinary collection is estimated by the urinary volume and creatinine content; creatinine is produced from muscle and excreted at a relatively constant

rate. For a 20- to 50-year-old man, creatinine excretion should be 18.5–25.0 mg/kg body weight; for a woman of the same age, it should be 16.5–22.4 mg/kg body weight. For example, an 80-kg man should excrete between ~1500 and 2000 mg of creatinine in an "adequate" collection. Creatinine is useful for estimating GFR because it is a small, freely filtered solute that is not reabsorbed by the tubules.  $P_{\text{Cr}}$  levels can increase acutely from dietary ingestion of cooked meat, however, and creatinine can be secreted into the proximal tubule through an organic cation pathway (especially in advanced progressive chronic kidney disease [CKD]), leading to overestimation of GFR. When a timed collection for CrCl is not available, decisions about drug dosing must be based on  $P_{\text{Cr}}$  alone. Two formulas are used widely to estimate kidney function from  $P_{\text{Cr}}$ : (1) Cockcroft-Gault and (2) four-variable MDRD (Modification of Diet in Renal Disease).



**FIGURE 52-1** Approach to the patient with azotemia. FeNa, fractional excretion of sodium; GBM, glomerular basement membrane; RBC, red blood cell; U, urine; WBC, white blood cell.

Cockcroft-Gault:

$$\text{CrCl}(\text{mL/min}) = \frac{(140 - \text{age}) \times \text{Lean Body Weight (kg)}}{\text{Serum Creatinine (mg/dL)} \times 72} \times 0.85 \text{ if female}$$

$$\text{MDRD: eGFR (mL/min per } 1.73 \text{ m}^2\text{)} = 186.3 \times P_{\text{Cr}} (e^{-0.154}) \times \text{age } (e^{-0.203}) \times 0.742 \text{ if female} \times 1.21 \text{ if black.}$$

Numerous websites are available to assist with these calculations ([www.kidney.org/professionals/kdoqi/gfr\\_calculator.cfm](http://www.kidney.org/professionals/kdoqi/gfr_calculator.cfm)). A newer Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) estimated GFR (eGFR), which was developed by pooling several cohorts with and without kidney disease who had data on directly measured GFR, appears to be more accurate:

$$\text{CKD-EPI: eGFR} = 141 \times \min(P_{\text{Cr}}/k, 1)^a \times \max(P_{\text{Cr}}/k, 1)^{-1.209} \times 0.993^{A_{\text{age}}} \times 1.018 \text{ [if female]} \times 1.159 \text{ [if black],}$$

where  $P_{\text{Cr}}$  is plasma creatinine,  $k$  is 0.7 for females and 0.9 for males,  $a$  is  $-0.329$  for females and  $-0.411$  for males,  $\min$  indicates the minimum of  $P_{\text{Cr}}/k$  or 1, and  $\max$  indicates the maximum of  $P_{\text{Cr}}/k$  or 1 (<https://www.mdcalc.com/ckd-epi-equations-glomerular-filtration-rate-gfr>).

There are limitations to all creatinine-based estimates of GFR. Each equation, along with 24-h urine collection for measurement of creatinine clearance, is based on the assumption that the patient is in *steady state*, without daily increases or decreases in  $P_{\text{Cr}}$  as a result of rapidly changing GFR. The MDRD equation is better correlated with true GFR when the GFR is  $<60$  mL/min per  $1.73 \text{ m}^2$ . The gradual loss of muscle from chronic illness, chronic use of glucocorticoids, or malnutrition can mask significant changes in GFR with small or imperceptible changes in  $P_{\text{Cr}}$ .

The coefficient of 1.159 in the CKD-EPI equation to adjust for self-reported black race reflects that measured GFR was 16% higher in blacks than nonblacks with similar age, sex, and creatinine in the data set used to develop the equation. Race is a social rather than a biological construct, for which reason the use of the “race modifier” in calculating eGFR using CKD-EPI and other equations has come under scrutiny. In particular, given the implications of utilizing self-reported race to modify clinical laboratory results, many medical centers have recently stopped reporting eGFRs that have been calculated using a race modifier. This change is projected to have positive consequences, in particular, improved access to waitlisting for renal transplantation in black patients at an earlier stage of CKD. Potential negative consequences include “overdiagnosis” of CKD, inadequate or inaccurate dosing of drugs that are eliminated through the kidney (e.g.,

metformin), reduced access to imaging modalities for black patients with CKD with a lower reported eGFR, and reductions in living kidney donation among blacks. These and the other limitations in creatinine-based eGFR have led to the development of alternative methods for estimating GFR.

Cystatin C, a member of the cystatin superfamily of cysteine protease inhibitors, is produced at a relatively constant rate from all nucleated cells. Serum cystatin C has been proposed to be a more sensitive marker of early GFR decline than is  $P_{Cr}$ , with lesser effects of muscle mass on circulating levels; however, cystatin C levels are influenced by the patient's sex and the presence of diabetes mellitus, smoking, and inflammation. To the extent that cystatin C-based calculation of eGFR is less affected by self-reported race and muscle mass, it is an increasingly important adjunct to creatinine-based eGFR.

## APPROACH TO THE PATIENT

### Azotemia

Once GFR reduction has been established, the physician must decide if it represents acute or chronic renal injury. The clinical circumstances, history, and laboratory data often make this an easy distinction. However, the laboratory abnormalities characteristic of chronic renal failure, including anemia, hypocalcemia, and hyperphosphatemia, are also often present in patients presenting with acute renal failure. Radiographic evidence of renal osteodystrophy (*Chap. 311*) can be seen only in chronic renal failure but is a very late finding, typically in patients with end-stage renal disease (ESRD) maintained on dialysis. The urinalysis and renal ultrasound can facilitate distinguishing acute from chronic renal failure. An approach to the evaluation of azotemic patients is shown in Fig. 52-1. Patients with advanced chronic renal insufficiency often have some proteinuria, nonconcentrated urine (isosthenuria; isosmotic with plasma), and small kidneys on ultrasound, characterized by increased echogenicity and cortical thinning. Treatment should be directed toward slowing the progression of renal disease and providing symptomatic relief for edema, acidosis, anemia, and hyperphosphatemia, as discussed in *Chap. 311*. Acute renal failure (*Chap. 310*) can result from processes that affect blood flow and glomerular perfusion (prerenal azotemia), intrinsic renal diseases (affecting small vessels, glomeruli, or tubules), or postrenal processes (obstruction of urine flow in ureters, bladder, or urethra) (*Chap. 319*).

#### PRERENAL FAILURE

Decreased renal perfusion accounts for 40–80% of cases of acute renal failure and, if appropriately treated, is readily reversible. The etiologies of prerenal azotemia include any cause of decreased circulating blood volume (gastrointestinal hemorrhage, burns, diarrhea, diuretics), volume sequestration (pancreatitis, peritonitis, rhabdomyolysis), or decreased effective arterial volume (cardio-genic shock, sepsis). Renal and glomerular perfusion also can be affected by reductions in cardiac output from peripheral vasodilation (sepsis, drugs) or profound renal vasoconstriction (severe heart failure, hepatorenal syndrome, agents such as nonsteroidal anti-inflammatory drugs [NSAIDs]). True or “effective” arterial hypovolemia leads to a fall in mean arterial pressure, which in turn triggers a series of neural and humoral responses, including activation of the sympathetic nervous and renin-angiotensin-aldosterone systems and vasopressin (AVP) release. GFR is maintained by prostaglandin-mediated dilatation of afferent arterioles and angiotensin II-mediated constriction of efferent arterioles. Once the mean arterial pressure falls below 80 mmHg, GFR declines steeply.

Blockade of prostaglandin production by NSAIDs can result in severe vasoconstriction and acute renal failure. Blocking angiotensin action with angiotensin-converting enzyme (ACE) inhibitors

TABLE 52-2 Laboratory Findings in Acute Renal Failure

INDEX	PRERENAL AZOTEMIA	OLIGURIC ACUTE RENAL FAILURE
BUN/ $P_{Cr}$ ratio	>20:1	10–15:1
Urine sodium $U_{Na}^+$ , meq/L	<20	>40
Urine osmolality, mosmol/L $H_2O$	>500	>350
Fractional excretion of sodium <sup>a</sup>	<1%	>2%
Urine/plasma creatinine $U_{Cr}/P_{Cr}$	>40	<20
Urinalysis (casts)	None or hyaline/granular	Muddy brown

$$^{a}FE_{Na} = \frac{U_{Na} \times P_{Cr} \times 100}{P_{Na} \times U_{Cr}}$$

Abbreviations: BUN, blood urea nitrogen;  $P_{Cr}$ , plasma creatinine concentration;  $P_{Na}^+$ , plasma sodium concentration;  $U_{Cr}$ , urine creatinine concentration;  $U_{Na}^+$ , urine sodium concentration.

or angiotensin receptor blockers (ARBs) decreases efferent arteriolar tone and in turn decreases glomerular capillary perfusion pressure. Patients taking NSAIDs and/or ACE inhibitors/ARBs are most susceptible to hemodynamically mediated acute renal failure when blood volume or arterial perfusion pressure is reduced for any reason; under these circumstances, preservation of GFR is dependent on afferent vasodilation due to prostaglandins and efferent vasoconstriction due to angiotensin II. Patients with bilateral renal artery stenosis (or stenosis in a solitary kidney) can also be dependent on efferent arteriolar vasoconstriction for maintenance of glomerular filtration pressure and are particularly susceptible to a precipitous decline in GFR when given ACE inhibitors or ARBs.

Prolonged renal hypoperfusion may lead to acute tubular necrosis (ATN), an intrinsic renal disease that is discussed below. The urinalysis and urinary electrolyte measurements can be useful in distinguishing prerenal azotemia from ATN (*Table 52-2*). The urine Na and osmolality of patients with prerenal azotemia can be predicted from the stimulatory actions of norepinephrine, angiotensin II, AVP, aldosterone, and low tubule fluid flow rate. In prerenal conditions, the tubules are intact, leading to a concentrated urine (>500 mosmol), avid Na retention (urine Na concentration, <20 mmol/L; fractional excretion of Na [ $FE_{Na}$ ], <1%), and  $U_{Cr}/P_{Cr} > 40$  (*Table 52-2*). The  $FE_{Na}$  is typically >1% in ATN, but may be <1% in patients with milder, nonoliguric ATN (e.g., from rhabdomyolysis) and in patients with underlying “prerenal” disorders, such as congestive heart failure (CHF) or cirrhosis or hepatorenal syndrome. The prerenal urine sediment is usually normal or has hyaline and granular casts, whereas the sediment of ATN usually is filled with cellular debris, tubular epithelial casts, and dark (muddy brown) granular casts. The measurement of urinary biomarkers associated with tubular injury is a promising technique to detect subclinical ATN and/or help further diagnose the exact cause of acute renal failure.

#### POSTRENAL AZOTEMIA

Urinary tract obstruction accounts for <5% of cases of acute renal failure but is usually reversible and must be ruled out early in the evaluation (*Fig. 52-1*). Since a single kidney is capable of adequate clearance, complete obstructive acute renal failure requires obstruction at the urethra or bladder outlet, bilateral ureteral obstruction, or unilateral obstruction in a patient with a single functioning kidney. Obstruction is usually diagnosed by the presence of ureteral and renal pelvic dilation on renal ultrasound. However, early in the course of obstruction or if the ureters are unable to dilate (e.g., encasement by pelvic or periureteral tumors or by retroperitoneal fibrosis), the ultrasound examination may be negative. Other

imaging, such as a furosemide renogram (MAG3 nuclear medicine study), may be required to better define the presence or absence of obstructive uropathy. The specific urologic conditions that cause obstruction are discussed in [Chap. 319](#).

### INTRINSIC RENAL DISEASE

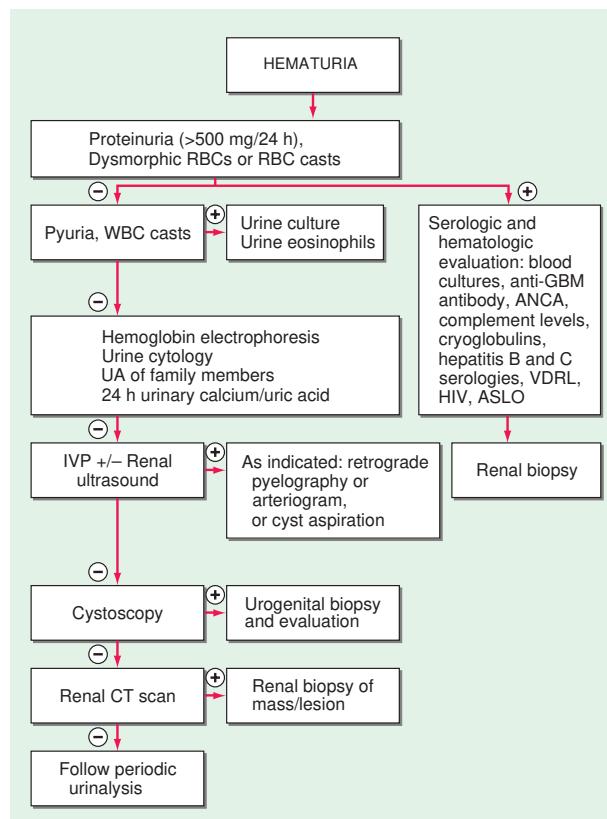
When prerenal and postrenal azotemia have been excluded as etiologies of renal failure, an intrinsic parenchymal renal disease is present. Intrinsic renal disease can arise from processes involving large renal vessels, intrarenal microvasculature and glomeruli, or the tubulointerstitium. Ischemic and toxic ATN account for ~90% of cases of acute intrinsic renal failure. As outlined in Fig. 52-1, the clinical setting and urinalysis are helpful in separating the possible etiologies. Prerenal azotemia and ATN are part of a spectrum of renal hypoperfusion; evidence of structural tubule injury is present in ATN, whereas prompt reversibility occurs with prerenal azotemia upon restoration of adequate renal perfusion. Thus, ATN often can be distinguished from prerenal azotemia by urinalysis and urine electrolyte composition (Table 52-2 and Fig. 52-1). Ischemic ATN is observed most frequently in patients who have undergone major surgery, trauma, severe hypovolemia, overwhelming sepsis, or extensive burns. Nephrotoxic ATN complicates the administration of many common medications, usually by inducing a combination of intrarenal vasoconstriction, direct tubule toxicity, and/or tubular obstruction. The kidney is vulnerable to toxic injury by virtue of its rich blood supply (25% of cardiac output) and its ability to concentrate and metabolize toxins. A diligent search for hypotension and nephrotoxins usually uncovers the specific etiology of ATN. Discontinuation of nephrotoxins and stabilization of blood pressure often suffice without the need for dialysis, with ongoing regeneration of tubular cells. [An extensive list of potential drugs and toxins implicated in ATN is found in Chap. 310](#).

Processes involving the tubules and interstitium can lead to acute kidney injury (AKI), a subtype of acute renal failure. These processes include drug-induced interstitial nephritis (especially by antibiotics, NSAIDs, and diuretics), severe infections (both bacterial and viral), systemic diseases (e.g., systemic lupus erythematosus), and systemic disorders (e.g., sarcoidosis, Sjögren's syndrome, lymphoma, or leukemia). A list of drugs associated with allergic interstitial nephritis is found in [Chap. 316](#). Urinalysis usually shows mild to moderate proteinuria, hematuria, and pyuria (~75% of cases) and occasionally WBC casts. The finding of RBC casts in interstitial nephritis has been reported but should prompt a search for glomerular diseases (Fig. 52-1). Occasionally, renal biopsy will be needed to distinguish among these possibilities. The classic sediment finding in allergic interstitial nephritis is a predominance (>10%) of urinary eosinophils with Wright's or Hansel's stain; however, urinary eosinophils can be increased in several other causes of AKI, such that measurement of urine eosinophils has no diagnostic utility in renal disease.

Occlusion of large renal vessels, including arteries and veins, is an uncommon cause of acute renal failure. A significant reduction in GFR by this mechanism suggests bilateral processes or, in a patient with a single functioning kidney, a unilateral process. In patients with preexisting renal artery stenosis, a substantial renal collateral circulation can develop over time and sustain renal perfusion—typically not enough to sustain glomerular filtration—in the event of total renal artery occlusion. Renal arteries can be occluded with atheroemboli, thromboemboli, in situ thrombosis, aortic dissection, or vasculitis. Atheroembolic renal failure can occur spontaneously but most often is associated with recent aortic instrumentation. The emboli are cholesterol-rich and lodge in medium and small renal arteries, with a consequent eosinophil-rich inflammatory reaction. Patients with atheroembolic acute renal failure often have a normal urinalysis, but the urine may contain eosinophils and casts. The diagnosis can be confirmed by renal biopsy, but this procedure is often unnecessary when other stigmata

of atheroemboli are present (livedo reticularis, distal peripheral infarcts, eosinophilia). Renal artery thrombosis may lead to mild proteinuria and hematuria, whereas renal vein thrombosis typically occurs in the context of heavy proteinuria and hematuria. These vascular complications often require angiography for confirmation and are discussed in [Chap. 317](#).

Diseases of the glomeruli (glomerulonephritis and vasculitis) and the renal microvasculature (hemolytic-uremic syndrome, thrombotic thrombocytopenic purpura, and malignant hypertension) usually present with various combinations of glomerular injury: proteinuria, hematuria, reduced GFR, and alterations of sodium excretion that lead to hypertension, edema, and circulatory congestion (acute nephritic syndrome). These findings may occur as primary renal diseases or as renal manifestations of systemic diseases. The clinical setting and other laboratory data help distinguish primary renal diseases from systemic diseases. The finding of RBC casts in the urine is an indication for early renal biopsy (Fig. 52-1), as the pathologic pattern has important implications for diagnosis, prognosis, and treatment. Hematuria without RBC casts can also be an indication of glomerular disease, since RBC casts are highly specific but very insensitive for glomerulonephritis. The specificity of urine microscopy can be enhanced by examining urine with a phase contrast microscope capable of detecting dysmorphic red cells ("acanthocytes") that are associated with glomerular disease. This evaluation is summarized in [Fig. 52-2](#). A detailed discussion of glomerulonephritis and diseases of the microvasculature is found in [Chap. 316](#).



**FIGURE 52-2** Approach to the patient with hematuria. ANCA, antineutrophil cytoplasmic antibody; ASLO, antistreptolysin O; CT, computed tomography; GBM, glomerular basement membrane; IVP, intravenous pyelography; RBC, red blood cell; UA, urinalysis; VDRL, Venereal Disease Research Laboratory; WBC, white blood cell.

## OLIGURIA AND ANURIA

*Oliguria* refers to a 24-h urine output <400 mL, and *anuria* is the complete absence of urine formation (<100 mL). Anuria can be caused by complete bilateral urinary tract obstruction; a vascular catastrophe (dissection or arterial occlusion); renal vein thrombosis; acute cast nephropathy in myeloma; renal cortical necrosis; severe ATN; combined therapy with NSAIDs, ACE inhibitors, and/or ARBs; and hypovolemic, cardiogenic, or septic shock. Oliguria is never normal, since at least 400 mL of maximally concentrated urine must be produced to excrete the obligate daily osmolar load. *Nonoliguria* refers to urine output >400 mL/d in patients with acute or chronic azotemia. With nonoliguric ATN, disturbances of potassium and hydrogen balance are less severe than in oliguric patients, and recovery to normal renal function is usually more rapid.

## ABNORMALITIES OF THE URINE

### ■ PROTEINURIA

The evaluation of proteinuria is shown schematically in Fig. 52-3 and typically is initiated after detection of proteinuria by dipstick examination. The dipstick measurement detects only albumin and gives false-positive results at pH >7.0 or when the urine is very concentrated or contaminated with blood. Because the dipstick relies on urinary albumin concentration, a very dilute urine may obscure significant proteinuria on dipstick examination. Quantification of urinary albumin on a spot urine sample (ideally from a first morning void) by measurement of an albumin-to-creatinine ratio (ACR) is helpful in approximating a 24-h albumin excretion rate (AER), where ACR (mg/g)  $\approx$  AER (mg/24 h). Furthermore, proteinuria that is not predominantly due to albumin will be missed by dipstick screening. This information is particularly important for the detection of Bence-Jones proteins in the urine of patients with multiple myeloma. Tests to measure total urine protein concentration accurately rely on precipitation

with sulfosalicylic or trichloroacetic acid (Fig. 52-3). As with albuminuria, the ratio of protein to creatinine in a random, “spot” urine can also provide a rough estimate of protein excretion; for example, a protein/creatinine ratio of 3.0 correlates to ~3.0 g of proteinuria per day. Formal assessment of urinary protein excretion requires a 24-h urine protein collection (see “Measurement of GFR,” above).

The magnitude of proteinuria and its composition in the urine depend on the mechanism of renal injury that leads to protein losses. Both charge and size selectivity normally prevent virtually all plasma albumin, globulins, and other high-molecular-weight proteins from crossing the glomerular wall; however, if this barrier is disrupted, plasma proteins may leak into the urine (glomerular proteinuria; Fig. 52-3). Smaller proteins (<20 kDa) are freely filtered but are readily reabsorbed by the proximal tubule. Typically, healthy individuals excrete <150 mg/d of total protein and <30 mg/d of albumin. However, even at albuminuria levels <30 mg/d, risk for progression to overt nephropathy or subsequent cardiovascular disease is increased. The remainder of the protein in the urine is secreted by the tubules (Tamm-Horsfall, IgA, and urokinase) or represents small amounts of filtered  $\beta_2$ -microglobulin, apoproteins, enzymes, and peptide hormones. Another mechanism of proteinuria entails excessive production of an abnormal protein that exceeds the capacity of the tubule for reabsorption. This situation most commonly occurs with plasma cell dyscrasias, such as multiple myeloma, amyloidosis, and lymphomas, that are associated with monoclonal production of immunoglobulin light chains.

The normal glomerular endothelial cell forms a barrier composed of pores of ~100 nm that retain blood cells but offer little impediment to passage of most proteins. The glomerular basement membrane traps most large proteins (>100 kDa), and the foot processes of epithelial cells (podocytes) cover the urinary side of the glomerular basement membrane and produce a series of narrow channels (slit diaphragms) to allow molecular passage of small solutes and water but not proteins. Some glomerular diseases, such as minimal change disease, cause fusion of glomerular epithelial cell foot processes, resulting in predominantly “selective” (Fig. 52-3) loss of albumin. Other glomerular diseases can present with disruption of the basement membrane and slit diaphragms (e.g., by immune complex deposition), resulting in losses of albumin and other plasma proteins. The fusion of foot processes causes increased pressure across the capillary basement membrane, resulting in areas with larger pore sizes (and more severe “nonspecific” proteinuria) (Fig. 52-3).

When the total daily urinary excretion of protein is >3.5 g, hypoalbuminemia, hyperlipidemia, and edema (nephrotic syndrome; Fig. 52-3) are often present as well. However, total daily urinary protein excretion >3.5 g can occur without the other features of the nephrotic syndrome in a variety of other renal diseases, including diabetes (Fig. 52-3). Plasma cell dyscrasias (multiple myeloma) can be associated with large amounts of excreted light chains in the urine, which may not be detected by dipstick. The light chains are filtered by the glomerulus and overwhelm the reabsorptive capacity of the proximal tubule. Renal failure from these disorders occurs through a variety of mechanisms, including but not limited to proximal tubule injury, tubule obstruction (cast nephropathy), amyloid deposition, and light chain deposition (Chap. 316). The specific renal lesion is dictated by the sequence and structural

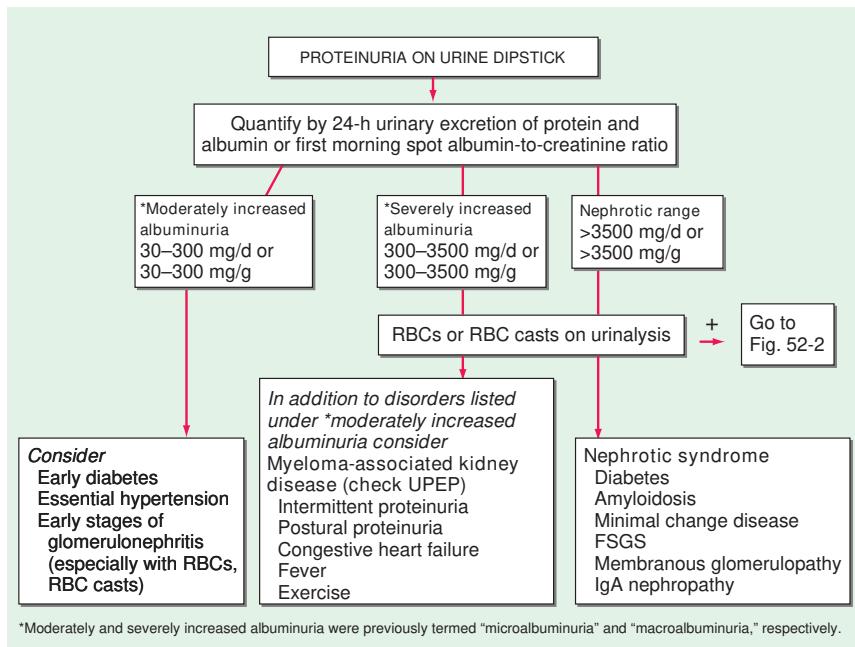


FIGURE 52-3 Approach to the patient with proteinuria. Investigation of proteinuria is often initiated by a positive dipstick on routine urinalysis. Conventional dipsticks detect predominantly albumin and provide a semiquantitative assessment (trace, 1+, 2+, or 3+), which is influenced by urinary concentration as reflected by urine specific gravity (minimum, <1.005; maximum, 1.030). However, more exact determination of proteinuria should employ a spot morning protein/creatinine ratio (mg/g) or a 24-h urine collection (mg/24 h). FSGS, focal segmental glomerulosclerosis; RBC, red blood cell; UPEP, urine protein electrophoresis.

characteristics of the monoclonal light chain; however, not all excreted light chains are nephrotoxic.

Hypoalbuminemia in nephrotic syndrome occurs through excessive urinary losses and increased proximal tubule catabolism of filtered albumin. Edema results from renal sodium retention and reduced plasma oncotic pressure, which favors fluid movement from capillaries to interstitium. To compensate for the perceived decrease in effective intravascular volume, activation of the renin-angiotensin system, stimulation of AVP, and activation of the sympathetic nervous system take place, promoting continued renal salt and water reabsorption and progressive edema. Filtered proteases, normally retained by the glomerular filtration barrier, can also directly activate sodium reabsorption by the epithelial Na channels in principal cells (ENaC) in nephrotic syndrome. Despite these changes, hypertension is uncommon in primary kidney diseases resulting in the nephrotic syndrome (Fig. 52-3 and [Chap. 314](#)). The urinary loss of regulatory proteins and changes in hepatic synthesis contribute to the other manifestations of the nephrotic syndrome. A hypercoagulable state may arise from urinary losses of antithrombin III, reduced serum levels of proteins S and C, hyperfibrinogenemia, and enhanced platelet aggregation. Hypercholesterolemia may be severe and results from increased hepatic lipoprotein synthesis. Loss of immunoglobulins contributes to an increased risk of infection. Many diseases (some listed in Fig. 52-3) and drugs can cause the nephrotic syndrome; a complete list is found in [Chap. 314](#).

### ■ HEMATURIA, PYURIA, AND CASTS

Isolated hematuria without proteinuria, other cells, or casts is often indicative of bleeding from the urinary tract. Hematuria is defined as two to five RBCs per high-power field (HPF) and can be detected by dipstick. A false-positive dipstick for hematuria (where no RBCs are seen on urine microscopy) may occur when myoglobinuria is present, often in the setting of rhabdomyolysis. Common causes of isolated hematuria include stones, neoplasms, tuberculosis, trauma, and prostatitis. Gross hematuria with blood clots usually is not an intrinsic renal process; rather, it suggests a postrenal source in the urinary collecting system. Evaluation of patients presenting with microscopic hematuria is outlined in Fig. 52-2. A single urinalysis with hematuria is common and can result from menstruation, viral illness, allergy, exercise, or mild trauma. Persistent or significant hematuria ( $>3$  RBCs/HPF on three urinalyses, a single urinalysis with  $>100$  RBCs, or gross hematuria) is associated with significant renal or urologic lesions in 9.1% of cases. The level of suspicion for urogenital neoplasms in patients with isolated painless hematuria and nondysmorphic RBCs increases with age. Neoplasms are rare in the pediatric population, and isolated hematuria is more likely to be “idiopathic” or associated with a congenital anomaly. Hematuria with pyuria and bacteriuria is typical of infection and should be treated with antibiotics after appropriate cultures. Acute cystitis or urethritis in women can cause gross hematuria. Hypercalcuria and hyperuricosuria are also risk factors for unexplained isolated hematuria in both children and adults. In some of these patients (50–60%), reducing calcium and uric acid excretion through dietary interventions can eliminate the microscopic hematuria.

Isolated microscopic hematuria can be a manifestation of glomerular diseases. The RBCs of glomerular origin are often dysmorphic when examined by phase-contrast microscopy. Irregular shapes of RBCs may also result from pH and osmolarity changes produced along the distal nephron. Observer variability in detecting dysmorphic RBCs is common. The most common etiologies of isolated glomerular hematuria are IgA nephropathy, hereditary nephritis, and thin basement membrane disease. IgA nephropathy and hereditary nephritis can lead to episodic gross hematuria. A family history of renal failure is often present in hereditary nephritis, and patients with thin basement membrane disease often have family members with microscopic hematuria. A renal biopsy is needed for the definitive diagnosis of these disorders, which are discussed in more detail in [Chap. 314](#). Hematuria with dysmorphic RBCs, RBC casts, and protein excretion  $>500$  mg/d is virtually diagnostic of glomerulonephritis. RBC casts form as RBCs that enter the tubule fluid and become trapped in a cylindrical mold of gelled Tamm-Horsfall protein. Even in the absence of azotemia,

these patients should undergo serologic evaluation and renal biopsy as outlined in Fig. 52-2.

Isolated pyuria is unusual since inflammatory reactions in the kidney or collecting system also are associated with hematuria. The presence of bacteria suggests infection, and WBC casts with bacteria are indicative of pyelonephritis; “sterile pyuria” with negative urinary bacterial cultures can be seen in urogenital tuberculosis. WBCs and/or WBC casts also may be seen in acute glomerulonephritis as well as in tubulointerstitial processes such as interstitial nephritis and transplant rejection.

*Casts* can be seen in chronic renal diseases. Degenerated cellular casts called *waxy casts* or *broad casts* (arising in the dilated tubules that have undergone compensatory hypertrophy in response to reduced renal mass) may be seen in the urine.

## ABNORMALITIES OF URINE VOLUME

### ■ POLYURIA

By history, it is often difficult for patients to distinguish urinary frequency (often of small volumes) from true polyuria ( $>3$  L/d), and a quantification of volume by 24-h urine collection may be needed ([Fig. 52-4](#)). Polyuria results from two potential mechanisms: (1) excretion of nonabsorbable solutes (such as glucose) or (2) excretion of water (usually from a defect in AVP production or renal responsiveness). To distinguish a solute diuresis from a water diuresis and to determine whether the diuresis is appropriate for the clinical circumstances, urine osmolality is measured. The average person excretes between 600 and 800 mosmol of solutes per day, primarily as urea and electrolytes. If the urine output is  $>3$  L/d and the urine is dilute ( $<250$  mosmol/L), total osmolar excretion is normal and a water diuresis is present. This circumstance could arise from polydipsia, inadequate secretion of AVP (*central diabetes*

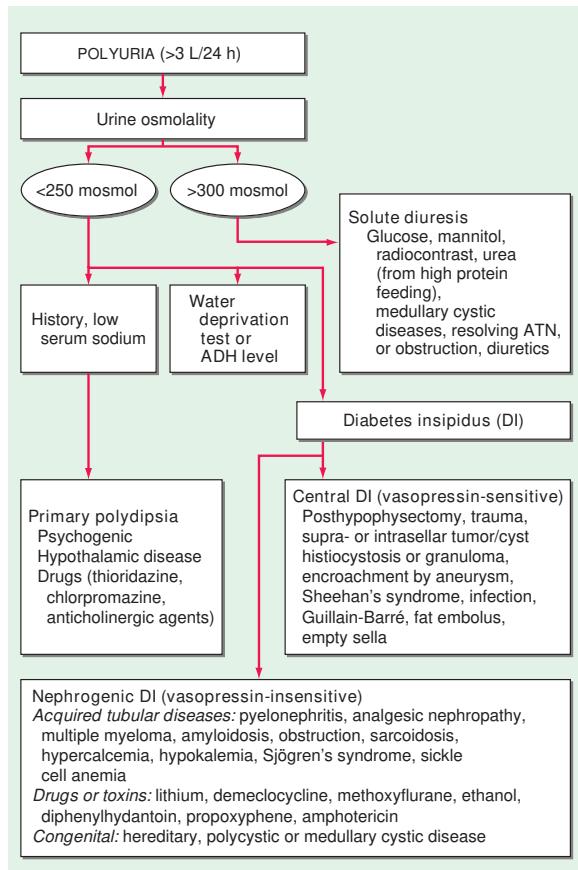


FIGURE 52-4 Approach to the patient with polyuria. ADH, antidiuretic hormone; ATN, acute tubular necrosis.

*insipidus*), or failure of renal tubules to respond to AVP (*nephrogenic diabetes insipidus*). If the urine volume is >3 L/d and urine osmolality is >300 mosmol/L, a solute diuresis is clearly present and a search for the responsible solute(s) is mandatory.

Excessive filtration of a poorly reabsorbed solute such as glucose or mannitol can depress reabsorption of NaCl and water in the proximal tubule and lead to enhanced excretion in the urine. Poorly controlled diabetes mellitus with glucosuria is the most common cause of a solute diuresis, leading to volume depletion and serum hypertonicity. Since the urine sodium concentration is less than that of blood, more water than sodium is lost, causing hypernatremia and hypertonicity. Common iatrogenic solute diuresis occurs in association with mannitol administration, radiocontrast media, and high-protein feedings (enteral or parenteral), leading to increased urea production and excretion. Less commonly, excessive sodium loss may result from cystic renal diseases or Bartter's syndrome or may develop during a tubulointerstitial process (such as resolving ATN). In these so-called salt-wasting disorders, the tubule damage results in direct impairment of sodium reabsorption and indirectly reduces the responsiveness of the tubule to aldosterone. Usually, the sodium losses are mild, and the obligatory urine output is <2 L/d; resolving ATN and postobstructive diuresis are exceptions and may be associated with significant natriuresis and polyuria.

Formation of large volumes of dilute urine is usually due to polydipsic states or diabetes insipidus. Primary polydipsia can result from habit, psychiatric disorders, neurologic lesions, or medications. During deliberate polydipsia, extracellular fluid volume is normal or expanded and plasma AVP levels are reduced because serum osmolality tends to be near the lower limits of normal. Urine osmolality is also maximally dilute at 50 mosmol/L.

Central diabetes insipidus may be idiopathic in origin or secondary to a variety of conditions, including hypophysectomy, trauma, neoplastic, inflammatory, vascular, or infectious hypothalamic diseases. Idiopathic central diabetes insipidus is associated with selective destruction of the AVP-secreting neurons in the supraoptic and paraventricular nuclei and can either be inherited as an autosomal dominant trait or occur spontaneously. Nephrogenic diabetes insipidus can occur in a variety of clinical situations, as summarized in Fig. 52-4.

A plasma AVP level is recommended as the best method for distinguishing between central and nephrogenic diabetes insipidus. Assays for circulating copeptin, a peptide that is cleaved from pre-pro-AVP during axonal transport in the posterior pituitary, are also now available in many centers. A water deprivation test plus exogenous AVP may distinguish primary polydipsia from central and nephrogenic diabetes insipidus. Measurement of hypertonic saline-stimulated plasma copeptin, if available, can substitute for water deprivation testing. For a detailed discussion, see Chap. 381.

A

Julie Lin and Brad Denker contributed to this chapter in the 19th edition, and some material from that chapter has been retained here.

## FURTHER READING

- E M et al: Approach to the patient with kidney disease, in *Brenner and Rector's The Kidney*, 10th ed, K Skorecki et al (eds). Philadelphia, W.B. Saunders & Company, 2016, pp. 754–779.
- E ND et al: Reconsidering the consequences of using race to estimate kidney function. *JAMA* 322:113, 2019.
- K H et al: Acanthocyturia—a characteristic marker for glomerular bleeding. *Kidney Int* 40:115, 1991.
- P MA: The urine sediment as a biomarker of kidney disease. *Am J Kidney Dis* 66:748, 2015.
- P NR: Black kidney function matters: Use or misuse of race? *JAMA* 324:737, 2020.
- W SD et al: Prevention and management of acute kidney injury in *Brenner and Rector's The Kidney*, 11th ed, ASL Yu et al: (eds). Philadelphia, W.B. Saunders & Company, 2020, pp. 940–977.



## SODIUM AND WATER

### COMPOSITION OF BODY FLUIDS

Water is the most abundant constituent in the body, comprising ~50% of body weight in women and 60% in men. Total-body water is distributed in two major compartments: 55–75% is intracellular (intracellular fluid [ICF]), and 25–45% is extracellular (extracellular fluid [ECF]). The ECF is further subdivided into intravascular (plasma water) and extravascular (interstitial) spaces in a ratio of 1:3. Fluid movement between the intravascular and interstitial spaces occurs across the capillary wall and is determined by Starling forces, i.e., capillary hydraulic pressure and colloid osmotic pressure. The transcapillary hydraulic pressure gradient exceeds the corresponding oncotic pressure gradient, thereby favoring the movement of plasma ultrafiltrate into the extravascular space. The return of fluid into the intravascular compartment occurs via lymphatic flow.

The solute or particle concentration of a fluid is known as its osmolality, expressed as milliosmoles per kilogram of water (mOsm/kg). Water easily diffuses across most cell membranes to achieve osmotic equilibrium (ECF osmolality = ICF osmolality). Notably, the extracellular and intracellular solute compositions differ considerably owing to the activity of various transporters, channels, and ATP-driven membrane pumps. The major ECF particles are  $\text{Na}^+$  and its accompanying anions  $\text{Cl}^-$  and  $\text{HCO}_3^-$ , whereas  $\text{K}^+$  and organic phosphate esters (ATP, creatine phosphate, and phospholipids) are the predominant ICF osmoles. Solutes that are restricted to the ECF or the ICF determine the ‘tonicity’ or effective osmolality of that compartment. Certain solutes, particularly urea, do not contribute to water shifts across most membranes and are thus known as *ineffective osmoles*.

**Water Balance** Vasopressin secretion, water ingestion, and renal water transport collaborate to maintain human body fluid osmolality between 280 and 295 mOsm/kg. Vasopressin (AVP) is synthesized in magnocellular neurons within the hypothalamus; the distal axons of these neurons project to the posterior pituitary or neurohypophysis, from which AVP is released into the circulation. A network of central “osmoreceptor” neurons, which includes the AVP-expressing magnocellular neurons themselves, sense circulating osmolality via nonselective, stretch-activated cation channels. These osmoreceptor neurons are activated or inhibited by modest increases and decreases in circulating osmolality, respectively; activation leads to AVP release and thirst.

AVP secretion is stimulated as systemic osmolality increases above a threshold level of ~285 mOsm/kg, above which there is a linear relationship between osmolality and circulating AVP (Fig. 53-1). Thirst and thus water ingestion are also activated at ~285 mOsm/kg, beyond which there is an equivalent linear increase in the perceived intensity of thirst as a function of circulating osmolality. Changes in blood volume and blood pressure are also direct stimuli for AVP release and thirst, albeit with a less sensitive response profile. Of perhaps greater clinical relevance to the pathophysiology of water homeostasis, ECF volume strongly modulates the relationship between circulating osmolality and AVP release, such that hypovolemia reduces the osmotic threshold and increases the slope of the response curve to osmolality; *hypervolemia* has an opposite effect, increasing the osmotic threshold and reducing the slope of the response curve (Fig. 53-1). Notably, AVP has a half-life in the circulation of only 10–20 min; thus, changes in ECF volume and/or circulating osmolality can rapidly affect water homeostasis. In addition to volume status, a number of other “nonosmotic” stimuli have potent activating effects on osmosensitive neurons and AVP

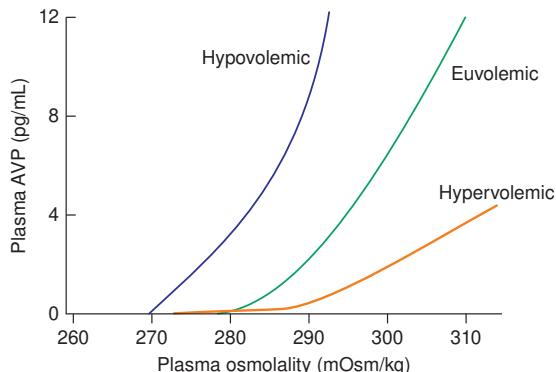


FIGURE 53-1 Circulating levels of vasopressin (AVP) in response to changes in osmolality. Plasma AVP becomes detectable in euvolemic, healthy individuals at a threshold of ~285 mOsm/kg, above which there is a linear relationship between osmolality and circulating AVP. The AVP response to osmolality is modulated strongly by volume status. The osmotic threshold is thus slightly lower in hypovolemia, with a steeper response curve; hypervolemia reduces the sensitivity of circulating AVP levels to osmolality.

release, including nausea, intracerebral angiotensin II, serotonin, and multiple drugs.

The excretion or retention of electrolyte-free water by the kidney is modulated by circulating AVP. AVP acts on renal, V<sub>2</sub>-type receptors in the thick ascending limb of Henle and principal cells of the collecting duct (CD), increasing intracellular levels of cyclic AMP and activating protein kinase A (PKA)-dependent phosphorylation of multiple transport proteins. The AVP- and PKA-dependent activation of Na<sup>+</sup>-Cl<sup>-</sup> and K<sup>+</sup> transport by the thick ascending limb of the loop of Henle (TALH) is a key participant in the countercurrent mechanism (Fig. 53-2). The countercurrent mechanism ultimately increases the interstitial osmolality in the inner medulla of the kidney, driving water absorption across the renal CD. However, water, salt, and solute transport by both proximal and distal nephron segments participates in the renal concentrating mechanism (Fig. 53-2). Water transport across apical and basolateral aquaporin-1 water channels in the descending thin limb of the loop of Henle is thus involved, as is passive absorption of Na<sup>+</sup>-Cl<sup>-</sup> by

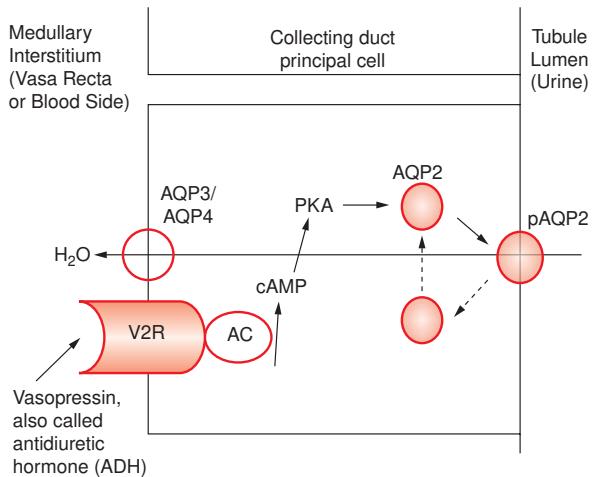


FIGURE 53-3 Vasopressin and the regulation of water permeability in the renal collecting duct. Vasopressin binds to the type 2 vasopressin receptor (V2R) on the basolateral membrane of principal cells, activates adenylyl cyclase (AC), increases intracellular cyclic adenosine monophosphate (cAMP), and stimulates protein kinase A (PKA) activity. Cytoplasmic vesicles carrying aquaporin-2 (AQP) water channel proteins are inserted into the luminal membrane in response to vasopressin, thereby increasing the water permeability of this membrane. When vasopressin stimulation ends, water channels are retrieved by an endocytic process and water permeability returns to its low basal rate. The AQP3 and AQP4 water channels are expressed on the basolateral membrane and complete the transcellular pathway for water reabsorption. pAQP2, phosphorylated aquaporin-2. (From *Annals of Internal Medicine* JM Sands, DG Bichet: Nephrogenic diabetes insipidus. 144(3):186, 2006. Copyright © 2006 American College of Physicians. All Rights Reserved. Reprinted with the permission of American College of Physicians, Inc.)

the thin ascending limb, via apical and basolateral CLC-K1 chloride channels and paracellular Na<sup>+</sup> transport. Renal urea transport in turn plays important roles in the generation of the medullary osmotic gradient and the ability to excrete solute-free water under conditions of both high and low protein intake (Fig. 53-2).

AVP-induced, PKA-dependent phosphorylation of the aquaporin-2 water channel in principal cells stimulates the insertion of active water

channels into the lumen of the CD, resulting in transepithelial water absorption down the medullary osmotic gradient (Fig. 53-3). Under “antidiuretic” conditions, with increased circulating AVP, the kidney reabsorbs water filtered by the glomerulus, equilibrating the osmolality across the CD epithelium to excrete a hypertonic, “concentrated” urine (osmolality of up to 1200 mOsm/kg). In the absence of circulating AVP, insertion of aquaporin-2 channels and water absorption across the CD is essentially abolished, resulting in secretion of a hypotonic, dilute urine (osmolality as low as 30–50 mOsm/kg). Abnormalities in this “final common pathway” are involved in most disorders of water homeostasis, e.g., a reduced or absent insertion of active aquaporin-2 water channels into the membrane of principal cells in diabetes insipidus (DI).

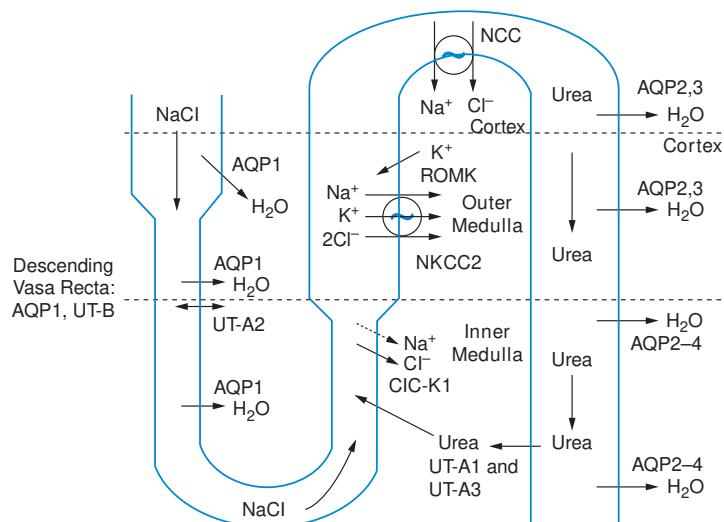


FIGURE 53-2 The renal concentrating mechanism. Water, salt, and solute transport by both proximal and distal nephron segments participates in the renal concentrating mechanism (see text for details). Diagram showing the location of the major transport proteins involved; a loop of Henle is depicted on the left, collecting duct on the right. AQP, aquaporin; CLC-K1, chloride channel; NKCC2, Na-K-2Cl cotransporter; ROMK, renal outer medullary K<sup>+</sup> channel; UT, urea transporter. (Republished with permission of American Society of Nephrology, from Molecular approaches to urea transporters, JM Sands, 13(11), 2002; permission conveyed through Copyright Clearance Center, Inc.)

Maintenance of Arterial Circulatory Integrity  
Sodium is actively pumped out of cells by the Na<sup>+</sup>/K<sup>+</sup>-ATPase membrane pump. In consequence, 85–90% of body Na<sup>+</sup> is extracellular, and the ECF volume (ECFV) is a function of total-body Na<sup>+</sup> content. Arterial perfusion and circulatory integrity are, in turn, determined by renal Na<sup>+</sup> retention or excretion, in addition to the modulation of systemic arterial resistance. Within the kidney, Na<sup>+</sup> is filtered by the glomeruli and then sequentially reabsorbed by the renal tubules. The Na<sup>+</sup> cation is typically reabsorbed with the chloride anion (Cl<sup>-</sup>), and thus, chloride homeostasis also affects the ECFV. On a quantitative level, at a glomerular filtration rate (GFR) of 180 L/d and

serum Na<sup>+</sup> of ~140 mM, the kidney filters some 25,200 mmol/d of Na<sup>+</sup>. This is equivalent to ~1.5 kg of salt, which would occupy roughly 10 times the extracellular space; 99.6% of filtered Na<sup>+</sup>-Cl<sup>-</sup> must be reabsorbed to excrete 100 mM per day. Minute changes in renal Na<sup>+</sup>-Cl<sup>-</sup> excretion will thus have significant effects on the ECFV, leading to edema syndromes or hypovolemia.

Approximately two-thirds of filtered Na<sup>+</sup>-Cl<sup>-</sup> is reabsorbed by the renal proximal tubule, via both paracellular and transcellular mechanisms. The TALH subsequently reabsorbs another 25–30% of filtered Na<sup>+</sup>-Cl<sup>-</sup> via the apical, furosemide-sensitive Na<sup>+</sup>-K<sup>+</sup>-2Cl<sup>-</sup> cotransporter. The adjacent aldosterone-sensitive distal nephron, comprising the distal convoluted tubule (DCT), connecting tubule (CNT), and CD, accomplishes the “fine-tuning” of renal Na<sup>+</sup>-Cl<sup>-</sup> excretion. The thiazide-sensitive apical Na<sup>+</sup>-Cl<sup>-</sup> cotransporter (NCC) reabsorbs 5–10% of filtered Na<sup>+</sup>-Cl<sup>-</sup> in the DCT. Principal cells in the CNT and CD reabsorb Na<sup>+</sup> via electrogenic, amiloride-sensitive epithelial Na<sup>+</sup> channels (ENaC); Cl<sup>-</sup> ions are primarily reabsorbed by adjacent intercalated cells, via apical Cl<sup>-</sup> exchange (Cl<sup>-</sup>-OH<sup>-</sup> and Cl<sup>-</sup>-HCO<sub>3</sub><sup>-</sup> exchange, mediated by the SLC26A4 anion exchanger) (Fig. 53-4).

Renal tubular reabsorption of filtered Na<sup>+</sup>-Cl<sup>-</sup> is regulated by multiple circulating and paracrine hormones, in addition to the activity of renal nerves. Angiotensin II activates proximal Na<sup>+</sup>-Cl<sup>-</sup> reabsorption, as do adrenergic receptors under the influence of renal sympathetic innervation; locally generated dopamine, in contrast, has a *natriuretic* effect. Aldosterone primarily activates Na<sup>+</sup>-Cl<sup>-</sup> reabsorption within the aldosterone-sensitive distal nephron. In particular, aldosterone activates the ENaC channel in principal cells, inducing Na<sup>+</sup> absorption and promoting K<sup>+</sup> excretion (Fig. 53-4).

Circulatory integrity is critical for the perfusion and function of vital organs. “Underfilling” of the arterial circulation is sensed by ventricular and vascular pressure receptors, resulting in a neurohumoral activation

(increased sympathetic tone, activation of the renin-angiotensin-aldosterone axis, and increased circulating AVP) that synergistically increases renal Na<sup>+</sup>-Cl<sup>-</sup> reabsorption, vascular resistance, and renal water reabsorption. This occurs in the context of decreased cardiac output, as occurs in hypovolemic states, low-output cardiac failure, decreased oncotic pressure, and/or increased capillary permeability. Alternatively, excessive arterial vasodilation results in *relative* arterial underfilling, leading to neurohumoral activation in the defense of tissue perfusion. These physiologic responses play important roles in many of the disorders discussed in this chapter. In particular, it is important to appreciate that AVP functions in the defense of circulatory integrity, inducing vasoconstriction, increasing sympathetic nervous system tone, increasing renal retention of both water and Na<sup>+</sup>-Cl<sup>-</sup>, and modulating the arterial baroreceptor reflex. Most of these responses involve activation of systemic V<sub>1A</sub> AVP receptors, but concomitant activation of V<sub>2</sub> receptors in the kidney can result in renal water retention and hyponatremia.

## ■ HYPOVOLEMIA

**Etiology** True volume depletion, or hypovolemia, generally refers to a state of combined salt and water loss, leading to contraction of the ECFV. The loss of salt and water may be renal or nonrenal in origin.

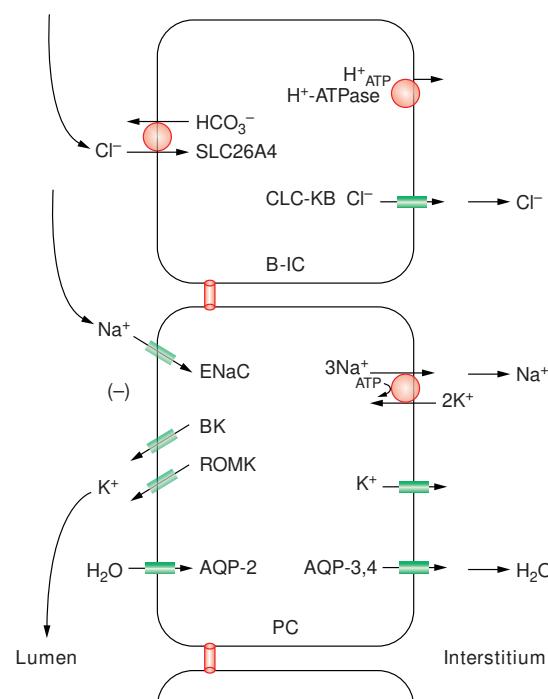
**RENAL CAUSES** Excessive urinary Na<sup>+</sup>-Cl<sup>-</sup> and water loss is a feature of several conditions. A high filtered load of endogenous solutes, such as glucose and urea, can impair tubular reabsorption of Na<sup>+</sup>-Cl<sup>-</sup> and water, leading to an osmotic diuresis. Exogenous mannitol, often used to decrease intracerebral pressure, is filtered by glomeruli but not reabsorbed by the proximal tubule, thus causing an osmotic diuresis. Pharmacologic diuretics selectively impair Na<sup>+</sup>-Cl<sup>-</sup> reabsorption at specific sites along the nephron, leading to increased urinary Na<sup>+</sup>-Cl<sup>-</sup> excretion. Other drugs can induce natriuresis as a side effect. For example, acetazolamide can inhibit proximal tubular Na<sup>+</sup>-Cl<sup>-</sup> absorption via its inhibition of carbonic anhydrase; other drugs, such as the antibiotics trimethoprim (TMP) and pentamidine, inhibit distal tubular Na<sup>+</sup> reabsorption through the amiloride-sensitive ENaC channel, leading to urinary Na<sup>+</sup>-Cl<sup>-</sup> loss. Hereditary defects in renal transport proteins are also associated with reduced reabsorption of filtered Na<sup>+</sup>-Cl<sup>-</sup> and/or water. Alternatively, mineralocorticoid deficiency, mineralocorticoid resistance, or inhibition of the mineralocorticoid receptor (MLR) can reduce Na<sup>+</sup>-Cl<sup>-</sup> reabsorption by the aldosterone-sensitive distal nephron. Finally, tubulointerstitial injury, as occurs in interstitial nephritis, acute tubular injury, or obstructive uropathy, can reduce distal tubular Na<sup>+</sup>-Cl<sup>-</sup> and/or water absorption.

Excessive excretion of free water, i.e., water without electrolytes, can also lead to hypovolemia. However, the effect on ECFV is usually less marked, given that two-thirds of the water volume is lost from the ICF. Excessive renal water excretion occurs in the setting of decreased circulating AVP or renal resistance to AVP (central and nephrogenic DI, respectively).

**EXTRARENAL CAUSES** Nonrenal causes of hypovolemia include fluid loss from the gastrointestinal tract, skin, and respiratory system. Accumulations of fluid within specific tissue compartments, typically the interstitium, peritoneum, or gastrointestinal tract, can also cause hypovolemia.

Approximately 9 L of fluid enter the gastrointestinal tract daily, 2 L by ingestion and 7 L by secretion; almost 98% of this volume is absorbed, such that daily fecal fluid loss is only 100–200 mL. Impaired gastrointestinal reabsorption or enhanced secretion of fluid can cause hypovolemia. Because gastric secretions have a low pH (high H<sup>+</sup> concentration), whereas biliary, pancreatic, and intestinal secretions are alkaline (high HCO<sub>3</sub><sup>-</sup> concentration), vomiting and diarrhea are often accompanied by metabolic alkalosis and acidosis, respectively.

Evaporation of water from the skin and respiratory tract (so-called “insensible losses”) constitutes the major route for loss of solute-free water, which is typically 500–650 mL/d in healthy adults. This evaporative loss can increase during febrile illness or prolonged heat exposure. Hyperventilation can also increase insensible losses via the respiratory tract, particularly in ventilated patients; the humidity of inspired air



**FIGURE 53-4** Sodium, water, and potassium transport in principal cells (PC) and adjacent  $\alpha$ -intercalated cells (B-IC). The absorption of Na<sup>+</sup> via the amiloride-sensitive epithelial sodium channel (ENaC) generates a lumen-negative potential difference, which drives K<sup>+</sup> excretion through the apical secretory K<sup>+</sup> channel ROMK (renal outer medullary K<sup>+</sup> channel) and/or the flow-dependent BK channel. Transepithelial Cl<sup>-</sup> transport occurs in adjacent  $\beta$ -intercalated cells, via apical Cl<sup>-</sup>-HCO<sub>3</sub><sup>-</sup> and Cl<sup>-</sup>-OH<sup>-</sup> exchange (SLC26A4 anion exchanger, also known as pendrin) basolateral CLC chloride channels. Water is absorbed down the osmotic gradient by principal cells, through the apical aquaporin-2 (AQP-2) and basolateral aquaporin-3 and aquaporin-4 (Fig. 53-3).

is another determining factor. In addition, increased exertion and/or ambient temperature will increase insensible losses via sweat, which is hypotonic to plasma. Profuse sweating without adequate repletion of water and  $\text{Na}^+ \text{-Cl}^-$  can thus lead to both hypovolemia and hypertonicity. Alternatively, replacement of these insensible losses with a surfeit of free water, without adequate replacement of electrolytes, may lead to hypovolemic hyponatremia.

Excessive fluid accumulation in interstitial and/or peritoneal spaces can also cause intravascular hypovolemia. Increases in vascular permeability and/or a reduction in oncotic pressure (hypoalbuminemia) alter Starling forces, resulting in excessive “third spacing” of the ECFV. This occurs in sepsis syndrome, burns, pancreatitis, nutritional hypoalbuminemia, and peritonitis. Alternatively, distributive hypovolemia can occur due to accumulation of fluid within specific compartments, for example, within the bowel lumen in gastrointestinal obstruction or ileus. Hypovolemia can also occur after extracorporeal hemorrhage or after significant hemorrhage into an expandable space, for example, the retroperitoneum.

**Diagnostic Evaluation** A careful history will usually determine the etiologic cause of hypovolemia. Symptoms of hypovolemia are non-specific and include fatigue, weakness, thirst, and postural dizziness; more severe symptoms and signs include oliguria, cyanosis, abdominal and chest pain, and confusion or obtundation. Associated electrolyte disorders may cause additional symptoms, for example, muscle weakness in patients with hypokalemia. On examination, diminished skin turgor and dry oral mucous membranes are less than ideal markers of a decreased ECFV in adult patients; more reliable signs of hypovolemia include a decreased jugular venous pressure (JVP), orthostatic tachycardia (an increase of >15–20 beats/min upon standing), and orthostatic hypotension (a >10–20 mmHg drop in blood pressure on standing). More severe fluid loss leads to hypovolemic shock, with hypotension, tachycardia, peripheral vasoconstriction, and peripheral hypoperfusion; these patients may exhibit peripheral cyanosis, cold extremities, oliguria, and altered mental status.

Routine chemistries may reveal an increase in blood urea nitrogen (BUN) and creatinine, reflective of a decrease in GFR. Creatinine is the more dependable measure of GFR, because BUN levels may be influenced by an increase in tubular reabsorption (“prerenal azotemia”), an increase in urea generation in catabolic states, hyperalimentation, or gastrointestinal bleeding, and/or a decreased urea generation in decreased protein intake. In hypovolemic shock, liver function tests and cardiac biomarkers may show evidence of hepatic and cardiac ischemia, respectively. Routine chemistries and/or blood gases may reveal evidence of acid-base disorders. For example, bicarbonate loss due to diarrheal illness is a very common cause of metabolic acidosis; alternatively, patients with severe hypovolemic shock may develop lactic acidosis with an elevated anion gap.

The neurohumoral response to hypovolemia stimulates an increase in renal tubular  $\text{Na}^+$  and water reabsorption. Therefore, the urine  $\text{Na}^+$  concentration is typically <20 mM in nonrenal causes of hypovolemia, with a urine osmolality of >450 mOsm/kg. The reduction in both GFR and distal tubular  $\text{Na}^+$  delivery may cause a defect in renal potassium excretion, with an increase in plasma  $\text{K}^+$  concentration. Of note, patients with hypovolemia and a hypochloremic alkalosis due to vomiting, diarrhea, or diuretics will typically have a urine  $\text{Na}^+$  concentration >20 mM and urine pH of >7.0, due to the increase in filtered  $\text{HCO}_3^-$ ; the urine  $\text{Cl}^-$  concentration in this setting is a more accurate indicator of volume status, with a level <25 mM suggestive of hypovolemia. The urine  $\text{Na}^+$  concentration is often >20 mM in patients with *renal* causes of hypovolemia, such as acute tubular necrosis; similarly, patients with DI will have an inappropriately dilute urine.

## TREATMENT

### Hypovolemia

The therapeutic goals in hypovolemia are to restore normovolemia and replace ongoing fluid losses. Mild hypovolemia can usually be treated with oral hydration and resumption of a normal

maintenance diet. More severe hypovolemia requires intravenous hydration, tailoring the choice of solution to the underlying pathophysiology. Isotonic, “normal” saline (0.9% NaCl, 154 mM  $\text{Na}^+$ ) is the most appropriate resuscitation fluid for normonatremic or hyponatremic patients with severe hypovolemia; colloid solutions such as intravenous albumin are not demonstrably superior for this purpose. Hypernatremic patients should receive a hypotonic solution, 5% dextrose if there has only been water loss (as in DI), or hypotonic saline (1/2 or 1/4 normal saline) if there has been water and  $\text{Na}^+ \text{-Cl}^-$  loss; changes in free water administration should be made if necessary, based on frequent measuring of serum chemistries. Patients with bicarbonate loss and metabolic acidosis, as occur frequently in diarrhea, should receive intravenous bicarbonate, either an isotonic solution (150 meq of  $\text{Na}^+ \text{-HCO}_3^-$  in 5% dextrose) or a more hypotonic bicarbonate solution in dextrose or dilute saline. Patients with severe hemorrhage or anemia should receive red cell transfusions, without increasing the hematocrit beyond 35%.

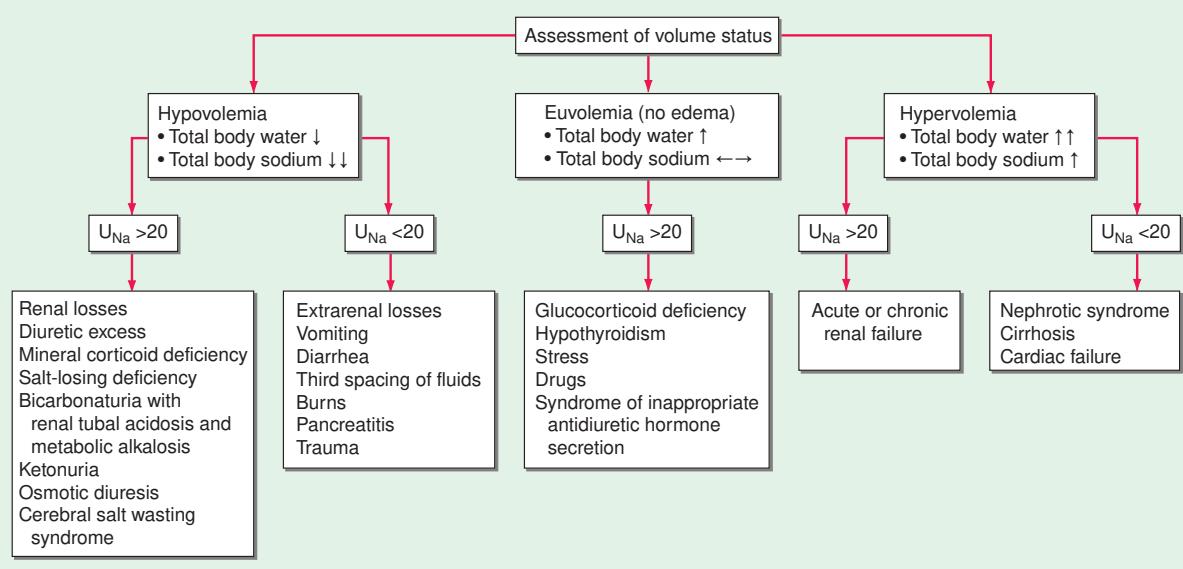
## SODIUM DISORDERS

Disorders of serum  $\text{Na}^+$  concentration are caused by abnormalities in water homeostasis, leading to changes in the relative ratio of  $\text{Na}^+$  to body water. Water intake and circulating AVP constitute the two key effectors in the defense of serum osmolality; defects in one or both of these two defense mechanisms cause most cases of hyponatremia and hypernatremia. In contrast, abnormalities in sodium homeostasis per se lead to a deficit or surplus of whole-body  $\text{Na}^+ \text{-Cl}^-$  content, a key determinant of the ECFV and circulatory integrity. Notably, volume status also modulates the release of AVP by the posterior pituitary, such that hypovolemia is associated with higher circulating levels of the hormone at each level of serum osmolality. Similarly, in “hypervolemic” causes of arterial underfilling, e.g., heart failure and cirrhosis, the associated neurohumoral activation encompasses an increase in circulating AVP, leading to water retention and hyponatremia. Therefore, a key concept in sodium disorders is that the absolute plasma  $\text{Na}^+$  concentration tells one nothing about the volume status of a given patient, which furthermore must be taken into account in the diagnostic and therapeutic approach.

### ■ HYponatremia

Hyponatremia, which is defined as a plasma  $\text{Na}^+$  concentration <135 mM, is a very common disorder, occurring in up to 22% of hospitalized patients. This disorder is almost always the result of an increase in circulating AVP and/or increased renal sensitivity to AVP, combined with an intake of free water; a notable exception is hyponatremia due to low solute intake (see below). The underlying pathophysiology for the exaggerated or “inappropriate” AVP response differs in patients with hyponatremia as a function of their ECFV. Hyponatremia is thus subdivided diagnostically into three groups, depending on clinical history and volume status, i.e., “hypovolemic,” “euvolemic,” and “hypervolemic” (Fig. 53-5).

**Hypovolemic Hyponatremia** Hypovolemia causes a marked neurohumoral activation, increasing circulating levels of AVP. The increase in circulating AVP helps preserve blood pressure via vascular and baroreceptor  $V_{1A}$  receptors and increases water reabsorption via renal  $V_2$  receptors; activation of  $V_2$  receptors can lead to hyponatremia in the setting of increased free water intake. Nonrenal causes of hypovolemic hyponatremia include gastrointestinal loss (e.g., vomiting, diarrhea, tube drainage) and insensible loss (sweating, burns) of  $\text{Na}^+ \text{-Cl}^-$  and water, in the absence of adequate oral replacement; urine  $\text{Na}^+$  concentration is typically <20 mM. Notably, these patients may be clinically classified as euvolemic, with only the reduced urinary  $\text{Na}^+$  concentration to indicate the cause of their hyponatremia. Indeed, a urine  $\text{Na}^+$  concentration <20 mM, in the absence of a cause of hypervolemic hyponatremia, predicts a rapid increase in plasma  $\text{Na}^+$  concentration in response to intravenous normal saline; saline therapy thus induces a water diuresis in this setting, as circulating AVP levels plummet.



**FIGURE 53-5** The diagnostic approach to hyponatremia. (Reproduced with permission from S Kumar, T Berl: Diseases of water metabolism, in RW Schrier [ed], *Atlas of Diseases of the Kidney*, Philadelphia, Current Medicine, Inc, 1999.)

The *renal* causes of hypovolemic hyponatremia share an inappropriate loss of Na<sup>+</sup>-Cl<sup>-</sup> in the urine, leading to volume depletion and an increase in circulating AVP; urine Na<sup>+</sup> concentration is typically >20 mM (Fig. 53-5). A deficiency in circulating aldosterone and/or its renal effects can lead to hyponatremia in primary adrenal insufficiency and other causes of hypoaldosteronism; hyperkalemia and hyponatremia in a hypotensive and/or hypovolemic patient with high urine Na<sup>+</sup> concentration (much greater than 20 mM) should strongly suggest this diagnosis. Salt-losing nephropathies may lead to hyponatremia when sodium intake is reduced, due to impaired renal tubular function; typical causes include reflux nephropathy, interstitial nephropathies, postobstructive uropathy, medullary cystic disease, and the recovery phase of acute tubular necrosis. Thiazide diuretics cause hyponatremia via a number of mechanisms, including polydipsia and diuretic-induced volume depletion. Notably, thiazides do not inhibit the renal concentrating mechanism, such that circulating AVP retains a full effect on renal water retention. In contrast, loop diuretics, which are less frequently associated with hyponatremia, inhibit Na<sup>+</sup>-Cl<sup>-</sup> and K<sup>+</sup> absorption by the TALH, blunting the countercurrent mechanism and reducing the ability to concentrate the urine. Increased excretion of an osmotically active nonreabsorbable or poorly reabsorbable solute can also lead to volume depletion and hyponatremia; important causes include glycosuria, ketonuria (e.g., in starvation or in diabetic or alcoholic ketoacidosis), and bicarbonaturia (e.g., in renal tubular acidosis or metabolic alkalosis, where the associated bicarbonaturia leads to loss of Na<sup>+</sup>).

Finally, the syndrome of “cerebral salt wasting” is a rare cause of hypovolemic hyponatremia, encompassing hyponatremia with clinical hypovolemia and inappropriate natriuresis in association with intracranial disease; associated disorders include subarachnoid hemorrhage, traumatic brain injury, craniotomy, encephalitis, and meningitis. Distinction from the more common syndrome of inappropriate antidiuresis (SIAD) is critical because cerebral salt wasting will typically respond to aggressive Na<sup>+</sup>-Cl<sup>-</sup> repletion.

**Hypervolemic Hyponatremia** Patients with hypervolemic hyponatremia develop an increase in total-body Na<sup>+</sup>-Cl<sup>-</sup> that is accompanied by a proportionately *greater* increase in total-body water, leading to a reduced plasma Na<sup>+</sup> concentration. As in hypovolemic hyponatremia, the causative disorders can be separated by the effect on urine Na<sup>+</sup> concentration, with acute or chronic renal failure uniquely associated with an increase in urine Na<sup>+</sup> concentration (Fig. 53-5).

The pathophysiology of hyponatremia in the sodium-avid edematous disorders (congestive heart failure [CHF], cirrhosis, and nephrotic syndrome) is similar to that in hypovolemic hyponatremia, except that arterial filling and circulatory integrity is decreased due to the specific etiologic factors (e.g., cardiac dysfunction in CHF, peripheral vasodilation in cirrhosis). Urine Na<sup>+</sup> concentration is typically very low, i.e., <10 mM, even after hydration with normal saline; this Na<sup>+</sup>-avid state may be obscured by diuretic therapy. The degree of hyponatremia provides an indirect index of the associated neurohumoral activation and is an important prognostic indicator in hypervolemic hyponatremia.

**Euvolemic Hyponatremia** Euvolemic hyponatremia can occur in moderate to severe hypothyroidism, with correction after achieving a euthyroid state. Severe hyponatremia can also be a consequence of secondary adrenal insufficiency due to pituitary disease; whereas the deficit in circulating aldosterone in primary adrenal insufficiency causes *hypovolemic* hyponatremia, the predominant glucocorticoid deficiency in secondary adrenal failure is associated with *euvolemic* hyponatremia. Glucocorticoids exert a negative feedback on AVP release by the posterior pituitary such that hydrocortisone replacement in these patients can rapidly normalize the AVP response to osmolality, reducing circulating AVP.

The SIAD is the most frequent cause of euvolemic hyponatremia (Table 53-1). The generation of hyponatremia in SIAD requires an intake of free water, with persistent intake at serum osmolalities that are lower than the usual threshold for thirst; as one would expect, the osmotic threshold and osmotic response curves for the sensation of thirst are shifted downward in patients with SIAD. Four distinct patterns of AVP secretion have been recognized in patients with SIAD, independent for the most part of the underlying cause. Unregulated, erratic AVP secretion is seen in about a third of patients, with no obvious correlation between serum osmolality and circulating AVP levels. Other patients fail to suppress AVP secretion at lower serum osmolalities, with a normal response curve to hyperosmolar conditions; others have a “reset osmostat,” with a lower threshold osmolality and a left-shifted osmotic response curve. Finally, the fourth subset of patients have essentially no detectable circulating AVP, suggesting either a gain in function in renal water reabsorption or a circulating antidiuretic substance that is distinct from AVP. Gain-in-function mutations of a single specific residue in the V<sub>2</sub> AVP receptor have been described in some of these patients, leading to constitutive activation of the receptor in the absence of AVP and “nephrogenic” SIAD.

TABLE 53-1 Causes of the Syndrome of Inappropriate Antidiuresis (SIAD)

MALIGNANT DISEASES	PULMONARY DISORDERS	DISORDERS OF THE CENTRAL NERVOUS SYSTEM	DRUGS	OTHER CAUSES
Carcinoma	Infections	Infection	Drugs that stimulate release of AVP or enhance its action	Heredity (gain-of-function mutations in the vasopressin V <sub>2</sub> receptor)
Lung	Bacterial pneumonia	Encephalitis	Chlorpropamide	Idiopathic
Small cell	Viral pneumonia	Meningitis	SSRIs	Transient
Mesothelioma	Pulmonary abscess	Brain abscess	Tricyclic antidepressants	Endurance exercise
Oropharynx	Tuberculosis	Rocky Mountain spotted fever	Clofibrate	General anesthesia
Gastrointestinal tract	Aspergillosis	AIDS	Carbamazepine	Nausea
Stomach	Asthma	Bleeding and masses	Vincristine	Pain
Duodenum	Cystic fibrosis	Subdural hematoma	Nicotine	Stress
Pancreas	Respiratory failure associated with positive-pressure breathing	Subarachnoid hemorrhage	Narcotics	
Genitourinary tract		Cerebrovascular accident	Antipsychotic drugs	
Ureter		Brain tumors	Ifosfamide	
Bladder		Head trauma	Cyclophosphamide	
Prostate		Hydrocephalus	Nonsteroidal anti-inflammatory drugs	
Endometrium		Cavernous sinus thrombosis	MDMA ("Ecstasy", "Molly")	
Endocrine thymoma		Other	AVP analogues	
Lymphomas		Multiple sclerosis	Desmopressin	
Sarcomas		Guillain-Barré syndrome	Oxytocin	
Ewing's sarcoma		Shy-Drager syndrome	Vasopressin	
		Delirium tremens		
		Acute intermittent porphyria		

Abbreviations: AVP, vasopressin; MDMA, 3,4-methylenedioxymethamphetamine; SSRI, selective serotonin reuptake inhibitor.

Source: From DH Elison, T Berl: The syndrome of inappropriate antidiuresis. N Engl J Med 356:2064, 2007. Copyright © 2007 Massachusetts Medical Society. Reprinted with permission from Massachusetts Medical Society.

Strictly speaking, patients with SIAD are not euvolemic but are subclinically volume-expanded, due to AVP-induced water and Na<sup>+</sup>-Cl<sup>-</sup> retention; "AVP escape" mechanisms invoked by sustained increases in AVP serve to limit distal renal tubular transport, preserving a modestly hypervolemic steady state. Serum uric acid is often low (<4 mg/dL) in patients with SIAD, consistent with suppressed proximal tubular transport in the setting of increased distal tubular Na<sup>+</sup>-Cl<sup>-</sup> and water transport; in contrast, patients with hypovolemic hyponatremia will often be hyperuricemic due to a shared activation of proximal tubular Na<sup>+</sup>-Cl<sup>-</sup> and urate transport.

Common causes of SIAD include pulmonary disease (e.g., pneumonia, tuberculosis, pleural effusion) and central nervous system (CNS) diseases (e.g., tumor, subarachnoid hemorrhage, meningitis). SIAD also occurs with malignancies, most commonly with small-cell lung carcinoma (75% of malignancy-associated SIAD); ~10% of patients with this tumor will have a plasma Na<sup>+</sup> concentration of <130 mM at presentation. SIAD is also a frequent complication of certain drugs, most commonly the selective serotonin reuptake inhibitors (SSRIs). Other drugs can potentiate the renal effect of AVP, without exerting direct effects on circulating AVP levels (Table 53-1).

**Low Solute Intake and Hyponatremia** Hyponatremia can occasionally occur in patients with a very low intake of dietary solutes. Classically, this occurs in alcoholics whose sole nutrient is beer, hence the diagnostic label of *beer potomania*; beer is very low in protein and salt content, containing only 1–2 mM of Na<sup>+</sup>. The syndrome has also been described in nonalcoholic patients with highly restricted solute intake due to nutrient-restricted diets, e.g., extreme vegetarian diets. Patients with hyponatremia due to low solute intake typically present with a very low urine osmolality (<100–200 mOsm/kg) with a urine Na<sup>+</sup> concentration that is <10–20 mM. The fundamental abnormality is the inadequate dietary intake of solutes; the reduced urinary solute excretion limits water excretion such that hyponatremia ensues after relatively modest polydipsia. AVP levels have not been reported in patients with beer potomania but are expected to be suppressed or rapidly suppressible with saline hydration; this fits with the overly rapid correction in plasma Na<sup>+</sup> concentration that can be seen with saline hydration. Resumption of a normal diet and/or saline hydration will also correct the causative deficit in urinary solute excretion, such

that patients with beer potomania typically correct their plasma Na<sup>+</sup> concentration promptly after admission to the hospital.

**Clinical Features of Hyponatremia** Hyponatremia induces generalized cellular swelling, a consequence of water movement down the osmotic gradient from the hypotonic ECF to the ICF. The symptoms of hyponatremia are primarily neurologic, reflecting the development of cerebral edema within a rigid skull. The initial CNS response to acute hyponatremia is an increase in interstitial pressure, leading to shunting of ECF and solutes from the interstitial space into the cerebrospinal fluid and then on into the systemic circulation. This is accompanied by an efflux of the major intracellular ions, Na<sup>+</sup>, K<sup>+</sup>, and Cl<sup>-</sup>, from brain cells. Acute hyponatremic encephalopathy ensues when these volume regulatory mechanisms are overwhelmed by a rapid decrease in tonicity, resulting in acute cerebral edema. Early symptoms can include nausea, headache, and vomiting. However, severe complications can rapidly evolve, including seizure activity, brainstem herniation, coma, and death. A key complication of acute hyponatremia is normocapneic or hypercapneic respiratory failure; the associated hypoxia may amplify the neurologic injury. Normocapneic respiratory failure in this setting is typically due to noncardiogenic, "neurogenic" pulmonary edema, with a normal pulmonary capillary wedge pressure.

Acute symptomatic hyponatremia is a medical emergency, occurring in a number of specific settings (Table 53-2). Women, particularly

TABLE 53-2 Causes of Acute Hyponatremia

Iatrogenic
Postoperative: premenopausal women
Hypotonic fluids with cause of ↑ vasopressin
Glycine irrigation: TURP, uterine surgery
Colonoscopy preparation
Recent institution of thiazides
Polydipsia
MDMA ("ecstasy," "Molly") ingestion
Exercise induced
Multifactorial, e.g., thiazide and polydipsia

Abbreviations: MDMA, 3,4-methylenedioxymethamphetamine; TURP, transurethral resection of the prostate.

before menopause, are much more likely than men to develop encephalopathy and severe neurologic sequelae. Acute hyponatremia often has an iatrogenic component, e.g., when hypotonic intravenous fluids are given to postoperative patients with an increase in circulating AVP. Exercise-associated hyponatremia, an important clinical issue at marathons and other endurance events, has similarly been linked to both a “nonosmotic” increase in circulating AVP and excessive free water intake. The recreational drugs Molly and Ecstasy, which share an active ingredient (MDMA, 3,4-methylenedioxymethamphetamine), cause a rapid and potent induction of both thirst and AVP, leading to severe acute hyponatremia.

Persistent, chronic hyponatremia results in an efflux of organic osmolytes (creatine, betaine, glutamate, myoinositol, and taurine) from brain cells; this response reduces intracellular osmolality and the osmotic gradient favoring water entry. This reduction in intracellular osmolytes is largely complete within 48 h, the time period that clinically defines chronic hyponatremia; this temporal definition has considerable relevance for the treatment of hyponatremia (see below). The cellular response to chronic hyponatremia does not fully protect patients from symptoms, which can include vomiting, nausea, confusion, and seizures, usually at plasma  $\text{Na}^+$  concentration <125 mM. Even patients who are judged “asymptomatic” can manifest subtle gait and cognitive defects that reverse with correction of hyponatremia; notably, chronic “asymptomatic” hyponatremia increases the risk of falls. Chronic hyponatremia also increases the risk of bony fractures owing to the associated neurologic dysfunction and to a hyponatremia-associated reduction in bone density. Therefore, every attempt should be made to safely correct the plasma  $\text{Na}^+$  concentration in patients with chronic hyponatremia, even in the absence of overt symptoms (see the section on treatment of hyponatremia below).

The management of chronic hyponatremia is complicated significantly by the asymmetry of the cellular response to correction of plasma  $\text{Na}^+$  concentration. Specifically, the *reaccumulation* of organic osmolytes by brain cells is attenuated and delayed as osmolality increases after correction of hyponatremia, sometimes resulting in degenerative loss of oligodendrocytes and an osmotic demyelination syndrome (ODS). Overly rapid correction of hyponatremia (>8–10 mM in 24 h or 18 mM in 48 h) causes hypertonic stress in astrocytes within brain regions prone to ODS, leading to generalized protein ubiquitination and endoplasmic reticulum stress due to activation of the unfolded protein response; this is accompanied by apoptotic and autophagic cell death. Rapid correction of hyponatremia also causes a disruption in integrity of the blood-brain barrier, allowing the entry of immune mediators that may contribute to demyelination. The lesions of ODS classically affect the pons, a neuroanatomic structure wherein the delay in the reaccumulation of osmotic osmolytes is particularly pronounced; clinically, patients with central pontine myelinolysis can present 1 or more days after overcorrection of hyponatremia with paraparesis or quadripareisis, dysphagia, dysarthria, diplopia, a “locked-in syndrome,” and/or loss of consciousness. Other regions of the brain can also be involved in ODS, most commonly in association with lesions of the pons but occasionally in isolation; in order of frequency, the lesions of extrapontine myelinolysis can occur in the cerebellum, lateral geniculate body, thalamus, putamen, and cerebral cortex or subcortex. Clinical presentation of ODS can, therefore, vary as a function of the extent and localization of extrapontine myelinolysis, with the reported development of ataxia, mutism, parkinsonism, dystonia, and catatonia. Relowering of plasma  $\text{Na}^+$  concentration after overly rapid correction can prevent or attenuate ODS (see the section on treatment of hyponatremia below). However, even appropriately slow correction can be associated with ODS, particularly in patients with additional risk factors; these include alcoholism, malnutrition, hypokalemia, and liver transplantation.

**Diagnostic Evaluation of Hyponatremia** Clinical assessment of hyponatremic patients should focus on the underlying cause; a detailed drug history is particularly crucial (Table 53-1). A careful clinical assessment of volume status is obligatory for the classical diagnostic approach to hyponatremia (Fig. 53-5). Hyponatremia is frequently

multifactorial, particularly when severe; clinical evaluation should consider *all* the possible causes for excessive circulating AVP, including volume status, drugs, and the presence of nausea and/or pain. Radiologic imaging may also be appropriate to assess whether patients have a pulmonary or CNS cause for hyponatremia. A screening chest x-ray may fail to detect a small-cell carcinoma of the lung; computed tomography (CT) scanning of the thorax should be considered in patients at high risk for this tumor (e.g., patients with a smoking history).

Laboratory investigation should include a measurement of serum osmolality to exclude pseudohyponatremia, which is defined as the coexistence of hyponatremia with a normal or increased plasma tonicity. Most clinical laboratories measure plasma  $\text{Na}^+$  concentration by testing diluted samples with automated ion-sensitive electrodes, correcting for this dilution by assuming that plasma is 93% water. This correction factor can be inaccurate in patients with pseudohyponatremia due to extreme hyperlipidemia and/or hyperproteinemia, in whom serum lipid or protein makes up a greater percentage of plasma volume. The measured osmolality should also be converted to the effective osmolality (tonicity) by subtracting the measured concentration of urea (divided by 2.8, if in mg/dL); patients with hyponatremia have an effective osmolality of <275 mOsm/kg.

Elevated BUN and creatinine in routine chemistries can also indicate renal dysfunction as a potential cause of hyponatremia, whereas hyperkalemia may suggest adrenal insufficiency or hypoaldosteronism. Serum glucose should also be measured; plasma  $\text{Na}^+$  concentration falls by ~1.6–2.4 mM for every 100-mg/dL increase in glucose, due to glucose-induced water efflux from cells; this “true” hyponatremia resolves after correction of hyperglycemia. Measurement of serum uric acid should also be performed; whereas patients with SIAD-type physiology will typically be hypouricemic (serum uric acid <4 mg/dL), volume-depleted patients will often be hyperuricemic. In the appropriate clinical setting, thyroid, adrenal, and pituitary function should also be tested; hypothyroidism and secondary adrenal failure due to pituitary insufficiency are important causes of euvolemic hyponatremia, whereas primary adrenal failure causes hypovolemic hyponatremia. A cosyntropin stimulation test is necessary to assess for primary adrenal insufficiency.

Urine electrolytes and osmolality are crucial tests in the initial evaluation of hyponatremia. A urine  $\text{Na}^+$  concentration <20–30 mM is consistent with hypovolemic hyponatremia, in the clinical absence of a hypervolemic,  $\text{Na}^+$ -avid syndrome such as CHF (Fig. 53-5). In contrast, patients with SIAD will typically excrete urine with an  $\text{Na}^+$  concentration that is >30 mM. However, there can be substantial overlap in urine  $\text{Na}^+$  concentration values in patients with SIAD and hypovolemic hyponatremia, particularly in the elderly; the ultimate “gold standard” for the diagnosis of hypovolemic hyponatremia is the demonstration that plasma  $\text{Na}^+$  concentration corrects after hydration with normal saline. Patients with thiazide-associated hyponatremia may also present with higher than expected urine  $\text{Na}^+$  concentration and other findings suggestive of SIAD; one should defer making a diagnosis of SIAD in these patients until 1–2 weeks after discontinuing the thiazide. A urine osmolality <100 mOsm/kg is suggestive of polydipsia; urine osmolality >400 mOsm/kg indicates that AVP excess is playing a more dominant role, whereas intermediate values are more consistent with multifactorial pathophysiology (e.g., AVP excess with a significant component of polydipsia). Patients with hyponatremia due to decreased solute intake (beer potomania) typically have urine  $\text{Na}^+$  concentration <20 mM and urine osmolality in the range of <100 to the low 200s. Finally, the measurement of urine  $\text{K}^+$  concentration is required to calculate the urine-to-plasma electrolyte ratio, which is useful to predict the response to fluid restriction (see the section on treatment of hyponatremia below).

## TREATMENT

### Hyponatremia

Three major considerations guide the therapy of hyponatremia. First, the presence and/or severity of symptoms determine the urgency and goals of therapy. Patients with acute hyponatremia

(Table 53-2) present with symptoms that can range from headache, nausea, and/or vomiting, to seizures, obtundation, and central herniation; patients with chronic hyponatremia, present for >48 h, are less likely to have severe symptoms. Second, patients with chronic hyponatremia are at risk for ODS if plasma Na<sup>+</sup> concentration is corrected by >8–10 mM within the first 24 h and/or by >18 mM within the first 48 h. Third, the response to interventions such as hypertonic saline, isotonic saline, or AVP antagonists can be highly unpredictable, such that frequent monitoring of plasma Na<sup>+</sup> concentration during corrective therapy is imperative.

Once the urgency in correcting the plasma Na<sup>+</sup> concentration has been established and appropriate therapy instituted, the focus should be on treatment or withdrawal of the underlying cause. Patients with euvolemic hyponatremia due to SIAD, hypothyroidism, or secondary adrenal failure will respond to successful treatment of the underlying cause, with an increase in plasma Na<sup>+</sup> concentration. However, not all causes of SIAD are immediately reversible, necessitating pharmacologic therapy to increase the plasma Na<sup>+</sup> concentration (see below). Hypovolemic hyponatremia will respond to intravenous hydration with isotonic normal saline, with a rapid reduction in circulating AVP and a brisk water diuresis; it may be necessary to reduce the rate of correction if the history suggests that hyponatremia has been chronic, i.e., present for >48 h (see below). Hypervolemic hyponatremia due to CHF will often respond to improved therapy of the underlying cardiomyopathy, e.g., following the institution or intensification of angiotensin-converting enzyme (ACE) inhibition. Finally, patients with hyponatremia due to beer potomania and low solute intake will respond very rapidly to intravenous saline and the resumption of a normal diet. Notably, patients with beer potomania have a very high risk of developing ODS, due to the associated hypokalemia, alcoholism, malnutrition, and high risk of overcorrecting the plasma Na<sup>+</sup> concentration.

Water deprivation has long been a cornerstone of the therapy of chronic hyponatremia. However, patients who are excreting minimal electrolyte-free water will require aggressive fluid restriction; this can be very difficult for patients with SIAD to tolerate, given that their thirst is also inappropriately stimulated. The urine-to-plasma electrolyte ratio (urinary [Na<sup>+</sup>] + [K<sup>+</sup>]/plasma [Na<sup>+</sup>]) can be exploited as a quick indicator of electrolyte-free water excretion (Table 53-3); patients with a ratio of >1 should be more aggressively restricted (<500 mL/d) if possible, those with a ratio of ~1 should be restricted to 500–700 mL/d, and those with a ratio <1 should be restricted to <1 L/d. In hypokalemic patients, potassium replacement will serve to increase plasma Na<sup>+</sup> concentration, given that

the plasma Na<sup>+</sup> concentration is a function of both exchangeable Na<sup>+</sup> and exchangeable K<sup>+</sup> divided by total-body water; a corollary is that aggressive repletion of K<sup>+</sup> has the potential to overcorrect the plasma Na<sup>+</sup> concentration even in the absence of hypertonic saline. Plasma Na<sup>+</sup> concentration will also tend to respond to an increase in dietary solute intake, which increases the ability to excrete free water; this can be accomplished with oral salt tablets and with newly available, palatable preparations of oral urea.

Patients in whom therapy with fluid restriction, potassium replacement, and/or increased solute intake fails may merit pharmacologic therapy to increase their plasma Na<sup>+</sup> concentration. Some patients with SIAD initially respond to combined therapy with oral furosemide, 20 mg twice a day (higher doses may be necessary in renal insufficiency), and oral salt tablets; furosemide serves to inhibit the renal countercurrent mechanism and blunt urinary concentrating ability, whereas the salt tablets counteract diuretic-associated natriuresis. The risk of hypokalemia and/or renal dysfunction limits enthusiasm for this approach, which requires careful titration of diuretic and salt tablets. Demeclocycline is a potent inhibitor of principal cells and can be used in patients whose Na levels do not increase in response to furosemide and salt tablets. However, this agent can be associated with a reduction in GFR, due to excessive natriuresis and/or direct renal toxicity; it should be avoided in cirrhotic patients in particular, who are at higher risk of nephrotoxicity due to drug accumulation. If available, palatable preparations of oral urea can also be used to manage SIAD, with comparable efficacy to AVP antagonists (vaptans); the increase in solute excretion with oral urea ingestion increases free water excretion, thus reducing the plasma Na<sup>+</sup>.

AVP antagonists (vaptans) are highly effective in SIAD and in hypervolemic hyponatremia due to heart failure or cirrhosis, reliably increasing plasma Na<sup>+</sup> concentration due to their “aquaretic” effects (augmentation of free water clearance). Most of these agents specifically antagonize the V<sub>2</sub> AVP receptor; tolvaptan is currently the only oral V<sub>2</sub> antagonist to be approved by the U.S. Food and Drug Administration. Conivaptan, the only available intravenous vaptan, is a mixed V<sub>1A</sub>/V<sub>2</sub> antagonist, with a modest risk of hypotension due to V<sub>1A</sub> receptor inhibition. Therapy with vaptans must be initiated in a hospital setting, with a liberalization of fluid restriction (>2 L/d) and close monitoring of plasma Na<sup>+</sup> concentration. Although approved for the management of all but hypovolemic hyponatremia and acute hyponatremia, the clinical indications are limited. Oral tolvaptan is perhaps most appropriate for the management of significant and persistent SIAD (e.g., in small-cell lung carcinoma) that has not responded to water restriction and/or oral furosemide and salt tablets. Abnormalities in liver function tests have been reported with chronic tolvaptan therapy; hence, the use of this agent should be restricted to <1–2 months.

Treatment of acute symptomatic hyponatremia should include hypertonic 3% saline (513 mM) to acutely increase plasma Na<sup>+</sup> concentration by 1–2 mM/h to a total of 4–6 mM; this modest increase is typically sufficient to alleviate severe acute symptoms, after which corrective guidelines for chronic hyponatremia are appropriate (see below). A bolus of 100 mL of hypertonic saline is more effective than an infusion, rapidly improving both serum sodium and mental status. For ongoing infusions, a number of equations have been developed to estimate the required rate of hypertonic saline, which has an Na<sup>+</sup>-Cl<sup>-</sup> concentration of 513 mM. The traditional approach is to calculate an Na<sup>+</sup> deficit, where the Na<sup>+</sup> deficit = 0.6 × body weight × (target plasma Na<sup>+</sup> concentration – starting plasma Na<sup>+</sup> concentration), followed by a calculation of the required rate. Regardless of the method used to determine the rate of administration, the increase in plasma Na<sup>+</sup> concentration can be highly unpredictable during treatment with hypertonic saline, due to rapid changes in the underlying physiology; plasma Na<sup>+</sup> concentration should be monitored every 2–4 h during treatment, with appropriate changes in therapy based on the observed rate of change. The administration of supplemental oxygen and ventilatory support is also critical in acute hyponatremia, in the event

**TABLE 53-3 Management of Hyponatremia**

#### Water Deficit

1. Estimate total-body water (TBW): 50% of body weight in women and 60% in men
2. Calculate free-water deficit: [(Na<sup>+</sup> – 140)/140] × TBW
3. Administer deficit over 48–72 h, without decrease in plasma Na<sup>+</sup> concentration by >10 mM/24 h

#### Ongoing Water Losses

4. Calculate free-water clearance, C<sub>e</sub>H<sub>2</sub>O:

$$C_e H_2 O = V \times 1 - \frac{U_{Na} + U_K}{P_{Na}}$$

where V is urinary volume, U<sub>Na</sub> is urinary [Na<sup>+</sup>], U<sub>K</sub> is urinary [K<sup>+</sup>], and P<sub>Na</sub> is plasma [Na<sup>+</sup>]

#### Insensible Losses

5. ~10 mL/kg per day: less if ventilated, more if febrile

#### Total

6. Add components to determine water deficit and ongoing water loss; correct the water deficit over 48–72 h and replace daily water loss. Avoid correction of plasma [Na<sup>+</sup>] by >10 mM/d.

that patients develop acute pulmonary edema or hypercapneic respiratory failure. Intravenous loop diuretics will help treat acute pulmonary edema and will also increase free water excretion, by interfering with the renal countercurrent multiplication system. AVP antagonists do *not* have an approved role in the management of acute hyponatremia.

The rate of correction should be comparatively slow in *chronic* hyponatremia (<6–8 mM in the first 24 h and <6 mM each subsequent 24 h), so as to avoid ODS; lower target rates are appropriate in patients at particular risk for ODS, such as alcoholics or hypokalemic patients. Overcorrection of the plasma Na<sup>+</sup> concentration can occur when AVP levels rapidly normalize, for example, following the treatment of patients with chronic hypovolemic hyponatremia with intravenous saline or following glucocorticoid replacement of patients with hypopituitarism and secondary adrenal failure. Approximately 10% of patients treated with vaptans will overcorrect; the risk is increased if water intake is not liberalized. In the event that the plasma Na<sup>+</sup> concentration overcorrects following therapy, be it with hypertonic saline, isotonic saline, or a vaptan, hyponatremia can be safely reinduced or stabilized by the administration of the AVP *agonist* desmopressin acetate (DDAVP) and/or the administration of free water, typically intravenous D<sub>5</sub>W; the goal is to prevent or reverse the development of ODS. Alternatively, the treatment of patients with marked hyponatremia can be initiated with the twice-daily administration of DDAVP to maintain constant AVP bioactivity, combined with the administration of hypertonic saline to slowly correct the serum sodium in a more controlled fashion, thus reducing upfront the risk of overcorrection.

## HYPERNATREMIA

**Etiology** Hypernatremia is defined as an increase in the plasma Na<sup>+</sup> concentration to >145 mM. Considerably less common than hyponatremia, hypernatremia is nonetheless associated with mortality rates of as high as 40–60%, mostly due to the severity of the associated underlying disease processes. Hypernatremia is usually the result of a combined water and electrolyte deficit, with losses of H<sub>2</sub>O in excess of Na<sup>+</sup>. Less frequently, the ingestion or iatrogenic administration of excess Na<sup>+</sup> can be causative, for example, after IV administration of excessive hypertonic Na<sup>+</sup>-Cl<sup>-</sup> or Na<sup>+</sup>-HCO<sub>3</sub><sup>-</sup> (Fig. 53-6).

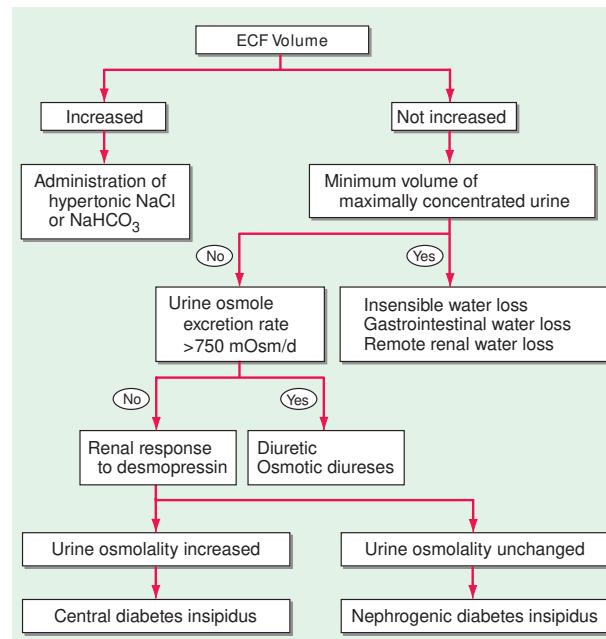


FIGURE 53-6 The diagnostic approach to hypernatremia. ECF, extracellular fluid.

Elderly individuals with reduced thirst and/or diminished access to fluids are at the highest risk of developing hypernatremia. Patients with hypernatremia may rarely have a central defect in hypothalamic osmoreceptor function, with a mixture of both decreased thirst and reduced AVP secretion. Causes of this adipsic DI include primary or metastatic tumor, occlusion or ligation of the anterior communicating artery, trauma, hydrocephalus, and inflammation.

Hypernatremia can develop following the loss of water via both renal and nonrenal routes. Insensible losses of water may increase in the setting of fever, exercise, heat exposure, severe burns, or mechanical ventilation. Diarrhea is, in turn, the most common gastrointestinal cause of hypernatremia. Notably, osmotic diarrhea and viral gastroenteritis typically generate stools with Na<sup>+</sup> and K<sup>+</sup> <100 mM, thus leading to water loss and hypernatremia; in contrast, secretory diarrhea typically results in isotonic stool and thus hypovolemia with or without hypovolemic hyponatremia.

Common causes of renal water loss include osmotic diuresis secondary to hyperglycemia, excess urea, postobstructive diuresis, or mannitol; these disorders share an increase in urinary solute excretion and urinary osmolality (see “Diagnostic Approach,” below). Hypernatremia due to a water diuresis occurs in central or nephrogenic DI (NDI).

NDI is characterized by renal resistance to AVP, which can be partial or complete (see “Diagnostic Approach,” below). Genetic causes include loss-of-function mutations in the X-linked V<sub>2</sub> receptor; mutations in the AVP-responsive aquaporin-2 water channel can cause autosomal recessive and autosomal dominant NDI, whereas recessive deficiency of the aquaporin-1 water channel causes a more modest concentrating defect (Fig. 53-2). Hypercalcemia can also cause polyuria and NDI; calcium signals directly through the calcium-sensing receptor to downregulate Na<sup>+</sup>, K<sup>+</sup>, and Cl<sup>-</sup> transport by the TALH and water transport in principal cells, thus reducing renal concentrating ability in hypercalcemia. Another common acquired cause of NDI is hypokalemia, which inhibits the renal response to AVP and downregulates aquaporin-2 expression. Several drugs can cause acquired NDI, in particular, lithium, ifosfamide, and several antiviral agents. Lithium causes NDI by multiple mechanisms, including direct inhibition of renal glycogen synthase kinase-3 (GSK3), a kinase thought to be the pharmacologic target of lithium in bipolar disease; GSK3 is required for the response of principal cells to AVP. The entry of lithium through the amiloride-sensitive Na<sup>+</sup> channel ENaC (Fig. 53-4) is required for the effect of the drug on principal cells, such that combined therapy within lithium and amiloride can mitigate lithium-associated NDI. However, lithium causes chronic tubulointerstitial scarring and chronic kidney disease after prolonged therapy, such that patients may have a persistent NDI long after stopping the drug, with a reduced therapeutic benefit from amiloride.

Finally, gestational DI is a rare complication of late-term pregnancy wherein increased activity of a circulating placental protease with “vasopressinase” activity leads to reduced circulating AVP and polyuria, often accompanied by hypernatremia. DDAVP is an effective therapy for this syndrome, given its resistance to the vasopressinase enzyme.

**Clinical Features** Hypernatremia increases osmolality of the ECF, generating an osmotic gradient between the ECF and ICF, an efflux of intracellular water, and cellular shrinkage. As in hyponatremia, the symptoms of hypernatremia are predominantly neurologic. Altered mental status is the most frequent manifestation, ranging from mild confusion and lethargy to deep coma. The sudden shrinkage of brain cells in acute hypernatremia may lead to parenchymal or subarachnoid hemorrhages and/or subdural hematomas; however, these vascular complications are primarily encountered in pediatric and neonatal patients. Rarely, osmotic demyelination may occur in acute hypernatremia. Osmotic damage to muscle membranes can also lead to hypernatremic rhabdomyolysis. Brain cells accommodate to a chronic increase in ECF osmolality (>48 h) by activating membrane transporters that mediate influx and intracellular accumulation of organic osmolytes (creatine, betaine, glutamate, myoinositol, and taurine); this results in an increase in ICF water and normalization of brain parenchymal volume. In consequence, patients with *chronic* hypernatremia are less likely to develop severe neurologic compromise. However, the cellular response

to chronic hypernatremia predisposes pediatric patients with hypernatremia, particularly infants, to the development of cerebral edema and seizures during overly rapid hydration (overcorrection of plasma Na<sup>+</sup> concentration by >10 mM/d). In critically ill adults, however, recent evidence does not indicate that rapid correction of hypernatremia is associated with a higher risk for mortality, seizure, alteration of consciousness, and/or cerebral edema. Given that restricting the rate of correction to <10 mM/d has no physiologic sequelae, it seems prudent to restrict correction in adults to this rate; however, should that rate be exceeded, hypernatremia does not need to be reinduced.

**Diagnostic Approach** The history should focus on the presence or absence of thirst, polyuria, and/or an extrarenal source for water loss, such as diarrhea. The physical examination should include a detailed neurologic exam and an assessment of the ECFV; patients with a particularly large water deficit and/or a combined deficit in electrolytes and water may be hypovolemic, with reduced JVP and orthostasis. Accurate documentation of daily fluid intake and daily urine output is also critical for the diagnosis and management of hypernatremia.

Laboratory investigation should include a measurement of serum and urine osmolality, in addition to urine electrolytes. The appropriate response to hypernatremia and a serum osmolality >295 mOsm/kg is an increase in circulating AVP and the excretion of low volumes (<500 mL/d) of maximally concentrated urine, i.e., urine with osmolality >800 mOsm/kg; should this be the case, then an extrarenal source of water loss is primarily responsible for the generation of hypernatremia. Many patients with hypernatremia are polyuric; should an osmotic diuresis be responsible, with excessive excretion of Na<sup>+</sup>-Cl<sup>-</sup>, glucose, and/or urea, then daily solute excretion will be >750–1000 mOsm/d (>15 mOsm/kg body water per day) (Fig. 53-6). More commonly, patients with hypernatremia and polyuria will have a predominant water diuresis, with excessive excretion of hypotonic, dilute urine.

Adequate differentiation between nephrogenic and central causes of DI requires the measurement of the response in urinary osmolality to DDAVP, combined with measurement of circulating AVP in the setting of hypertonicity. If measurement of serum copeptin is available, an “indirect water deprivation” test can be performed in patients with hypotonic polyuria without hypernatremia; if an infusion of hypertonic saline increases the level of circulating copeptin, a peptide co-secreted with AVP, then the patient suffers from polydipsia rather than central DI. By definition, patients with baseline hypernatremia are hypertonic, with an adequate stimulus for AVP by the posterior pituitary. Therefore, in contrast to polyuric patients with a normal or reduced baseline plasma Na<sup>+</sup> concentration and osmolality, a water deprivation test (Chap. 52) is unnecessary in hypernatremia; indeed, water deprivation is absolutely contraindicated in this setting, given the risk for worsening the hypernatremia. Hypernatremic patients with NDI will have high serum levels of AVP and copeptin. Their low urine osmolality will also fail to respond to DDAVP, increasing by <50% or <150 mOsm/kg from baseline; patients with central DI will respond to DDAVP, with a reduced circulating AVP and copeptin. Patients may exhibit a partial response to DDAVP, with a >50% rise in urine osmolality that nonetheless fails to reach 800 mOsm/kg; the level of circulating AVP will help differentiate the underlying cause, i.e., NDI versus central DI. In pregnant patients, AVP assays should be drawn in tubes containing the protease inhibitor 1,10-phenanthroline to prevent *in vitro* degradation of AVP by placental vasopressinase.

For patients with hypernatremia due to renal loss of water, it is critical to quantify *ongoing* daily losses using the calculated electrolyte-free water clearance, in addition to calculation of the baseline water deficit (the relevant formulas are discussed in Table 53-3). This requires daily measurement of urine electrolytes, combined with accurate measurement of daily urine volume.

## TREATMENT

### Hypernatremia

The underlying cause of hypernatremia should be withdrawn or corrected, be it drugs, hyperglycemia, hypercalcemia, hypokalemia, or diarrhea. The approach to the correction of hypernatremia is

outlined in Table 53-3. It is imperative to correct hypernatremia slowly to avoid cerebral edema, typically replacing the calculated free water deficit over 48 h. Notably, the plasma Na<sup>+</sup> concentration should be corrected by no more than 10 mM/d, which may take longer than 48 h in patients with severe hypernatremia (>160 mM). A rare exception is patients with acute hypernatremia (<48 h) due to sodium loading, who can safely be corrected rapidly at a rate of 1 mM/h.

Water should ideally be administered by mouth or by nasogastric tube, as the most direct way to provide free water, i.e., water without electrolytes. Alternatively, patients can receive free water in dextrose-containing IV solutions, such as 5% dextrose (D<sub>5</sub>W); blood glucose should be monitored in case hyperglycemia occurs. Depending on the history, blood pressure, or clinical volume status, it may be appropriate to initially treat with hypotonic saline solutions (1/4 or 1/2 normal saline); normal saline is usually inappropriate in the absence of very severe hypernatremia, where normal saline is proportionally more hypotonic relative to plasma, or frank hypotension. Calculation of urinary electrolyte-free water clearance (Table 53-3) is required to estimate daily, ongoing loss of free water in patients with NDI or central DI, which should be replenished daily.

Additional therapy may be feasible in specific cases. Patients with central DI should respond to the administration of intravenous, intranasal, or oral DDAVP. Patients with NDI due to lithium may reduce their polyuria with amiloride (2.5–10 mg/d), which decreases entry of lithium into principal cells by inhibiting ENaC (see above); in practice, however, most patients with lithium-associated DI are able to compensate for their polyuria by simply increasing their daily water intake. Thiazides may reduce polyuria due to NDI, ostensibly by inducing hypovolemia and increasing proximal tubular water reabsorption. Occasionally, nonsteroidal anti-inflammatory drugs (NSAIDs) have been used to treat polyuria associated with NDI, reducing the negative effect of intrarenal prostaglandins on urinary concentrating mechanisms; however, this assumes the risks of NSAID-associated gastric and/or renal toxicity. Furthermore, it must be emphasized that thiazides, amiloride, and NSAIDs are only appropriate for *chronic* management of polyuria from NDI and have *no* role in the acute management of associated hypernatremia, where the focus is on replacing free water deficits and ongoing free water loss.

## POTASSIUM DISORDERS

Homeostatic mechanisms maintain plasma K<sup>+</sup> concentration between 3.5 and 5.0 mM, despite marked variation in dietary K<sup>+</sup> intake. In a healthy individual at steady state, the entire daily intake of potassium is excreted, ~90% in the urine and 10% in the stool; thus, the kidney plays a dominant role in potassium homeostasis. However, >98% of total-body potassium is intracellular, chiefly in muscle; buffering of extracellular K<sup>+</sup> by this large intracellular pool plays a crucial role in the regulation of plasma K<sup>+</sup> concentration. Changes in the exchange and distribution of intra- and extracellular K<sup>+</sup> can thus lead to marked hypo- or hyperkalemia. A corollary is that massive necrosis and the attendant release of tissue K<sup>+</sup> can cause severe hyperkalemia, particularly in the setting of acute kidney injury and reduced excretion of K<sup>+</sup>.

Changes in whole-body K<sup>+</sup> content are primarily mediated by the kidney, which *reabsorbs* filtered K<sup>+</sup> in hypokalemic, K<sup>+</sup>-deficient states and *secretes* K<sup>+</sup> in hyperkalemic, K<sup>+</sup>-replete states. Although K<sup>+</sup> is transported along the entire nephron, it is the principal cells of the connecting segment (CNT) and cortical CD that play a dominant role in renal K<sup>+</sup> secretion, whereas alpha-intercalated cells of the outer medullary CD function in renal tubular reabsorption of filtered K<sup>+</sup> in K<sup>+</sup>-deficient states. In principal cells, apical Na<sup>+</sup> entry via the amiloride-sensitive ENaC generates a lumen-negative potential difference, which drives passive K<sup>+</sup> exit through apical K<sup>+</sup> channels (Fig. 53-4). Two major K<sup>+</sup> channels mediate distal tubular K<sup>+</sup> secretion: the secretory K<sup>+</sup> channel ROMK (renal outer medullary K<sup>+</sup> channel; also known as Kir1.1 or KcnJ1) and the flow-sensitive “big potassium” (BK) or maxi-K

$K^+$  channel. ROMK is thought to mediate the bulk of constitutive  $K^+$  secretion, whereas increases in distal flow rate and/or genetic absence of ROMK activate  $K^+$  secretion via the BK channel.

An appreciation of the relationship between ENaC-dependent  $Na^+$  entry and distal  $K^+$  secretion (Fig. 53-4) is required for the bedside interpretation of potassium disorders. For example, decreased distal delivery of  $Na^+$ , as occurs in hypovolemic, prerenal states, tends to blunt the ability to excrete  $K^+$ , leading to hyperkalemia; on the other hand, an increase in distal delivery of  $Na^+$  and distal flow rate, as occurs after treatment with thiazide and loop diuretics, can enhance  $K^+$  secretion and lead to hypokalemia. Hyperkalemia is also a predictable consequence of drugs that directly inhibit ENaC, due to the role of this  $Na^+$  channel in generating a lumen-negative potential difference. Aldosterone one in turn has a major influence on potassium excretion, increasing the activity of ENaC channels and thus amplifying the driving force for  $K^+$  secretion across the luminal membrane of principal cells. Abnormalities in the renin-angiotensin-aldosterone system can thus cause both hypokalemia and hyperkalemia. Notably, however, potassium excess and potassium restriction have opposing, aldosterone-independent effects on the density and activity of apical  $K^+$  channels in the distal nephron, i.e., factors other than aldosterone modulate the renal capacity to secrete  $K^+$ . In addition, potassium restriction and hypokalemia activate aldosterone-independent distal *reabsorption* of filtered  $K^+$ , activating apical  $H^+/K^+$ -ATPase activity in intercalated cells within the outer medullary CD. Reflective perhaps of this physiology, changes in plasma  $K^+$  concentration are not universal in disorders associated with changes in aldosterone activity.

## HYPOKALEMIA

Hypokalemia, defined as a plasma  $K^+$  concentration of  $<3.5\text{ mM}$ , occurs in up to 20% of hospitalized patients. Hypokalemia is associated with a tenfold increase in in-hospital mortality, due to adverse effects on cardiac rhythm, blood pressure, and cardiovascular morbidity. Mechanistically, hypokalemia can be caused by redistribution of  $K^+$  between tissues and the ECF or by renal and nonrenal loss of  $K^+$  (Table 53-4). Systemic hypomagnesemia can also cause treatment-resistant hypokalemia, due to a combination of reduced cellular uptake of  $K^+$  and exaggerated renal secretion. Spurious hypokalemia or “pseudohypokalemia” can occasionally result from in vitro cellular uptake of  $K^+$  after venipuncture, for example, due to profound leukocytosis in acute leukemia.

**Redistribution and Hypokalemia** Insulin,  $\beta_2$ -adrenergic activity, thyroid hormone, and alkalosis promote  $Na^+/K^+$ -ATPase-mediated cellular uptake of  $K^+$ , leading to hypokalemia. Inhibition of the passive efflux of  $K^+$  can also cause hypokalemia, albeit rarely; this typically occurs in the setting of systemic inhibition of  $K^+$  channels by toxic barium ions. Exogenous insulin can cause iatrogenic hypokalemia, particularly during the management of  $K^+$ -deficient states such as diabetic ketoacidosis. Alternatively, the stimulation of endogenous insulin can provoke hypokalemia, hypomagnesemia, and/or hypophosphatemia in malnourished patients given a carbohydrate load. Alterations in the activity of the endogenous sympathetic nervous system can cause hypokalemia in several settings, including alcohol withdrawal, hyperthyroidism, acute myocardial infarction, and severe head injury.  $\beta_2$  agonists, including both bronchodilators and tocolytics (ritodrine), are powerful activators of cellular  $K^+$  uptake; “hidden” sympathomimetics, such as pseudoephedrine and ephedrine in cough syrup or dieting agents, may also cause unexpected hypokalemia. Finally, xanthine-dependent activation of cAMP-dependent signaling, downstream of the  $\beta_2$  receptor, can lead to hypokalemia, usually in the setting of overdose (theophylline) or marked overingestion (dietary caffeine).

Redistributive hypokalemia can also occur in the setting of hyperthyroidism, with periodic attacks of hypokalemic paralysis (thyrotoxic periodic paralysis [TPP]). Similar episodes of hypokalemic weakness in the absence of thyroid abnormalities occur in familial hypokalemic periodic paralysis, usually caused by missense mutations of voltage sensor domains within the  $\alpha$  subunit of L-type calcium channels or the skeletal  $Na^+$  channel; these mutations generate an abnormal gating pore

TABLE 53-4 Causes of Hypokalemia

- I. Decreased intake
  - A. Starvation
  - B. Clay ingestion
- II. Redistribution into cells
  - A. Acid-base
    - 1. Metabolic alkalosis
  - B. Hormonal
    - 1. Insulin
    - 2. Increased  $\beta_2$ -adrenergic sympathetic activity: post-myocardial infarction, head injury
    - 3.  $\beta_2$ -Adrenergic agonists—bronchodilators, tocolytics
    - 4.  $\alpha$ -Adrenergic antagonists
    - 5. Thyrotoxic periodic paralysis
    - 6. Downstream stimulation of  $Na^+/K^+$ -ATPase: theophylline, caffeine
- C. Anabolic state
  - 1. Vitamin  $B_{12}$  or folic acid administration (red blood cell production)
  - 2. Granulocyte-macrophage colony-stimulating factor (white blood cell production)
  - 3. Total parenteral nutrition
- D. Other
  - 1. Pseudohypokalemia
  - 2. Hypothermia
  - 3. Familial hypokalemic periodic paralysis
  - 4. Barium toxicity: systemic inhibition of “leak”  $K^+$  channels
- III. Increased loss
  - A. Nonrenal
    - 1. Gastrointestinal loss (diarrhea)
    - 2. Integumentary loss (sweat)
  - B. Renal
    - 1. Increased distal flow and distal  $Na^+$  delivery: diuretics, osmotic diuresis, salt-wasting nephropathies
    - 2. Increased secretion of potassium
      - a. Mineralocorticoid excess: primary hyperaldosteronism ( $Na^+$ -producing adenomas, primary or unilateral adrenal hyperplasia, idiopathic hyperaldosteronism due to bilateral adrenal hyperplasia, and adrenal carcinoma), genetic hyperaldosteronism (familial hyperaldosteronism types I/II/III, congenital adrenal hyperplasia), secondary hyperaldosteronism (malignant hypertension, renin-secreting tumors, renal artery stenosis, hypovolemia), Cushing's syndrome, Bartter's syndrome, Gitelman's syndrome
      - b. Apparent mineralocorticoid excess: genetic deficiency of 11 $\beta$ -dehydrogenase-2 (syndrome of apparent mineralocorticoid excess), inhibition of 11 $\beta$ -dehydrogenase-2 (glycyrrhetic acid and/or carbonoxolone; itraconazole and posaconazole; licorice, food products, drugs), Liddle's syndrome (genetic activation of epithelial  $Na^+$  channels)
      - c. Distal delivery of nonreabsorbed anions: vomiting, nasogastric suction, proximal renal tubular acidosis, diabetic ketoacidosis, glue-sniffing (toluene abuse), penicillin derivatives (penicillin, nafcillin, dicloxacillin, ticarcillin, oxacillin, and carbenicillin)
    - 3. Magnesium deficiency

current activated by hyperpolarization. TPP develops more frequently in patients of Asian or Hispanic origin; this shared predisposition has been linked to genetic variation in Kir2.6, a muscle-specific, thyroid hormone-responsive  $K^+$  channel. Genome-wide association studies have also implicated variation in the *KCNJ2* gene, which encodes a related muscle  $K^+$  channel, Kir 2.1, in predisposition to TPP. Patients with TPP typically present with weakness of the extremities and limb girdles, with paralytic episodes that occur most frequently between 1 and 6 . . Signs and symptoms of hyperthyroidism are not invariably present. Hypokalemia is usually profound and almost invariably accompanied by hypophosphatemia and hypomagnesemia. The hypokalemia in TPP is also attributed to both direct and indirect activation of the  $Na^+/K^+$ -ATPase, resulting in increased uptake of  $K^+$  by muscle

and other tissues. Increases in  $\beta$ -adrenergic activity play an important role in that high-dose propranolol (3 mg/kg) rapidly reverses the associated hypokalemia, hypophosphatemia, and paralysis. Outward-directed inward-rectifying K<sup>+</sup> current, mediated by KIR channels (primarily Kir2.1 and Kir2.2 tetramers), is also reduced in skeletal muscles of patients with TPP, providing an additional mechanism for hypokalemia. Together with increased Na<sup>+</sup>/K<sup>+</sup>-ATPase activity and increased circulating insulin, this reduced KIR current may trigger a “feedforward” cycle of hypokalemia leading to inactivation of muscle Na<sup>+</sup> channels, paradoxical depolarization, and paralysis.

**Nonrenal Loss of Potassium** The loss of K<sup>+</sup> in sweat is typically low, except under extremes of physical exertion. Direct gastric losses of K<sup>+</sup> due to vomiting or nasogastric suctioning are also minimal; however, the ensuing hypochloremic alkalosis results in persistent kaliuresis due to secondary hyperaldosteronism and bicarbonaturia, i.e., a *renal* loss of K<sup>+</sup>. Diarrhea is a globally important cause of hypokalemia, given the worldwide prevalence of infectious diarrheal disease. Noninfectious gastrointestinal processes such as celiac disease, ileostomy, villous adenomas, inflammatory bowel disease, colonic pseudo-obstruction (Ogilvie’s syndrome), VIPomas, and chronic laxative abuse can also cause significant hypokalemia; an exaggerated intestinal secretion of potassium by upregulated colonic BK channels has been directly implicated in the pathogenesis of hypokalemia in many of these disorders.

**Renal Loss of Potassium** Drugs can increase renal K<sup>+</sup> excretion by a variety of different mechanisms. Diuretics are a particularly common cause, due to associated increases in distal tubular Na<sup>+</sup> delivery and distal tubular flow rate, in addition to secondary hyperaldosteronism. Thiazides have a greater effect on plasma K<sup>+</sup> concentration than loop diuretics, despite their lesser natriuretic effect. The diuretic effect of thiazides is largely due to inhibition of the Na<sup>+</sup>-Cl<sup>-</sup> cotransporter NCC in DCT cells. This leads to a direct increase in the delivery of luminal Na<sup>+</sup> to the principal cells immediately downstream in the CNT and cortical CD, which augments Na<sup>+</sup> entry via ENaC, increases the lumen-negative potential difference, and amplifies K<sup>+</sup> secretion. The higher propensity of thiazides to cause hypokalemia may also be secondary to thiazide-associated hypocalcuria, versus the *hypercalcuria* seen with loop diuretics; the increases in downstream luminal calcium in response to loop diuretics inhibit ENaC in principal cells, thus reducing the lumen-negative potential difference and attenuating distal K<sup>+</sup> excretion. High doses of penicillin-related antibiotics (nafcillin, dicloxacillin, ticarcillin, oxacillin, and carbenicillin) can increase obligatory K<sup>+</sup> excretion by acting as nonreabsorbable anions in the distal nephron. Finally, several renal tubular toxins cause renal K<sup>+</sup> and magnesium wasting, leading to hypokalemia and hypomagnesemia; these drugs include aminoglycosides, amphotericin, foscarnet, cisplatin, and ifosfamide (see also “Magnesium Deficiency and Hypokalemia,” below).

Aldosterone activates the ENaC channel in principal cells via multiple synergistic mechanisms, thus increasing the driving force for K<sup>+</sup> excretion. In consequence, increases in aldosterone bioactivity and/or gains in function of aldosterone-dependent signaling pathways are associated with hypokalemia. Increases in circulating aldosterone (hyperaldosteronism) may be primary or secondary. Increased levels of circulating renin in secondary forms of hyperaldosteronism lead to increased angiotensin II and thus aldosterone; renal artery stenosis is perhaps the most frequent cause (Table 53-4). Primary hyperaldosteronism may be genetic or acquired. Hypertension and hypokalemia, due to increases in circulating 11-deoxycorticosterone, occur in patients with congenital adrenal hyperplasia caused by defects in either steroid 11 $\beta$ -hydroxylase or steroid 17 $\alpha$ -hydroxylase; deficient 11 $\beta$ -hydroxylase results in associated virilization and other signs of androgen excess, whereas reduced sex steroids in 17 $\alpha$ -hydroxylase deficiency lead to hypogonadism.

The major forms of *isolated* primary genetic hyperaldosteronism are familial hyperaldosteronism type I (FH-I, also known as glucocorticoid-remediable hyperaldosteronism [GRA]) and familial hyperaldosteronism types II and III (FH-II and FH-III), in which aldosterone production is not repressible by exogenous glucocorticoids.

FH-I is caused by a chimeric gene duplication between the homologous 11 $\beta$ -hydroxylase (*CYP11B1*) and aldosterone synthase (*CYP11B2*) genes, fusing the adrenocorticotrophic hormone (ACTH)-responsive 11 $\beta$ -hydroxylase promoter to the coding region of aldosterone synthase; this chimeric gene is under the control of ACTH and thus repressible by glucocorticoids. FH-III is caused by mutations in the *KCNJ5* gene, which encodes the G protein-activated inward rectifier K<sup>+</sup> channel 4 (GIRK4); these mutations lead to the acquisition of sodium permeability in the mutant GIRK4 channels, causing an exaggerated membrane depolarization in adrenal glomerulosa cells and the activation of voltage-gated calcium channels. The resulting calcium influx is sufficient to produce aldosterone secretion and cell proliferation, leading to adrenal adenomas and hyperaldosteronism.

Acquired causes of primary hyperaldosteronism include aldosterone-producing adenomas (APAs), primary or unilateral adrenal hyperplasia (PAH), idiopathic hyperaldosteronism (IHA) due to bilateral adrenal hyperplasia, and adrenal carcinoma; APA and IHA account for close to 60% and 40%, respectively, of diagnosed hyperaldosteronism. Acquired somatic mutations in *KCNJ5* or less frequently in the *ATPIA1* (an Na<sup>+</sup>/K<sup>+</sup> ATPase  $\alpha$  subunit) and *ATP2B3* (a Ca<sup>2+</sup> ATPase) genes can be detected in APAs; as in FH-III (see above), the exaggerated depolarization of adrenal glomerulosa cells caused by these mutations is implicated in the excessive adrenal proliferation and the exaggerated release of aldosterone.

Random testing of plasma renin activity (PRA) and aldosterone is a helpful screening tool in hypokalemic and/or hypertensive patients, with an aldosterone:PRA ratio of >50 suggestive of primary hyperaldosteronism. Hypokalemia and multiple antihypertensive drugs may alter the aldosterone:PRA ratio by suppressing aldosterone or increasing PRA, leading to a ratio of <50 in patients who do in fact have primary hyperaldosteronism; therefore, the clinical context should always be considered when interpreting these results.

The glucocorticoid cortisol has equal affinity for the MR to that of aldosterone, with resultant “mineralocorticoid-like” activity. However, cells in the aldosterone-sensitive distal nephron are protected from this “illicit” activation by the enzyme 11 $\beta$ -hydroxysteroid dehydrogenase-2 (11 $\beta$ HSD-2), which converts cortisol to cortisone; cortisone has minimal affinity for the MR. Recessive loss-of-function mutations in the *11 $\beta$ HSD-2* gene are thus associated with cortisol-dependent activation of the MR and the syndrome of apparent mineralocorticoid excess (SAME), encompassing hypertension, hypokalemia, hypercalcioria, and metabolic alkalosis, with suppressed PRA and suppressed aldosterone. A similar syndrome is caused by biochemical inhibition of 11 $\beta$ HSD-2 by glycyrrhetic/glycyrrhizinic acid and/or carbenoxolone. Glycyrrhizinic acid is a natural sweetener found in licorice root, typically encountered in licorice and its many guises or as a flavoring agent in tobacco and food products. More recently, the antifungals itraconazole and posaconazole have been shown to inhibit 11 $\beta$ HSD-2, leading to hypertension and hypokalemia.

Finally, hypokalemia may also occur with systemic increases in glucocorticoids. In Cushing’s syndrome caused by increases in pituitary ACTH (Chap. 386), the incidence of hypokalemia is only 10%, whereas it is 60–100% in patients with ectopic secretion of ACTH, despite a similar incidence of hypertension. Indirect evidence suggests that the activity of renal 11 $\beta$ HSD-2 is reduced in patients with ectopic ACTH compared with Cushing’s syndrome, resulting in SAME.

Finally, defects in multiple renal tubular transport pathways are associated with hypokalemia. For example, loss-of-function mutations in subunits of the acidifying H<sup>+</sup>-ATPase in alpha-intercalated cells cause hypokalemic distal renal tubular acidosis, as do many acquired disorders of the distal nephron. Liddle’s syndrome is caused by autosomal dominant gain-in-function mutations of ENaC subunits. Disease-associated mutations either activate the channel directly or abrogate aldosterone-inhibited retrieval of ENaC subunits from the plasma membrane; the end result is increased expression of activated ENaC channels at the plasma membrane of principal cells. Patients with Liddle’s syndrome classically manifest severe hypertension with hypokalemia, unresponsive to spironolactone yet sensitive to amiloride. Hypertension and hypokalemia are, however, variable aspects

of the Liddle's phenotype; more consistent features include a blunted aldosterone response to ACTH and reduced urinary aldosterone excretion.

Loss of the transport functions of the TALH and DCT nephron segments causes hereditary hypokalemic alkalosis and Bartter's syndrome (BS) and Gitelman's syndrome (GS), respectively. Patients with classic BS typically suffer from polyuria and polydipsia, due to the reduction in renal concentrating ability. They may have an increase in urinary calcium excretion, and 20% are hypomagnesemic. Other features include marked activation of the renin-angiotensin-aldosterone axis. Patients with antenatal BS suffer from a severe systemic disorder characterized by marked electrolyte wasting, polyhydramnios, and hypercalciuria with nephrocalcinosis; renal prostaglandin synthesis and excretion are significantly increased, accounting for much of the systemic symptoms. There are five disease genes for BS, all of them functioning in some aspect of regulated  $\text{Na}^+$ ,  $\text{K}^+$ , and  $\text{Cl}^-$  transport by the TALH. In contrast, GS is genetically homogeneous, caused almost exclusively by loss-of-function mutations in the thiazide-sensitive  $\text{Na}^+/\text{Cl}^-$  cotransporter of the DCT. Patients with GS are uniformly hypomagnesemic and exhibit marked hypocalciuria, rather than the hypercalciuria typically seen in BS; urinary calcium excretion is thus a critical diagnostic test in GS. GS is a milder phenotype than BS; however, patients with GS may suffer from chondrocalcinosis, an abnormal deposition of calcium pyrophosphate dihydrate (CPPD) in joint cartilage (Chap. 315).

**Magnesium Deficiency and Hypokalemia** Magnesium depletion has inhibitory effects on muscle  $\text{Na}^+/\text{K}^+$ -ATPase activity, reducing influx into muscle cells and causing a secondary kaliuresis. In addition, magnesium depletion causes exaggerated  $\text{K}^+$  secretion by the distal nephron; this effect is attributed to a reduction in the magnesium-dependent, intracellular block of  $\text{K}^+$  efflux through the secretory  $\text{K}^+$  channel of principal cells (ROMK; Fig. 53-4). In consequence, hypomagnesemic patients are clinically refractory to  $\text{K}^+$  replacement in the absence of  $\text{Mg}^{2+}$  repletion. Notably, magnesium deficiency is also a common concomitant of hypokalemia because many disorders of the distal nephron may cause both potassium and magnesium wasting (Chap. 315).

**Clinical Features** Hypokalemia has prominent effects on cardiac, skeletal, and intestinal muscle cells. In particular, hypokalemia is a major risk factor for both ventricular and atrial arrhythmias. Hypokalemia predisposes to digoxin toxicity by a number of mechanisms, including reduced competition between  $\text{K}^+$  and digoxin for shared binding sites on cardiac  $\text{Na}^+/\text{K}^+$ -ATPase subunits. Electrocardiographic changes in hypokalemia include broad flat T waves, ST depression, and QT prolongation; these are most marked when serum  $\text{K}^+$  is  $<2.7 \text{ mmol/L}$ . Hypokalemia can thus be an important precipitant of arrhythmia in patients with additional genetic or acquired causes of QT prolongation. Hypokalemia also results in hyperpolarization of skeletal muscle, thus impairing the capacity to depolarize and contract; weakness and even paralysis may ensue. It also causes a skeletal myopathy and predisposes to rhabdomyolysis. Finally, the paralytic effects of hypokalemia on intestinal smooth muscle may cause intestinal ileus.

The functional effects of hypokalemia on the kidney can include  $\text{Na}^+/\text{Cl}^-$  and  $\text{HCO}_3^-$  retention, polyuria, phosphaturia, hypocitraturia, and an activation of renal ammoniogenesis. Bicarbonate retention and other acid-base effects of hypokalemia can contribute to the generation of metabolic alkalosis. Hypokalemic polyuria is due to a combination of central polydipsia and an AVP-resistant renal concentrating defect. Structural changes in the kidney due to hypokalemia include a relatively specific vacuolizing injury to proximal tubular cells, interstitial nephritis, and renal cysts. Hypokalemia also predisposes to acute kidney injury and can lead to end-stage renal disease (ESRD) in patients with long-standing hypokalemia due to eating disorders and/or laxative abuse.

Hypokalemia and/or reduced dietary  $\text{K}^+$  are implicated in the pathophysiology and progression of hypertension, heart failure, vascular disease, and stroke. For example, short-term  $\text{K}^+$  restriction in healthy humans and patients with essential hypertension induces  $\text{Na}^+/\text{Cl}^-$  retention and hypertension. Correction of hypokalemia is particularly

important in hypertensive patients treated with diuretics, in whom blood pressure improves with potassium supplementation and the establishment of normokalemia.

**Diagnostic Approach** The cause of hypokalemia is usually evident from history, physical examination, and/or basic laboratory tests. The history should focus on medications (e.g., laxatives, diuretics, antibiotics), diet and dietary habits (e.g., licorice), and/or symptoms that suggest a particular cause (e.g., periodic weakness, diarrhea). The physical examination should pay particular attention to blood pressure, volume status, and signs suggestive of specific hypokalemic disorders, e.g., hyperthyroidism and Cushing's syndrome. Initial laboratory evaluation should include electrolytes, BUN, creatinine, serum osmolality,  $\text{Mg}^{2+}$ ,  $\text{Ca}^{2+}$ , a complete blood count, and urinary pH, osmolality, creatinine, and electrolytes (Fig. 53-7). The presence of a non-anion gap acidosis suggests a distal, hypokalemic renal tubular acidosis or diarrhea; calculation of the urinary anion gap can help differentiate these two diagnoses. Renal  $\text{K}^+$  excretion can be assessed with a 24-h urine collection; a 24-h  $\text{K}^+$  excretion of  $<15 \text{ mmol}$  is indicative of an extrarenal cause of hypokalemia (Fig. 53-7). If only a random, spot urine sample is available, serum and urine osmolality can be used to calculate the transtubular  $\text{K}^+$  gradient (TTKG), which should be  $<3$  in the presence of hypokalemia (see also "Hyperkalemia"). Alternatively, a urinary  $\text{K}^+$ -to-creatinine ratio of  $>13 \text{ mmol/g}$  creatinine ( $>1.5 \text{ mmol/mmol}$  creatinine) is compatible with excessive renal  $\text{K}^+$  excretion. Urine  $\text{Cl}^-$  is usually decreased in patients with hypokalemia from a nonreabsorbable anion, such as antibiotics or  $\text{HCO}_3^-$ . The most common causes of chronic hypokalemic alkalosis are surreptitious vomiting, diuretic abuse, and GS; these can be distinguished by the pattern of urinary electrolytes. Hypokalemic patients with vomiting due to bulimia will thus typically have a urinary  $\text{Cl}^- < 10 \text{ mmol/L}$ ; urine  $\text{Na}^+$ ,  $\text{K}^+$ , and  $\text{Cl}^-$  are persistently elevated in GS, due to loss of function in the thiazide-sensitive  $\text{Na}^+/\text{Cl}^-$  cotransporter, but less elevated in diuretic abuse and with greater variability. Urine diuretic screens for loop diuretics and thiazides may be necessary to further exclude diuretic abuse.

Other tests, such as urinary  $\text{Ca}^{2+}$ , thyroid function tests, and/or PRA and aldosterone levels, may also be appropriate in specific cases. A plasma aldosterone:PRA ratio of  $>50$ , due to suppression of circulating renin and an elevation of circulating aldosterone, is suggestive of hyperaldosteronism. Patients with hyperaldosteronism or apparent mineralocorticoid excess may require further testing, for example, adrenal vein sampling (Chap. 386) or the clinically available testing for specific genetic causes (e.g., FH-I, SAME, Liddle's syndrome). Patients with primary aldosteronism should thus be tested for the chimeric FH-I/GRA gene (see above) if they are younger than 20 years of age or have a family history of primary aldosteronism or stroke at a young age ( $<40$  years). Preliminary differentiation of Liddle's syndrome due to mutant ENaC channels from SAME due to mutant  $11\beta\text{HSD}-2$  (see above), both of which cause hypokalemia and hypertension with aldosterone suppression, can be made on a clinical basis and then confirmed by genetic analysis; patients with Liddle's syndrome should respond to amiloride (ENaC inhibition) but not spironolactone, whereas patients with SAME will respond to spironolactone.

## TREATMENT

### Hypokalemia

The goals of therapy in hypokalemia are to prevent life-threatening and/or serious chronic consequences, to replace the associated  $\text{K}^+$  deficit, and to correct the underlying cause and/or mitigate future hypokalemia. The urgency of therapy depends on the severity of hypokalemia, associated clinical factors (e.g., cardiac disease, digoxin therapy), and the rate of decline in serum  $\text{K}^+$ . Patients with a prolonged QT interval and/or other risk factors for arrhythmia should be monitored by continuous cardiac telemetry during repletion. Urgent but cautious  $\text{K}^+$  replacement should be considered in patients with severe redistributive hypokalemia (plasma  $\text{K}^+$  concentration  $<2.5 \text{ mM}$ ) and/or when serious complications ensue; however, this approach has a risk of rebound hyperkalemia following

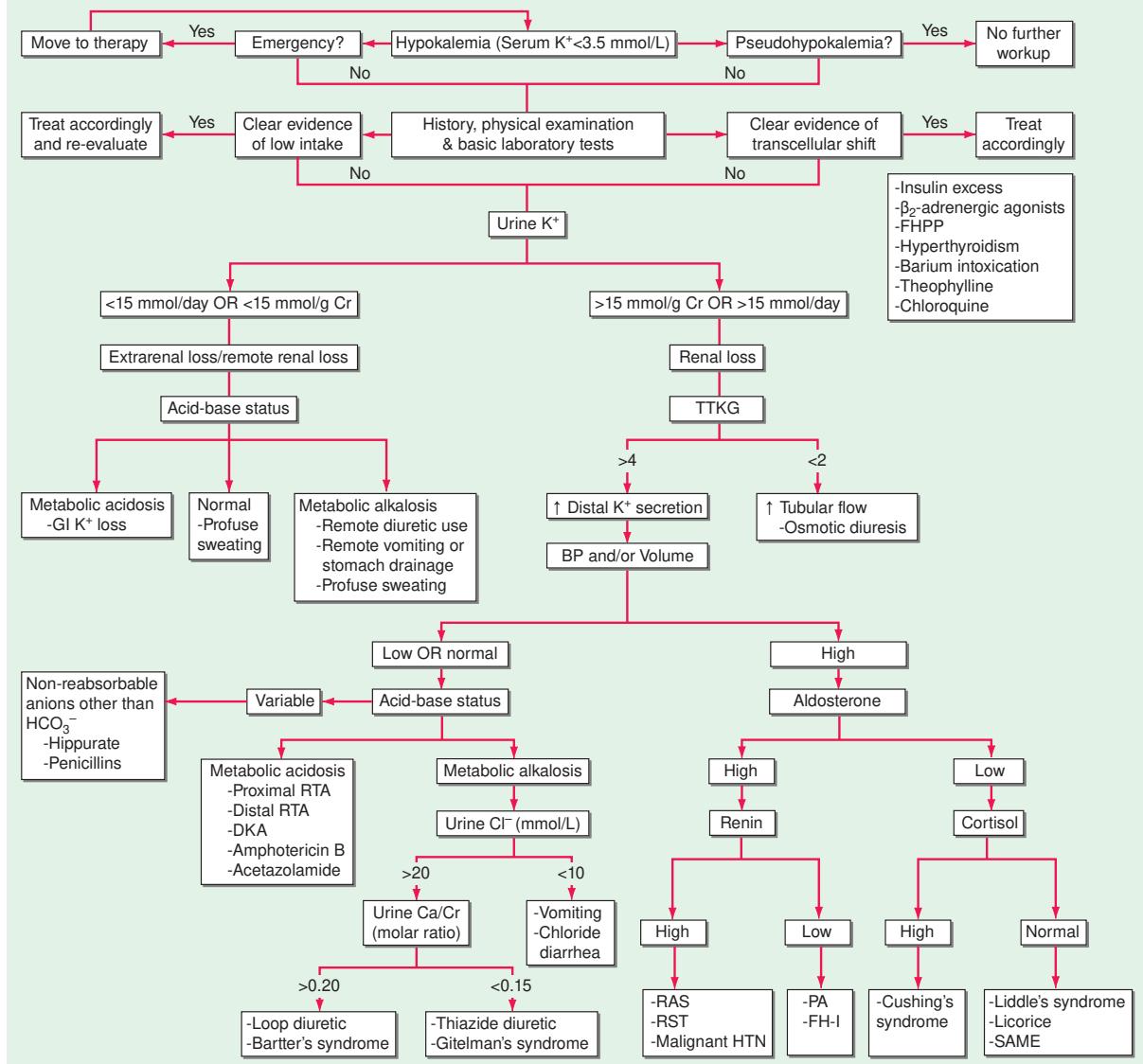


FIGURE 53-7 The diagnostic approach to hypokalemia. See text for details. AME, apparent mineralocorticoid excess; BP, blood pressure; CCD, cortical collecting duct; DKA, diabetic ketoacidosis; FH-I, familial hyperaldosteronism type I; FHPP, familial hypokalemic periodic paralysis; GI, gastrointestinal; GRA, glucocorticoid remediable aldosteronism; HTN, hypertension; PA, primary aldosteronism; RAS, renal artery stenosis; RST, renin-secreting tumor; RTA, renal tubular acidosis; SAME, syndrome of apparent mineralocorticoid excess; TTKG, transtubular potassium gradient. (Reproduced with permission from DB Mount, K Zandi-Nejad: Disorders of potassium balance, in BM Brenner [ed], *Brenner and Rector's The Kidney*, 8th ed, Philadelphia, W.B. Saunders & Company, 2008.)

acute resolution of the underlying cause. When excessive activity of the sympathetic nervous system is thought to play a dominant role in redistributive hypokalemia, as in TPP, theophylline overdose, and acute head injury, high-dose propranolol (3 mg/kg) should be considered; this nonspecific β-adrenergic blocker will correct hypokalemia without the risk of rebound hyperkalemia.

Oral replacement with K<sup>+</sup>-Cl<sup>-</sup> is the mainstay of therapy in hypokalemia. Potassium phosphate, oral or IV, may be appropriate in patients with combined hypokalemia and hypophosphatemia. Potassium bicarbonate or potassium citrate should be considered in patients with concomitant metabolic acidosis. Notably, hypomagnesemic patients are refractory to K<sup>+</sup> replacement alone, such that concomitant Mg<sup>2+</sup> deficiency should always be corrected with oral or intravenous repletion. The deficit of K<sup>+</sup> and the rate of correction should be estimated as accurately as possible; renal function, medications, and comorbid conditions such as diabetes should

also be considered, so as to gauge the risk of overcorrection. In the absence of abnormal K<sup>+</sup> redistribution, the total deficit correlates with serum K<sup>+</sup>, such that serum K<sup>+</sup> drops by ~0.27 mM for every 100-mmol reduction in total-body stores; loss of 400–800 mmol of total-body K<sup>+</sup> results in a reduction in serum K<sup>+</sup> by ~2.0 mM. Notably, given the delay in redistributing potassium into intracellular compartments, this deficit must be replaced gradually over 24–48 h, with frequent monitoring of plasma K<sup>+</sup> concentration to avoid transient overrepletion and transient hyperkalemia.

The use of intravenous administration should be limited to patients unable to use the enteral route or in the setting of severe complications (e.g., paralysis, arrhythmia). Intravenous K<sup>+</sup>-Cl<sup>-</sup> should always be administered in saline solutions, rather than dextrose, because the dextrose-induced increase in insulin can acutely exacerbate hypokalemia. The peripheral intravenous dose is usually 20–40 mmol of K<sup>+</sup>-Cl<sup>-</sup> per liter; higher concentrations

can cause localized pain from chemical phlebitis, irritation, and sclerosis. If hypokalemia is severe (<2.5 mmol/L) and/or critically symptomatic, intravenous K<sup>+</sup>-Cl<sup>-</sup> can be administered through a central vein with cardiac monitoring in an intensive care setting, at rates of 10–20 mmol/h; higher rates should be reserved for acutely life-threatening complications. The absolute amount of administered K<sup>+</sup> should be restricted (e.g., 20 mmol in 100 mL of saline solution) to prevent inadvertent infusion of a large dose.

Strategies to minimize K<sup>+</sup> losses should also be considered. These measures may include minimizing the dose of non-K<sup>+</sup>-sparing diuretics, restricting Na<sup>+</sup> intake, and using clinically appropriate combinations of non-K<sup>+</sup>-sparing and K<sup>+</sup>-sparing medications (e.g., loop diuretics with ACE inhibitors).

## HYPERKALEMIA

Hyperkalemia is defined as a plasma potassium level of 5.5 mM, occurring in up to 10% of hospitalized patients; severe hyperkalemia (>6.0 mM) occurs in ~1%, with a significantly increased risk of mortality. Although redistribution and reduced tissue uptake can acutely cause hyperkalemia, a decrease in renal K<sup>+</sup> excretion is the most frequent underlying cause (Table 53-5). Excessive intake of K<sup>+</sup> is a rare cause, given the adaptive capacity to increase renal secretion; however, dietary intake can have a major effect in susceptible patients, e.g., diabetics with hyporeninemic hypoaldosteronism and chronic kidney disease. Drugs that impact on the renin-angiotensin-aldosterone axis are also a major cause of hyperkalemia.

**Pseudohyperkalemia** Hyperkalemia should be distinguished from factitious hyperkalemia or “pseudohyperkalemia,” an artifactual increase in serum K<sup>+</sup> due to the release of K<sup>+</sup> during or after venipuncture. Pseudohyperkalemia can occur in the setting of excessive muscle activity during venipuncture (e.g., fist clenching), a marked increase in cellular elements (thrombocytosis, leukocytosis, and/or erythrocytosis) with in vitro efflux of K<sup>+</sup>, and acute anxiety during venipuncture with respiratory alkalosis and redistributive hyperkalemia. Cooling of blood following venipuncture is another cause, due to reduced cellular uptake; the converse is the increased uptake of K<sup>+</sup> by cells at high ambient temperatures, leading to normal values for hyperkalemic patients and/or to spurious hypokalemia in normokalemic patients. Finally, there are multiple genetic subtypes of hereditary pseudohyperkalemia, caused by increases in the passive K<sup>+</sup> permeability of erythrocytes. For example, causative mutations have been described in the red cell anion exchanger (AE1, encoded by the *SLC4A1* gene), leading to reduced red cell anion transport, hemolytic anemia, the acquisition of a novel AE1-mediated K<sup>+</sup> leak, and pseudohyperkalemia.

**Redistribution and Hyperkalemia** Several different mechanisms can induce an efflux of intracellular K<sup>+</sup> and hyperkalemia. Acidemia is associated with cellular uptake of H<sup>+</sup> and an associated efflux of K<sup>+</sup>; it is thought that this effective K<sup>+</sup>-H<sup>+</sup> exchange serves to help maintain extracellular pH. Notably, this effect of acidosis is limited to non-anion gap causes of metabolic acidosis and, to a lesser extent, respiratory causes of acidosis; hyperkalemia due to an acidosis-induced shift of potassium from the cells into the ECF does *not* occur in the anion gap acidoses lactic acidosis and ketoacidosis. Hyperkalemia due to hypertonic mannitol, hypertonic saline, and intravenous immune globulin is generally attributed to a “solvent drag” effect, as water moves out of cells along the osmotic gradient. Diabetics are also prone to osmotic hyperkalemia in response to intravenous hypertonic glucose, when given without adequate insulin. Cationic amino acids, specifically lysine, arginine, and the structurally related drug epsilon-aminocaproic acid, cause efflux of K<sup>+</sup> and hyperkalemia, through an effective cation-K<sup>+</sup> exchange of unknown identity and mechanism. Digoxin inhibits Na<sup>+</sup>/K<sup>+</sup>-ATPase and impairs the uptake of K<sup>+</sup> by skeletal muscle, such that digoxin overdose predictably results in hyperkalemia. Structurally related glycosides are found in specific plants (e.g., yellow oleander, foxglove) and in the cane toad, *Bufo marinus* (bufadienolide); ingestion of these substances and extracts thereof can also

TABLE 53-5 Causes of Hyperkalemia

- I. Pseudohyperkalemia
  - A. Cellular efflux; thrombocytosis, erythrocytosis, leukocytosis, in vitro hemolysis
  - B. Hereditary defects in red cell membrane transport
- II. Intra- to extracellular shift
  - A. Acidosis
  - B. Hyperosmolality; radiocontrast, hypertonic dextrose, mannitol
  - C.  $\beta_2$ -Adrenergic antagonists (noncardioselective agents)
  - D. Digoxin and related glycosides (yellow oleander, foxglove, bufadienolide)
  - E. Hyperkalemic periodic paralysis
  - F. Lysine, arginine, and epsilon-aminocaproic acid (structurally similar, positively charged)
  - G. Succinylcholine; thermal trauma, neuromuscular injury, disuse atrophy, mucositis, or prolonged immobilization
  - H. Rapid tumor lysis
- III. Inadequate excretion
  - A. Inhibition of the renin-angiotensin-aldosterone axis; ↑ risk of hyperkalemia when used in combination
    - 1. Angiotensin-converting enzyme (ACE) inhibitors
    - 2. Renin inhibitors; aliskiren (in combination with ACE inhibitors or angiotensin receptor blockers [ARBs])
    - 3. ARBs
    - 4. Blockade of the mineralocorticoid receptor: spironolactone, eplerenone, doxiprenone
    - 5. Blockade of the epithelial sodium channel (ENaC): amiloride, triamterene, trimethoprim, pentamidine, nafamostat
  - B. Decreased distal delivery
    - 1. Congestive heart failure
    - 2. Volume depletion
  - C. Hyporeninemic hypoaldosteronism
    - 1. Tubulointerstitial diseases: systemic lupus erythematosus (SLE), sickle cell anemia, obstructive uropathy
    - 2. Diabetes, diabetic nephropathy
    - 3. Drugs: nonsteroidal anti-inflammatory drugs (NSAIDs), cyclooxygenase 2 (COX2) inhibitors,  $\beta$  blockers, cyclosporine, tacrolimus
    - 4. Chronic kidney disease, advanced age
    - 5. Pseudohypoaldosteronism type II: defects in WNK1 or WNK4 kinases, Kelch-like 3 (KLHL3), or Cullin 3 (CUL3)
  - D. Renal resistance to mineralocorticoid
    - 1. Tubulointerstitial diseases: SLE, amyloidosis, sickle cell anemia, obstructive uropathy, post-acute tubular necrosis
    - 2. Hereditary: pseudohypoaldosteronism type I; defects in the mineralocorticoid receptor or the epithelial sodium channel (ENaC)
  - E. Advanced renal insufficiency
    - 1. Chronic kidney disease
    - 2. End-stage renal disease
    - 3. Acute oliguric kidney injury
  - F. Primary adrenal insufficiency
    - 1. Autoimmune: Addison's disease, polyglandular endocrinopathy
    - 2. Infectious: HIV, cytomegalovirus, tuberculosis, disseminated fungal infection
    - 3. Infiltrative: amyloidosis, malignancy, metastatic cancer
    - 4. Drug-associated: heparin, low-molecular-weight heparin
    - 5. Hereditary: adrenal hypoplasia congenita, congenital lipoid adrenal hyperplasia, aldosterone synthase deficiency
    - 6. Adrenal hemorrhage or infarction, including in antiphospholipid syndrome

cause hyperkalemia. Finally, fluoride ions also inhibit Na<sup>+</sup>/K<sup>+</sup>-ATPase, such that fluoride poisoning is typically associated with hyperkalemia.

Succinylcholine depolarizes muscle cells, causing an efflux of K<sup>+</sup> through acetylcholine receptors (AChRs). The use of this agent is contraindicated in patients who have sustained thermal trauma, neuromuscular injury, disuse atrophy, mucositis, or prolonged immobilization.

These disorders share a marked increase and redistribution of AChRs at the plasma membrane of muscle cells; depolarization of these upregulated AChRs by succinylcholine leads to an exaggerated efflux of K<sup>+</sup> through the receptor-associated cation channels, resulting in acute hyperkalemia.

**Hyperkalemia Caused by Excess Intake or Tissue Necrosis** Increased intake of even small amounts of K<sup>+</sup> may provoke severe hyperkalemia in patients with predisposing factors; hence, an assessment of dietary intake is crucial. Foods rich in potassium include tomatoes, bananas, and citrus fruits; occult sources of K<sup>+</sup>, particularly K<sup>+</sup>-containing salt substitutes, may also contribute significantly. Iatrogenic causes include simple overreplacement with K<sup>+</sup>-Cl<sup>-</sup> or the administration of a potassium-containing medication (e.g., K<sup>+</sup>-penicillin) to a susceptible patient. Red cell transfusion is a well-described cause of hyperkalemia, typically in the setting of massive transfusions. Finally, severe tissue necrosis, as in acute tumor lysis syndrome and rhabdomyolysis, will predictably cause hyperkalemia from the release of intracellular K<sup>+</sup>.

**Hypoaldosteronism and Hyperkalemia** Aldosterone release from the adrenal gland may be reduced by hyporeninemic hypoaldosteronism, medications, primary hypoaldosteronism, or isolated deficiency of ACTH (secondary hypoaldosteronism). Primary hypoaldosteronism may be genetic or acquired (Chap. 386) but is commonly caused by autoimmunity, either in Addison's disease or in the context of a polyglandular endocrinopathy. HIV has surpassed tuberculosis as the most important infectious cause of adrenal insufficiency. The adrenal involvement in HIV disease is usually subclinical; however, adrenal insufficiency may be precipitated by stress, drugs such as ketoconazole that inhibit steroidogenesis, or the acute withdrawal of steroid agents such as megestrol. Among medications associated with hyperkalemia, heparin preparations can cause selective inhibition of aldosterone synthesis by zona glomerulosa cells, leading to hyporeninemic hypoaldosteronism.

Hyporeninemic hypoaldosteronism is a very common predisposing factor in several overlapping subsets of hyperkalemic patients: diabetics, the elderly, and patients with renal insufficiency. Classically, patients should have suppressed PRA and aldosterone; ~50% have an associated acidosis, with a reduced renal excretion of NH<sub>4</sub><sup>+</sup>, a positive urinary anion gap, and urine pH <5.5. Most patients are volume expanded, with secondary increases in circulating atrial natriuretic peptide (ANP) that inhibit both renal renin release and adrenal aldosterone release.

**Renal Disease and Hyperkalemia** Chronic kidney disease and end-stage kidney disease are very common causes of hyperkalemia, due to the associated deficit or absence of functioning nephrons. Hyperkalemia is more common in oliguric acute kidney injury; distal tubular flow rate and Na<sup>+</sup> delivery are less limiting factors in nonoliguric patients. Hyperkalemia out of proportion to GFR can also be seen in the context of tubulointerstitial disease that affects the distal nephron, such as amyloidosis, sickle cell anemia, interstitial nephritis, and obstructive uropathy.

Hereditary renal causes of hyperkalemia have overlapping clinical features with hypoaldosteronism, hence the diagnostic label *pseudo-hypoaldosteronism* (PHA). PHA type I (PHA-I) has both an autosomal recessive and an autosomal dominant form. The autosomal dominant form is due to loss-of-function mutations in the MLR; the recessive form is caused by various combinations of mutations in the three subunits of ENaC, resulting in impaired Na<sup>+</sup> channel activity in principal cells and other tissues. Patients with recessive PHA-I suffer from lifelong salt wasting, hypotension, and hyperkalemia, whereas the phenotype of autosomal dominant PHA-I due to MLR dysfunction improves in adulthood. PHA type II (PHA-II; also known as *hereditary hypertension with hyperkalemia*) is in every respect the mirror image of GS caused by loss of function in NCC, the thiazide-sensitive Na<sup>+</sup>-Cl<sup>-</sup> cotransporter (see above); the clinical phenotype includes hypertension, hyperkalemia, hyperchloremic metabolic acidosis, suppressed PRA and aldosterone, hypercalciuria, and reduced bone density.

PHA-II thus behaves like a gain of function in NCC, and treatment with thiazides results in resolution of the entire clinical phenotype. However, the NCC gene is not directly involved in PHA-II, which is caused by mutations in the WNK1 and WNK4 serine-threonine kinases or the upstream Kelch-like 3 (KLHL3) and Cullin 3 (CUL3) proteins, two components of an E3 ubiquitin ligase complex that regulates these kinases; these proteins collectively regulate NCC activity, with PHA-II-associated activation of the transporter.

**Medication-Associated Hyperkalemia** Most medications associated with hyperkalemia cause inhibition of some component of the renin-angiotensin-aldosterone axis. ACE inhibitors, angiotensin receptor blockers, renin inhibitors, and MRAs are predictable and common causes of hyperkalemia, particularly when prescribed in combination. The oral contraceptive agent Yasmin-28 contains the progestin drospirenone, which inhibits the MLR and can cause hyperkalemia in susceptible patients. Cyclosporine, tacrolimus, NSAIDs, and cyclooxygenase 2 (COX2) inhibitors cause hyperkalemia by multiple mechanisms, but share the ability to cause hyporeninemic hypoaldosteronism. Notably, most drugs that affect the renin-angiotensin-aldosterone axis also block the local adrenal response to hyperkalemia, thus attenuating the *direct* stimulation of aldosterone release by increased plasma K<sup>+</sup> concentration.

Inhibition of apical ENaC activity in the distal nephron by amiloride and other K<sup>+</sup>-sparing diuretics results in hyperkalemia, often with a voltage-dependent hyperchloremic acidosis and/or hypovolemic hyponatremia. Amiloride is structurally similar to the antibiotics TMP and pentamidine, which also block ENaC; risk factors for TMP-associated hyperkalemia include the administered dose, renal insufficiency, and hyporeninemic hypoaldosteronism. Indirect inhibition of ENaC at the plasma membrane is also a cause of drug-associated hyperkalemia; nafamostat, a protease inhibitor used in some countries for anticoagulation and for the management of pancreatitis, inhibits aldosterone-induced renal proteases that activate ENaC by proteolytic cleavage.

**Clinical Features** Hyperkalemia is a medical emergency due to its effects on the heart. Cardiac arrhythmias associated with hyperkalemia include sinus bradycardia, sinus arrest, slow idioventricular rhythms, ventricular tachycardia, ventricular fibrillation, and asystole. Mild increases in extracellular K<sup>+</sup> affect the repolarization phase of the cardiac action potential, resulting in changes in T-wave morphology; further increase in plasma K<sup>+</sup> concentration depresses intracardiac conduction, with progressive prolongation of the PR and QRS intervals. Severe hyperkalemia results in loss of the P wave and a progressive widening of the QRS complex; development of a sine-wave sinoventricular rhythm suggests impending ventricular fibrillation or asystole. Hyperkalemia can also cause a type I Brugada pattern in the electrocardiogram (ECG), with a pseudo-right bundle branch block and persistent coved ST-segment elevation in at least two precordial leads. This hyperkalemic Brugada's sign occurs in critically ill patients with severe hyperkalemia and can be differentiated from genetic Brugada's syndrome by an absence of P waves, marked QRS widening, and an abnormal QRS axis. Classically, the ECG manifestations in hyperkalemia progress from tall peaked T waves (5.5–6.5 mM), to a loss of P waves (6.5–7.5 mM), to a widened QRS complex (7.0–8.0 mM), and, ultimately, a to a sine wave pattern (>8.0 mM). However, these changes are notoriously insensitive, particularly in patients with chronic kidney disease or ESRD.

Hyperkalemia from a variety of causes can also present with ascending paralysis, denoted *secondary hyperkalemic paralysis* to differentiate it from familial hyperkalemic periodic paralysis (HYPP). The presentation may include diaphragmatic paralysis and respiratory failure. Patients with familial HYPP develop myopathic weakness during hyperkalemia induced by increased K<sup>+</sup> intake or rest after heavy exercise. Depolarization of skeletal muscle by hyperkalemia unmasks an inactivation defect in skeletal Na<sup>+</sup> channel; autosomal dominant mutations in the SCN4A gene encoding this channel are the predominant cause.

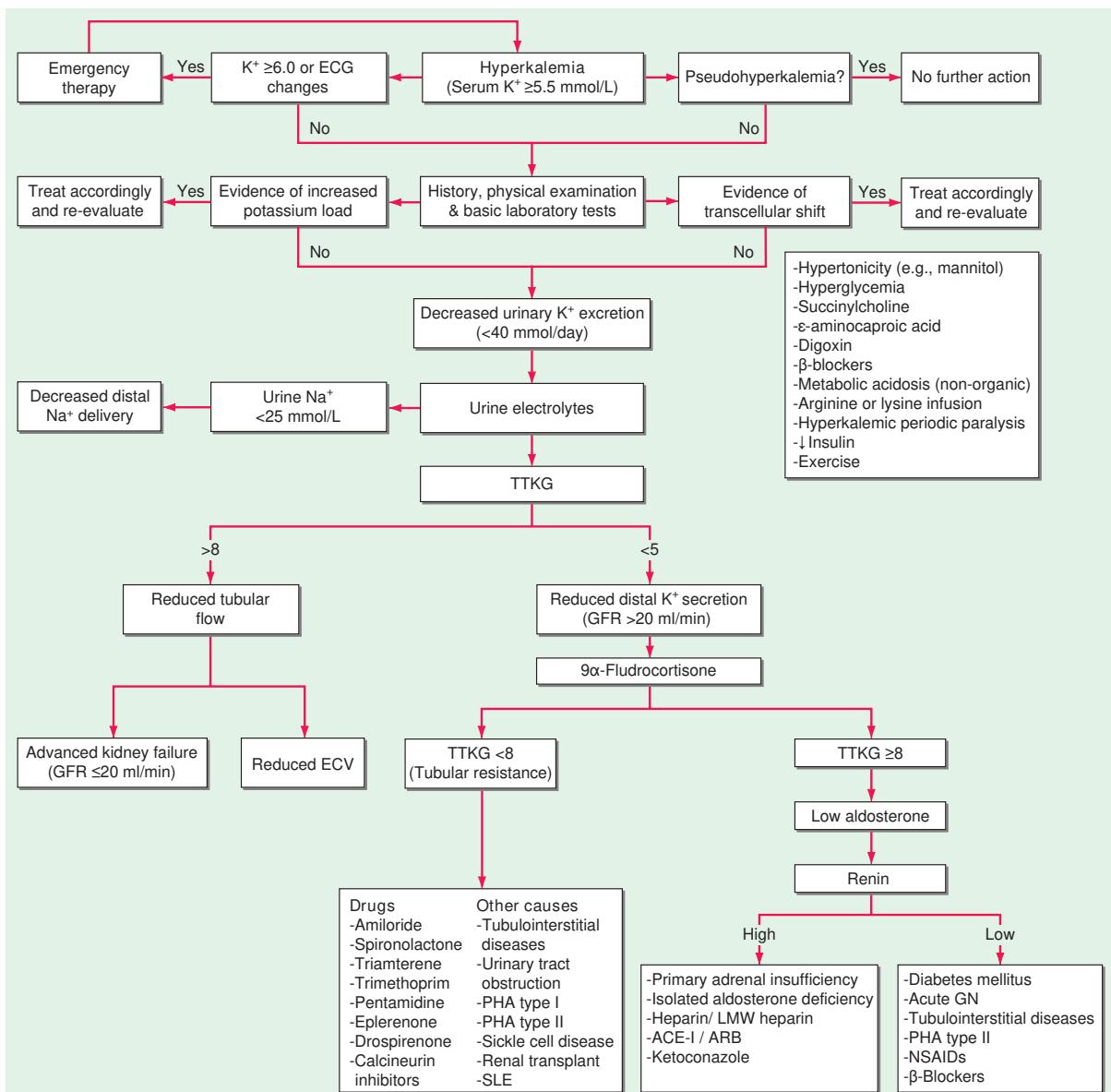
Within the kidney, hyperkalemia has negative effects on the ability to excrete an acid load, such that hyperkalemia per se can contribute to

metabolic acidosis. This defect appears to be due in part to competition between  $K^+$  and  $NH_4^+$  for reabsorption by the TALH and subsequent countercurrent multiplication, ultimately reducing the medullary gradient for  $NH_3/NH_4$  excretion by the distal nephron. Regardless of the underlying mechanism, restoration of normokalemia can, in many instances, correct hyperkalemic metabolic acidosis.

**Diagnostic Approach** The first priority in the management of hyperkalemia is to assess the need for emergency treatment, followed by a comprehensive workup to determine the cause (Fig. 53-8). History and physical examination should focus on medications, diet and dietary supplements, risk factors for kidney failure, reduction in urine output, blood pressure, and volume status. Initial laboratory tests should include electrolytes, BUN, creatinine, serum osmolality,  $Mg^{2+}$  and  $Ca^{2+}$ , a complete blood count, and urinary pH, osmolality, creatinine, and electrolytes. A urine  $Na^+$  concentration of  $<20$  mM indicates

that distal  $Na^+$  delivery is a limiting factor in  $K^+$  excretion; volume repletion with 0.9% saline or treatment with furosemide may be effective in reducing plasma  $K^+$  concentration. Serum and urine osmolality are required for calculation of the transtubular  $K^+$  gradient (TTKG) (Fig. 53-8). The expected values of the TTKG are largely based on historical data, and are  $<3$  in the presence of hypokalemia and  $>7-8$  in the presence of hyperkalemia. Notably, some authors have opined that the TTKG does not consider the effects of distal tubular urea reabsorption on potassium excretion, concluding that the TTKG is, thus, an unreliable test in the assessment of hyperkalemia. These criticisms are theoretical and not supported by animal experiments; the TTKG remains a helpful bedside test of urinary potassium excretion in hyperkalemia.

$$\text{TTKG} = \frac{[K^+]_{\text{urine}} \times \text{Osm}_{\text{serum}}}{[K^+]_{\text{serum}} \times \text{Osm}_{\text{urine}}}$$



**FIGURE 53-8** The diagnostic approach to hyperkalemia. See text for details. ACE-I, angiotensin-converting enzyme inhibitor; ARB, angiotensin II receptor blocker; CCD, cortical collecting duct; ECG, electrocardiogram; ECV, effective circulatory volume; GFR, glomerular filtration rate; GN, glomerulonephritis; HIV, human immunodeficiency virus; LMW heparin, low-molecular-weight heparin; NSAIDs, nonsteroidal anti-inflammatory drugs; PHA, pseudohypoaldosteronism; SLE, systemic lupus erythematosus; TTKG, transtubular potassium gradient. (Reproduced with permission from DB Mount, K Zandi-Nejad: Disorders of potassium balance, in BM Brenner and Rector's *The Kidney*, 8th ed, Philadelphia, W.B. Saunders & Company, 2008.)

## TREATMENT

### Hyperkalemia

ECG manifestations of hyperkalemia should be considered a medical emergency and treated urgently. However, patients with significant hyperkalemia (plasma K<sup>+</sup> concentration ≥ 6.5 mM) in the absence of ECG changes should also be aggressively managed, given the limitations of ECG changes as a predictor of cardiac toxicity. Urgent management of hyperkalemia includes admission to the hospital, continuous cardiac monitoring, and immediate treatment. The treatment of hyperkalemia is divided into three stages:

**1. Immediate antagonism of the cardiac effects of hyperkalemia.**

Intravenous calcium serves to protect the heart, whereas other measures are taken to correct hyperkalemia. Calcium raises the action potential threshold and reduces excitability, without changing the resting membrane potential. By restoring the difference between resting and threshold potentials, calcium reverses the depolarization blockade due to hyperkalemia. The recommended dose is 10 mL of 10% calcium gluconate (3–4 mL of calcium chloride), infused intravenously over 2–3 min with cardiac monitoring. The effect of the infusion starts in 1–3 min and lasts 30–60 min; the dose should be repeated if there is no change in ECG findings or if they recur after initial improvement. Hypercalcemia potentiates the cardiac toxicity of digoxin; hence, intravenous calcium should be used with extreme caution in patients taking this medication; if judged necessary, 10 mL of 10% calcium gluconate can be added to 100 mL of 5% dextrose in water and infused over 20–30 min to avoid acute hypercalcemia.

**2. Rapid reduction in plasma K<sup>+</sup> concentration by redistribution into cells.**

Insulin lowers plasma K<sup>+</sup> concentration by shifting K<sup>+</sup> into cells. The recommended dose is 10 units of intravenous regular insulin followed immediately by 50 mL of 50% dextrose (D<sub>50</sub>W, 25 g of glucose total); the effect begins in 10–20 min, peaks at 30–60 min, and lasts for 4–6 h. Bolus D<sub>50</sub>W without insulin is never appropriate, given the risk of acutely worsening hyperkalemia due to the osmotic effect of hypertonic glucose. Hypoglycemia is common with insulin plus glucose; hence, this should be followed by an infusion of 10% dextrose at 50–75 mL/h, with close monitoring of plasma glucose concentration. In hyperkalemic patients with glucose concentrations of ≥200–250 mg/dL, insulin should be administered *without* glucose, again with close monitoring of glucose concentrations.

β<sub>2</sub>-Agonists, most commonly albuterol, are effective but underused agents for the acute management of hyperkalemia. Albuterol and insulin with glucose have an additive effect on plasma K<sup>+</sup> concentration; however, ~20% of patients with ESRD are resistant to the effect of β<sub>2</sub>-agonists; hence, these drugs should not be used without insulin. The recommended dose for inhaled albuterol is 10–20 mg of nebulized albuterol in 4 mL of normal saline, inhaled over 10 min; the effect starts at about 30 min, reaches its peak at about 90 min, and lasts for 2–6 h. Hyperglycemia is a side effect, along with tachycardia. β<sub>2</sub>-Agonists should be used with caution in hyperkalemic patients with known cardiac disease.

Intravenous bicarbonate has no role in the acute treatment of hyperkalemia, but may slowly attenuate hyperkalemia with sustained administration over several hours. It should not be given repeatedly as a hypertonic intravenous bolus of undiluted ampules, given the risk of associated hypernatremia and hypertonicity, but should instead be infused in an isotonic or hypotonic fluid (e.g., 150 milliequivalents of sodium bicarbonate in 1 L of D<sub>5</sub>W). In patients with metabolic acidosis, a delayed drop in plasma K<sup>+</sup> concentration can be seen after 4–6 h of isotonic bicarbonate infusion.

**3. Removal of potassium.** This is typically accomplished using cation exchange resins, diuretics, and/or dialysis. The cation exchange resin sodium polystyrene sulfonate (SPS) exchanges Na<sup>+</sup> for K<sup>+</sup> in the gastrointestinal tract and increases the fecal excretion of

K<sup>+</sup>. The recommended dose of SPS is 15–30 g of powder, almost always given in a premade suspension with 33% sorbitol. The effect of SPS on plasma K<sup>+</sup> concentration is slow; the full effect may take up to 24 h and usually requires repeated doses every 4–6 h. Intestinal necrosis, typically of the colon or ileum, is a rare but usually fatal complication of SPS. Intestinal necrosis is more common in patients with reduced intestinal motility (e.g., in the postoperative state or after treatment with opioids). The coadministration of SPS with sorbitol appears to increase the risk of intestinal necrosis; however, this complication can also occur with SPS alone, and in animal models, SPS is the causative agent. The low but real risk of intestinal necrosis with SPS, which can sometimes be the only available or appropriate therapy for the removal of potassium, must be weighed against the delayed onset of efficacy. Whenever possible, alternative therapies for the acute management of hyperkalemia (i.e., alternative potassium binders, aggressive redistributive therapy, isotonic bicarbonate infusion, diuretics, and/or hemodialysis) should be used instead of SPS.

Novel intestinal potassium binders have recently become available for the management of hyperkalemia. These agents lack the intestinal toxicity of SPS and are preferred over SPS for the management of hyperkalemia. Patiromer is a nonabsorbed polymer provided as a powder for suspension, which binds K<sup>+</sup> in exchange for Ca<sup>2+</sup>. In healthy adults, patiromer causes a decrease in urinary potassium, magnesium, and sodium excretion, suggesting the binding of the polymer to these cations in the intestine; notably, a major side effect of the medication is hypomagnesemia. ZS-9 (sodium zirconium cyclosilicate) is an inorganic, nonabsorbable crystalline compound that exchanges both Na<sup>+</sup> and H<sup>+</sup> ions in exchange for K<sup>+</sup> and NH<sub>4</sub><sup>+</sup> in the intestine. These agents have revolutionized the management of both chronic and acute hyperkalemia. In particular, the availability of safe, well-tolerated potassium binders allows for greater intensity of renin-angiotensin-aldosterone system inhibition in both renal and cardiac disease.

Therapy with intravenous saline may be beneficial in hypovolemic patients with oliguria and decreased distal delivery of Na<sup>+</sup>, with the associated reductions in renal K<sup>+</sup> excretion. Loop and thiazide diuretics can be used to reduce plasma K<sup>+</sup> concentration in volume-replete or hypervolemic patients with sufficient renal function for a diuretic response; this may need to be combined with intravenous saline or isotonic bicarbonate to achieve or maintain euvolemia.

Hemodialysis is the most effective and reliable method to reduce plasma K<sup>+</sup> concentration; peritoneal dialysis is considerably less effective. Patients with acute kidney injury require temporary, urgent venous access for hemodialysis, with the attendant risks; in contrast, patients with ESRD or advanced chronic kidney disease may have a preexisting venous access. The amount of K<sup>+</sup> removed during hemodialysis depends on the relative distribution of K<sup>+</sup> between ICF and ECF (potentially affected by prior therapy for hyperkalemia), the type and surface area of the dialyzer used, dialysate and blood flow rates, dialysate flow rate, dialysis duration, and the plasma-to-dialysate K<sup>+</sup> gradient.

### FURTHER READING

- C M et al: K<sup>+</sup> channel mutations in adrenal aldosterone-producing adenomas and hereditary hypertension. *Science* 331:768, 2011.
- F W et al: A copeptin-based approach in the diagnosis of diabetes insipidus. *N Engl J Med* 379:428, 2018.
- G -K F et al: Osmotic stress-induced defective glial proteostasis contributes to brain demyelination after hyponatremia treatment. *J Am Soc Nephrol* 28:1802, 2017.
- M DB: Disorders of potassium balance, in *Brenner and Rector's The Kidney*, 11th ed, ASL Yu et al: (eds). Philadelphia, W.B. Saunders & Company, 2020, pp. 537–579.
- P DK et al: Sodium zirconium cyclosilicate in hyperkalemia. *N Engl J Med* 372:222, 2015.

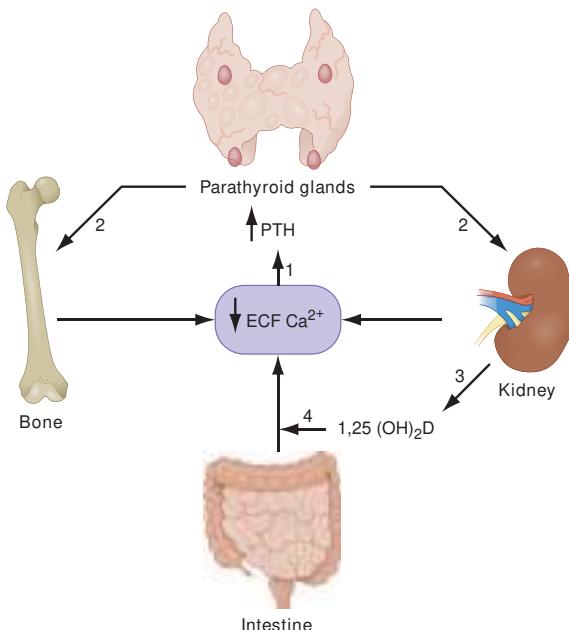
- P A et al: DDAVP is effective in preventing and reversing inadvertent overcorrection of hyponatremia. *Clin J Am Soc Nephrol* 3:331, 2008.
- S RW: Decreased effective blood volume in edematous disorders: What does this mean? *J Am Soc Nephrol* 18:2028, 2007.
- S L et al: Hypertonic saline and desmopressin: A simple strategy for safe correction of severe hyponatremia. *Am J Kidney Dis* 61:571, 2013.
- S A et al: Efficacy and tolerance of urea compared with vaptans for long-term treatment of patients with SIADH. *Clin J Am Soc Nephrol* 7:742, 2012.

## 54 Hypercalcemia and Hypocalcemia

Sundeep Khosla



The calcium ion plays a critical role in normal cellular function and signaling, regulating diverse physiologic processes such as neuromuscular signaling, cardiac contractility, hormone secretion, and blood coagulation. Thus, extracellular calcium concentrations are maintained within an exquisitely narrow range through a series of feedback mechanisms that involve parathyroid hormone (PTH) and the active vitamin D metabolite 1,25-dihydroxyvitamin D [1,25(OH)<sub>2</sub>D]. These feedback mechanisms are orchestrated by integrating signals between the parathyroid glands, kidney, intestine, and bone (Fig. 54-1; Chap. 409).



**FIGURE 54-1** Feedback mechanisms maintaining extracellular calcium concentrations within a narrow, physiologic range (8.9–10.1 mg/dL [2.2–2.5 mM]). A decrease in extracellular (ECF) calcium ( $\text{Ca}^{2+}$ ) triggers an increase in parathyroid hormone (PTH) secretion (1) via the calcium sensor receptor on parathyroid cells. PTH, in turn, results in increased tubular reabsorption of calcium by the kidney (2) and resorption of calcium from bone (2) and also stimulates renal 1,25(OH)<sub>2</sub>D production (3). 1,25(OH)<sub>2</sub>D, in turn, acts principally on the intestine to increase calcium absorption (4). Collectively, these homeostatic mechanisms serve to restore serum calcium levels to normal.

Disorders of serum calcium concentration are relatively common and often serve as a harbinger of underlying disease. This chapter provides a brief summary of the approach to patients with altered serum calcium levels. See Chap. 410 for a detailed discussion of this topic.

## HYPERCALCEMIA

### ETIOLOGY

The causes of hypercalcemia can be understood and classified based on derangements in the normal feedback mechanisms that regulate serum calcium (Table 54-1). Excess PTH production, which is not appropriately suppressed by increased serum calcium concentrations, occurs in primary neoplastic disorders of the parathyroid glands (parathyroid adenomas; hyperplasia; or, rarely, carcinoma) that are associated with increased parathyroid cell mass and impaired feedback inhibition by calcium. Inappropriate PTH secretion for the ambient level of serum calcium also occurs in familial hypocalciuric hypercalcemia (FHH), which is an autosomal dominant syndrome most commonly involving inactivating mutations in the calcium sensor receptor (*CaSR*; FHH type 1), with rare families having mutations in the  $\text{G}\alpha_{11}$  protein (*GNA11*; FHH type 2) or the adaptor-related protein complex 2,  $\sigma$ -2 subunit (*AP2S1*; FHH type 3); all of these mutations impair extracellular calcium sensing by the parathyroid glands and the kidneys, leading to inappropriate PTH secretion and increased renal tubular calcium reabsorption. Although PTH secretion by tumors is extremely rare, many solid tumors produce PTH-related peptide (PTHRP), which shares homology with PTH in the first 13 amino acids and binds the PTH receptor, thus mimicking effects of PTH on bone and the kidney. In PTHRP-mediated hypercalcemia of malignancy, PTH levels are suppressed by the high serum calcium levels. Hypercalcemia associated with granulomatous disease (e.g., sarcoidosis) or lymphomas is caused by enhanced conversion of 25(OH)D to the potent 1,25(OH)<sub>2</sub>D. In these disorders, 1,25(OH)<sub>2</sub>D enhances intestinal calcium absorption, resulting in hypercalcemia and suppressed PTH. Disorders that directly increase calcium mobilization from bone, such as hyperthyroidism or osteolytic metastases, also lead to hypercalcemia.

TABLE 54-1 Causes of Hypercalcemia

Excessive PTH production
Primary hyperparathyroidism (adenoma, hyperplasia, rarely carcinoma)
Tertiary hyperparathyroidism (long-term stimulation of PTH secretion in renal insufficiency)
Ectopic PTH secretion (very rare)
FHH
Alterations in CaSR function (lithium therapy)
Hypercalcemia of malignancy
Overproduction of PTHRP (many solid tumors)
Lytic skeletal metastases (breast, myeloma)
Excessive 1,25(OH) <sub>2</sub> D production
Granulomatous diseases (sarcoidosis, tuberculosis, silicosis)
Lymphomas
Vitamin D intoxication
Primary increase in bone resorption
Hyperthyroidism
Immobilization
Excessive calcium intake
Milk-alkali syndrome
Total parenteral nutrition
Other causes
Endocrine disorders (adrenal insufficiency, pheochromocytoma, VIPoma)
Medications (thiazides, vitamin A, antiestrogens)

Abbreviations: CaSR, calcium sensor receptor; FHH, familial hypocalciuric hypercalcemia; PTH, parathyroid hormone; PTHRP, PTH-related peptide.

with suppressed PTH secretion as does exogenous calcium overload, as in milk-alkali syndrome, or total parenteral nutrition with excessive calcium supplementation.

## ■ CLINICAL MANIFESTATIONS

Mild hypercalcemia (up to 11–11.5 mg/dL) is usually asymptomatic and recognized only on routine calcium measurements. Some patients may complain of vague neuropsychiatric symptoms, including trouble concentrating, personality changes, or depression. Other presenting symptoms may include peptic ulcer disease or nephrolithiasis, and fracture risk may be increased. More severe hypercalcemia (>12–13 mg/dL), particularly if it develops acutely, may result in lethargy, stupor, or coma, as well as gastrointestinal symptoms (nausea, anorexia, constipation, or pancreatitis). Hypercalcemia decreases renal concentrating ability, which may cause polyuria and polydipsia. With long-standing hyperparathyroidism, patients may present with bone pain or pathologic fractures. Finally, hypercalcemia can result in significant electrocardiographic changes, including bradycardia, atrioventricular (AV) block, and short QT interval; changes in serum calcium can be monitored by following the QT interval.

## ■ DIAGNOSTIC APPROACH

The first step in the diagnostic evaluation of hyper- or hypocalcemia is to ensure that the alteration in serum calcium levels is not due to abnormal albumin concentrations. About 50% of total calcium is ionized, and the rest is bound principally to albumin. Although direct measurements of ionized calcium are possible, they are easily influenced by collection methods and other artifacts; thus, it is generally preferable to measure total calcium and albumin to “correct” the serum calcium. When serum albumin concentrations are reduced, a corrected calcium concentration is calculated by adding 0.2 mM (0.8 mg/dL) to the total calcium level for every decrement in serum albumin of 1.0 g/dL below the reference value of 4.1 g/dL for albumin, and, conversely, for elevations in serum albumin.

A detailed history may provide important clues regarding the etiology of the hypercalcemia (Table 54-1). Chronic hypercalcemia is most commonly caused by primary hyperparathyroidism, as opposed to the second most common etiology of hypercalcemia, an underlying malignancy. The history should include medication use, previous neck surgery, and systemic symptoms suggestive of sarcoidosis or lymphoma.

Once true hypercalcemia is established, the second most important laboratory test in the diagnostic evaluation is a PTH level using a two-site assay for the intact hormone. Increases in PTH are often accompanied by hypophosphatemia. In addition, serum creatinine should be measured to assess renal function; hypercalcemia may impair renal function, and renal clearance of PTH may be altered depending on the fragments detected by the assay. If the PTH level is increased (or “inappropriately normal”) in the setting of elevated calcium and low phosphorus, the diagnosis is almost always primary hyperparathyroidism. Because individuals with FHH may also present with mildly elevated PTH levels and hypercalcemia, this diagnosis should be considered and excluded because parathyroid surgery is ineffective in this condition. A calcium/creatinine clearance ratio (calculated as urine calcium/serum calcium divided by urine creatinine/serum creatinine) of <0.01 is suggestive of FHH, particularly when there is a family history of mild, asymptomatic hypercalcemia. In addition, sequence analysis of the *CASR* gene is now commonly performed for the definitive diagnosis of FHH, although as noted above, in rare families, FHH may be caused by mutations in the *GNA11* or *AP2S1* genes, and patients may have to pay out-of-pocket for the genetic analysis. Ectopic PTH secretion is extremely rare.

A suppressed PTH level in the face of hypercalcemia is consistent with non-parathyroid-mediated hypercalcemia, most often due to underlying malignancy. Although a tumor that causes hypercalcemia is generally overt, a PTHrP level may be needed to establish the diagnosis of hypercalcemia of malignancy. Serum 1,25(OH)<sub>2</sub>D levels are increased in granulomatous disorders, and clinical evaluation in combination with laboratory testing will generally provide a diagnosis for the various disorders listed in Table 54-1.

## TREATMENT

### Hypercalcemia

Mild, asymptomatic hypercalcemia does not require immediate therapy, and management should be dictated by the underlying diagnosis. By contrast, significant, symptomatic hypercalcemia usually requires therapeutic intervention independent of the etiology of hypercalcemia. Initial therapy of significant hypercalcemia begins with volume expansion because hypercalcemia invariably leads to dehydration; 4–6 L of intravenous saline may be required over the first 24 h, keeping in mind that underlying comorbidities (e.g., congestive heart failure) may require the use of loop diuretics to enhance sodium and calcium excretion. However, loop diuretics should not be initiated until the volume status has been restored to normal. If there is increased calcium mobilization from bone (as in malignancy or severe hyperparathyroidism), drugs that inhibit bone resorption should be considered. Although salmon calcitonin (4–8 IU/kg intramuscularly or subcutaneously every 6–12 h) is sometimes used, the mainstays of therapy are bisphosphonates, which are potent inhibitors of bone resorption. Zoledronic acid (e.g., 4 mg intravenously over ~30 min) and pamidronate (e.g., 60–90 mg intravenously over 2–4 h) are bisphosphonates that are commonly used for the treatment of hypercalcemia of malignancy in adults. Onset of action is within 1–3 days, with normalization of serum calcium levels occurring in 60–90% of patients. Bisphosphonate infusions may need to be repeated if hypercalcemia relapses. Denosumab (120 mg subcutaneously on days 1, 8, 15, and 29, and then every 4 weeks), an antibody to RANKL, is a potent inhibitor of bone resorption and has been shown to be effective in treating hypercalcemia refractory to bisphosphonates. An alternative to the bisphosphonates or denosumab is gallium nitrate (200 mg/m<sup>2</sup> intravenously daily for 5 days), which is also effective, but has potential nephrotoxicity. In rare instances, dialysis may be necessary. Finally, although intravenous phosphate chelates calcium and decreases serum calcium levels, this therapy can be toxic because calcium-phosphate complexes may deposit in tissues and cause extensive organ damage.

In patients with 1,25(OH)<sub>2</sub>D-mediated hypercalcemia, glucocorticoids are the preferred therapy, as they decrease 1,25(OH)<sub>2</sub>D production. Intravenous hydrocortisone (100–300 mg daily) or oral prednisone (40–60 mg daily) for 3–7 days is used most often. Other drugs, such as ketoconazole, chloroquine, and hydroxychloroquine, may also decrease 1,25(OH)<sub>2</sub>D production and are used occasionally.

## HYPOCALCEMIA

### ■ ETIOLOGY

The causes of hypocalcemia can be differentiated according to whether serum PTH levels are low (hypoparathyroidism) or high (secondary hyperparathyroidism). Although there are many potential causes of hypocalcemia, impaired PTH production and impaired vitamin D production are the most common etiologies (Table 54-2) (Chap. 410). Because PTH is the main defense against hypocalcemia, disorders associated with deficient PTH production or secretion may be associated with profound, life-threatening hypocalcemia. In adults, hypoparathyroidism most commonly results from inadvertent damage to all four glands during thyroid or parathyroid gland surgery. Hypoparathyroidism is a cardinal feature of autoimmune endocrinopathies (Chap. 388); rarely, it may be associated with infiltrative diseases such as sarcoidosis. Impaired PTH secretion may be secondary to magnesium deficiency or to activating mutations in the CaSR or in the G proteins that mediate CaSR signaling (autosomal dominant hypocalcemia), which suppress PTH, leading to effects that are opposite to those that occur in FHH.

Vitamin D deficiency, impaired 1,25(OH)<sub>2</sub>D production (primarily secondary to renal insufficiency), or vitamin D resistance also cause hypocalcemia. However, the degree of hypocalcemia in these disorders is generally not as severe as that seen with hypoparathyroidism because the parathyroids are capable of mounting a compensatory increase in

TABLE 54-2 Causes of Hypocalcemia

## Low Parathyroid Hormone Levels (Hypoparathyroidism)

- Parathyroid agenesis
  - Isolated
  - DiGeorge's syndrome
- Parathyroid destruction
  - Surgical
  - Radiation
  - Infiltration by metastases or systemic diseases
  - Autoimmune
- Reduced parathyroid function
  - Hypomagnesemia
  - Autosomal dominant hypocalcemia

## High Parathyroid Hormone Levels (Secondary Hyperparathyroidism)

- Vitamin D deficiency or impaired  $1,25(\text{OH})_2\text{D}$  production/action
  - Nutritional vitamin D deficiency (poor intake or absorption)
  - Renal insufficiency with impaired  $1,25(\text{OH})_2\text{D}$  production
  - Vitamin D resistance, including receptor defects
- Parathyroid hormone resistance syndromes
  - PTH receptor mutations
  - Pseudohypoparathyroidism (Gprotein mutations)
- Drugs
  - Calcium chelators
  - Inhibitors of bone resorption (bisphosphonates, plicamycin)
  - Altered vitamin D metabolism (phenytoin, ketoconazole)
- Miscellaneous causes
  - Acute pancreatitis
  - Acute rhabdomyolysis
  - Hungry bone syndrome after parathyroidectomy
  - Osteoblastic metastases with marked stimulation of bone formation (prostate cancer)

Abbreviation: PTH, parathyroid hormone.

PTH secretion. Hypocalcemia may also occur in conditions associated with severe tissue injury such as burns, rhabdomyolysis, tumor lysis, or pancreatitis. The cause of hypocalcemia in these settings may include a combination of low albumin, hyperphosphatemia, tissue deposition of calcium, and impaired PTH secretion.

### CLINICAL MANIFESTATIONS

Patients with hypocalcemia may be asymptomatic if the decreases in serum calcium are relatively mild and chronic, or they may present with life-threatening complications. Moderate to severe hypocalcemia is associated with paresthesias, usually of the fingers, toes, and circumoral regions, and is caused by increased neuromuscular irritability. On physical examination, a Chvostek's sign (twitching of the circumoral muscles in response to gentle tapping of the facial nerve just anterior to the ear) may be elicited, although it is also present in ~10% of normal individuals. Carpal spasm may be induced by inflation of a blood pressure cuff to 20 mmHg above the patient's systolic blood pressure for 3 min (Trousseau's sign). Severe hypocalcemia can induce seizures, carpopedal spasm, bronchospasm, laryngospasm, and prolongation of the QT interval.

### DIAGNOSTIC APPROACH

In addition to measuring serum calcium, it is useful to determine albumin, phosphorus, and magnesium levels. As for the evaluation of

hypercalcemia, determining the PTH level is central to the evaluation of hypocalcemia. A suppressed (or "inappropriately low") PTH level in the setting of hypocalcemia establishes absent or reduced PTH secretion (hypoparathyroidism) as the cause of the hypocalcemia. Further history will often elicit the underlying cause (i.e., parathyroid agenesis vs destruction). By contrast, an elevated PTH level (secondary hyperparathyroidism) should direct attention to the vitamin D axis as the cause of the hypocalcemia. Nutritional vitamin D deficiency is best assessed by obtaining serum 25-hydroxyvitamin D levels, which reflect vitamin D stores. In the setting of renal insufficiency or suspected vitamin D resistance, serum  $1,25(\text{OH})_2\text{D}$  levels are informative.

## TREATMENT

### Hypocalcemia

The approach to treatment depends on the severity of the hypocalcemia, the rapidity with which it develops, and the accompanying complications (e.g., seizures, laryngospasm). Acute, symptomatic hypocalcemia is initially managed with calcium gluconate, 10 mL 10% wt/vol (90 mg or 2.2 mmol) intravenously, diluted in 50 mL of 5% dextrose or 0.9% sodium chloride, given intravenously over 5 min. Continuing hypocalcemia often requires a constant intravenous infusion (typically 10 ampules of calcium gluconate or 900 mg of calcium in 1 L of 5% dextrose or 0.9% sodium chloride administered over 24 h). Accompanying hypomagnesemia, if present, should be treated with appropriate magnesium supplementation.

Chronic hypocalcemia due to hypoparathyroidism is treated with calcium supplements (1000–1500 mg/d elemental calcium in divided doses) and either vitamin  $D_2$  or  $D_3$  (25,000–100,000 U daily) or calcitriol [ $1,25(\text{OH})_2\text{D}$ , 0.25–2  $\mu\text{g}/\text{d}$ ]. Other vitamin D metabolites (dihydrotachysterol, alfacalcidol) are now used less frequently. Importantly, PTH (1-84) (Natpara) is now approved by the Food and Drug Administration for the treatment of refractory hypoparathyroidism, representing an important advance in treatment of these patients. Vitamin D deficiency is best treated using vitamin D supplementation, with the dose depending on the severity of the deficit and the underlying cause. Thus, nutritional vitamin D deficiency generally responds to relatively low doses of vitamin D (50,000 IU, 2–3 times per week for several months), whereas vitamin D deficiency due to malabsorption may require much higher doses (100,000 IU/d or more). The treatment goal is to bring serum calcium into the low normal range and to avoid hypercalcuria, which may lead to nephrolithiasis.

### GLOBAL CONSIDERATIONS

In countries with more limited access to health care or screening laboratory testing of serum calcium levels, primary hyperparathyroidism often presents in its severe form with skeletal complications (osteitis fibrosa cystica) in contrast to the asymptomatic form that is common in developed countries. In addition, vitamin D deficiency is paradoxically common in some countries despite extensive sunlight (e.g., India) due to avoidance of sun exposure and poor dietary vitamin D intake.

### FURTHER READING

- B JP et al: Hyperparathyroidism. Lancet 391:168, 2018.
- B ML et al: Management of hypoparathyroidism: Summary statement and guidelines. J Clin Endocrinol Metab 101:2273, 2016.
- H FM et al: The calcium-sensing receptor in physiology and in calcitropic and noncalcitropic diseases. Nat Rev Endocrinol 15:33, 2018.
- M S et al: The diagnosis and management of hypercalcemia. BMJ 350:h2723, 2015.

## NORMAL ACID BASE HOMEOSTASIS

Systemic arterial pH is maintained between 7.35 and 7.45 by extracellular and intracellular chemical buffering together with respiratory and renal regulatory mechanisms. The control of arterial CO<sub>2</sub> tension (Pa<sub>CO<sub>2</sub></sub>) by the central nervous system (CNS) and respiratory system and the control of plasma bicarbonate by the kidneys stabilize the arterial pH by excretion or retention of acid or alkali. The metabolic and respiratory components that regulate systemic pH are described by the Henderson-Hasselbalch equation and solved for pH when the solubility of CO<sub>2</sub> is considered (dissolved CO<sub>2</sub> in mmol/L = 0.03 × Pa<sub>CO<sub>2</sub></sub> in mmHg), at a pK' of 6.1:

$$\text{pH} = \text{pK}' + \log_{10} \frac{[\text{HCO}_3^-]}{\alpha_{\text{CO}_2} \text{PCO}_2}$$

Under most circumstances, CO<sub>2</sub> production and excretion are matched, and the usual steady-state Pa<sub>CO<sub>2</sub></sub> is maintained at ~40 mmHg. Underexcretion of CO<sub>2</sub> produces hypercapnia, and overexcretion causes hypocapnia. Nevertheless, production and excretion are again matched at a new steady-state Pa<sub>CO<sub>2</sub></sub>. Therefore, the Pa<sub>CO<sub>2</sub></sub> is regulated primarily by neural respiratory factors and is not subject to regulation by the rate of CO<sub>2</sub> production. Hypercapnia is usually the result of hypoventilation rather than of increased CO<sub>2</sub> production. Increases or decreases in Pa<sub>CO<sub>2</sub></sub> represent derangements of neural respiratory control or are due to compensatory changes in response to a primary alteration in the plasma [HCO<sub>3</sub><sup>-</sup>].

## DIAGNOSIS OF GENERAL TYPES OF DISTURBANCES

The most common clinical disturbances are simple acid-base disorders; i.e., metabolic acidosis or alkalosis or respiratory acidosis or alkalosis occurring individually. Recognition of simple acid-base disorders requires appreciation of the limits of physiologic compensation for a primary disturbance.

### SIMPLE ACID BASE DISORDERS

Primary respiratory disturbances (primary changes in Pa<sub>CO<sub>2</sub></sub>) invoke compensatory metabolic responses (secondary changes in [HCO<sub>3</sub><sup>-</sup>]), and primary metabolic disturbances elicit predictable compensatory respiratory responses (secondary changes in Pa<sub>CO<sub>2</sub></sub>). Physiologic compensation can be predicted from the relationships displayed in Table 55-1. In general, with one exception, compensatory responses return the pH toward, but not to, the normal value. Chronic respiratory alkalosis when prolonged is an exception to this rule and may return the pH to a normal value. Metabolic acidosis due to an increase in endogenous acid production (e.g., ketoacidosis or lactic acid acidosis) lowers extracellular fluid [HCO<sub>3</sub><sup>-</sup>] and decreases extracellular pH. This stimulates the medullary chemoreceptors to increase ventilation and to return the ratio of [HCO<sub>3</sub><sup>-</sup>] to Pa<sub>CO<sub>2</sub></sub>, and thus pH, toward, but not typically to, the normal value. The degree of respiratory compensation expected in a metabolic acidosis can be predicted from the relationship: Pa<sub>CO<sub>2</sub></sub> = (1.5 × [HCO<sub>3</sub><sup>-</sup>]) + 8 ± 2 (Winter's equation). Thus, applying this equation, a patient with metabolic acidosis and [HCO<sub>3</sub><sup>-</sup>] of 12 mmol/L would be expected to have a Pa<sub>CO<sub>2</sub></sub> of approximately 26 mmHg. In this example, if values for Pa<sub>CO<sub>2</sub></sub> were <24 or >28 mmHg, values that exceed the boundaries for compensation for a simple disorder, a *mixed* disturbance should be recognized (metabolic acidosis plus respiratory alkalosis or metabolic acidosis plus respiratory acidosis, respectively). Compensatory responses for primary metabolic disorders move the Pa<sub>CO<sub>2</sub></sub> in the same direction as the change in [HCO<sub>3</sub><sup>-</sup>], while compensation for primary respiratory disorders moves the [HCO<sub>3</sub><sup>-</sup>] in the same direction as the primary change in Pa<sub>CO<sub>2</sub></sub>.

TABLE 55-1 Prediction of Compensatory Responses to Simple Acid-Base Disturbances and Pattern of Changes

DISORDER	PREDICTION OF COMPENSATION	RANGE OF VALUES		
		pH	[HCO <sub>3</sub> <sup>-</sup> ]	Pa <sub>CO<sub>2</sub></sub>
Metabolic acidosis	Pa <sub>CO<sub>2</sub></sub> = (1.5 × [HCO <sub>3</sub> <sup>-</sup> ]) + 8 ± 2 or Pa <sub>CO<sub>2</sub></sub> will ↓ 1.25 mmHg per mmol/L ↓ in [HCO <sub>3</sub> <sup>-</sup> ] or Pa <sub>CO<sub>2</sub></sub> = [HCO <sub>3</sub> <sup>-</sup> ] + 15	Low	Low	Low
Metabolic alkalosis	Pa <sub>CO<sub>2</sub></sub> will ↑ 0.75 mmHg per mmol/L ↑ in [HCO <sub>3</sub> <sup>-</sup> ] or Pa <sub>CO<sub>2</sub></sub> will ↑ 6 mmHg per 10 mmol/L ↑ in [HCO <sub>3</sub> <sup>-</sup> ] or Pa <sub>CO<sub>2</sub></sub> = [HCO <sub>3</sub> <sup>-</sup> ] + 15	High	High	High
Respiratory alkalosis		High	Low	Low
Acute	[HCO <sub>3</sub> <sup>-</sup> ] will ↓ 0.2 mmol/L per mmHg ↓ in Pa <sub>CO<sub>2</sub></sub>			
Chronic	[HCO <sub>3</sub> <sup>-</sup> ] will ↓ 0.4 mmol/L per mmHg ↓ in Pa <sub>CO<sub>2</sub></sub>			
Respiratory acidosis		Low	High	High
Acute	[HCO <sub>3</sub> <sup>-</sup> ] will ↑ 0.1 mmol/L per mmHg ↑ in Pa <sub>CO<sub>2</sub></sub>			
Chronic	[HCO <sub>3</sub> <sup>-</sup> ] will ↑ 0.4 mmol/L per mmHg ↑ in Pa <sub>CO<sub>2</sub></sub>			

(Table 55-1). Therefore, changes in Pa<sub>CO<sub>2</sub></sub> and [HCO<sub>3</sub><sup>-</sup>] in opposite directions (i.e., Pa<sub>CO<sub>2</sub></sub> or [HCO<sub>3</sub><sup>-</sup>] is increased, whereas the other value is decreased) indicate a mixed acid-base disturbance. Another way to judge the appropriateness of the response in [HCO<sub>3</sub><sup>-</sup>] or Pa<sub>CO<sub>2</sub></sub> is to use an acid-base nomogram (Fig. 55-1). While the shaded areas of the nomogram show the 95% confidence limits for physiologic

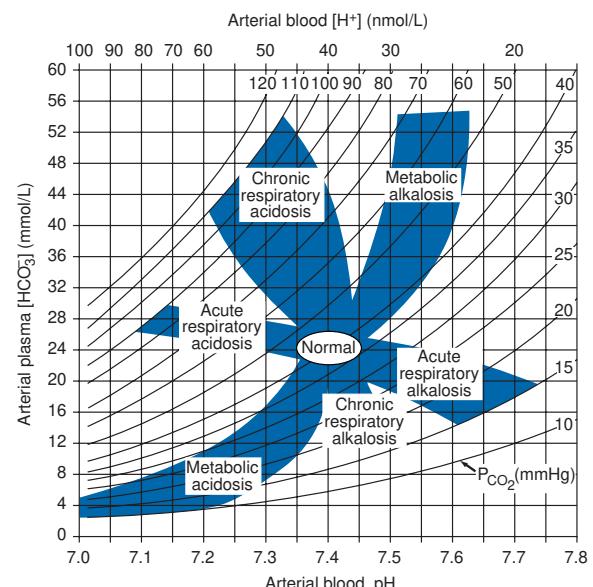


FIGURE 55-1 Acid-base nomogram. Shown are the 95% confidence limits (range of values) of the normal respiratory and metabolic compensations for primary acid-base disturbances. (Reproduced with permission from LL Hamm and TD DuBose Jr, in Alan S.L. Yu, et al (eds): Brenner and Rector's The Kidney, 11th ed. Philadelphia, Elsevier, 2020.)

compensation in simple disturbances, finding acid-base values within the shaded area does not necessarily rule out a mixed disturbance. Imposition of one disorder over another may result in values lying within the area of a third. Thus, the nomogram, while convenient, is not a substitute for the equations in Table 55-1.

### MIXED ACID BASE DISORDERS

Mixed acid-base disorders—defined as independently coexisting disorders, not merely compensatory responses—are often seen in patients in critical care units and can lead to dangerous extremes of pH (Table 55-2). The diagnosis of mixed acid-base disorders requires consideration of the anion gap (AG). To be accurate, the AG requires the presence of, or correction to, a normal serum albumin of 4.5 g/dL (see below, “Evaluate the Anion Gap”). If a patient with diabetic ketoacidosis (metabolic acidosis) and a high AG has an independent and concomitant respiratory disorder (e.g., pneumonia), the latter may lead to a superimposed respiratory acidosis or alkalosis and the  $\text{PaCO}_2$  will deviate from the predicted value for the response to a pure high-AG metabolic acidosis (Table 55-2). Patients with underlying chronic obstructive pulmonary disease may not respond to metabolic acidosis with an appropriate ventilatory response because of insufficient respiratory reserve (Table 55-2). Such imposition of respiratory acidosis on metabolic acidosis can lead to severe acidemia. When metabolic acidosis and metabolic alkalosis coexist in the same patient, the pH may be in the normal range. In this circumstance, it is the presence of an elevated AG (see below) that denotes the presence of a metabolic acidosis. Assuming a normal value for the AG of 10 mmol/L, incongruity in the  $\Delta\text{AG}$  (existing minus normal AG) and the  $\Delta\text{HCO}_3^-$  (normal value of 25 mmol/L minus abnormal  $\text{HCO}_3^-$  in the patient) indicates the presence of a mixed high-gap acidosis—metabolic alkalosis (see example below). A diabetic patient with ketoacidosis may have acute or chronic kidney failure resulting in a combination of metabolic acidoses from

TABLE 55-2 Examples of Mixed Acid-Base Disorders

#### Mixed Metabolic and Respiratory

Metabolic acidosis—respiratory alkalosis

Key: High-AG metabolic acidosis; prevailing  $\text{PaCO}_2$  *below* predicted value (Table 55-1)

Example:  $\text{Na}^+$ , 140;  $\text{K}^+$ , 4.0;  $\text{Cl}^-$ , 106;  $\text{HCO}_3^-$ , 14; AG, 20;  $\text{PaCO}_2$ , 24; pH, 7.39 (lactic acidosis, sepsis in ICU)

Metabolic acidosis—respiratory acidosis

Key: High-AG metabolic acidosis; prevailing  $\text{PaCO}_2$  *above* predicted value (Table 55-1)

Example:  $\text{Na}^+$ , 140;  $\text{K}^+$ , 4.0;  $\text{Cl}^-$ , 102;  $\text{HCO}_3^-$ , 18; AG, 20;  $\text{PaCO}_2$ , 38; pH, 7.30 (severe pneumonia, pulmonary edema)

Metabolic alkalosis—respiratory alkalosis

Key:  $\text{PaCO}_2$  does not increase as predicted; pH higher than expected

Example:  $\text{Na}^+$ , 140;  $\text{K}^+$ , 4.0;  $\text{Cl}^-$ , 91;  $\text{HCO}_3^-$ , 33; AG, 16;  $\text{PaCO}_2$ , 38; pH, 7.55 (liver disease and diuretics)

Metabolic alkalosis—respiratory acidosis

Key:  $\text{PaCO}_2$  higher than predicted; pH normal

Example:  $\text{Na}^+$ , 140;  $\text{K}^+$ , 3.5;  $\text{Cl}^-$ , 88;  $\text{HCO}_3^-$ , 42; AG, 10;  $\text{PaCO}_2$ , 67; pH, 7.42 (COPD on diuretics)

#### Mixed Metabolic Disorders

Metabolic acidosis—metabolic alkalosis

Key: Only detectable with high-AG acidosis;  $\Delta\text{AG} (10) >> \Delta\text{HCO}_3^-$

Example:  $\text{Na}^+$ , 140;  $\text{K}^+$ , 3.0;  $\text{Cl}^-$ , 95;  $\text{HCO}_3^-$ , 25; AG, 20;  $\text{PaCO}_2$ , 40; pH, 7.42 (uremia with vomiting)

Metabolic acidosis—metabolic acidosis

Key: Mixed high-AG—normal-AG acidosis;  $\Delta\text{HCO}_3^-$  accounted for by combined change in  $\Delta\text{AG}$  and  $\Delta\text{Cl}^-$

Example:  $\text{Na}^+$ , 135;  $\text{K}^+$ , 3.0;  $\text{Cl}^-$ , 110;  $\text{HCO}_3^-$ , 10; AG, 15;  $\text{PaCO}_2$ , 25; pH, 7.20 (diarrhea and lactic acidosis, toluene toxicity, treatment of diabetic ketoacidosis)

**Abbreviations:** AG, anion gap; COPD, chronic obstructive pulmonary disease; ICU, intensive care unit.

accumulation of both ketoacids and uremic acids. Patients who have ingested an overdose of drug combinations such as sedatives and salicylates may have mixed disturbances as a result of the acid-base response to the individual drugs (metabolic acidosis mixed with respiratory acidosis or respiratory alkalosis, respectively). Triple acid-base disturbances are more complex. For example, patients with metabolic acidosis due to alcoholic ketoacidosis may develop metabolic alkalosis due to vomiting and superimposed respiratory alkalosis due to the hyperventilation of hepatic dysfunction or alcohol withdrawal.

## APPROACH TO THE PATIENT

### Acid-Base Disorders

The diagnosis of acid-base disorders follows a stepwise approach (Table 55-3). Blood for electrolytes and arterial blood gases should be drawn simultaneously, prior to therapy. An increase in  $[\text{HCO}_3^-]$  occurs with either metabolic alkalosis or respiratory acidosis. Conversely, a decrease in  $[\text{HCO}_3^-]$  occurs with either metabolic acidosis or respiratory alkalosis. In the determination of arterial blood gases by the clinical laboratory, both pH and  $\text{PaCO}_2$  are measured, and the  $[\text{HCO}_3^-]$  is calculated from the Henderson-Hasselbalch equation. This *calculated* value should be compared with the *measured*  $[\text{HCO}_3^-]$  (or total  $\text{CO}_2$ ) on the electrolyte panel. These two values should agree within 2 mmol/L. If they do not, the values may not have been drawn simultaneously, or a laboratory error may be present. After verifying the blood acid-base values, the precise acid-base disorder can then be classified.

#### EVALUATE THE ANION GAP

Evaluations of acid-base disorders should involve acknowledgement of the AG. The AG is calculated, either by the clinical laboratory or the clinician, as follows:  $\text{AG} = \text{Na}^+ - (\text{Cl}^- + \text{HCO}_3^-)$ . The value for plasma  $[\text{K}^+]$  is typically omitted from the calculation of the AG in the United States. The “normal” value for the AG reported by clinical laboratories has declined with improved methodology for measuring plasma electrolytes and ranges from 6–12 mmol/L, with an average of approximately 10 mmol/L. The unmeasured anions normally present in plasma include anionic proteins (e.g., albumin), phosphate, sulfate, and organic anions. When acid anions, such as acetoacetate and lactate, accumulate in extracellular fluid, the AG increases, causing a high-AG acidosis. An increase in the AG is most often due to an increase in unmeasured anions but, less commonly, may be due to a decrease in unmeasured cations (calcium, magnesium, potassium). In addition, the AG may increase with an increase in anionic albumin (e.g., severe dehydration). A decrease in the AG can be due to (1) an increase in unmeasured cations; (2) the addition to the blood of abnormal cations, such as lithium (lithium intoxication) or cationic immunoglobulins (plasma cell dyscrasias); (3) a reduction in the plasma anion albumin concentration (nephrotic syndrome, liver disease, or malabsorption); or (4) hyperviscosity and severe hyperlipidemia, which can lead to an underestimation of sodium and chloride concentrations. Because the normal AG of 10 mmol/L assumes that the serum albumin is normal, if hypoalbuminemia is present, the value for the AG must

TABLE 55-3 Steps in Acid-Base Diagnosis

- Obtain arterial blood gas (ABG) and electrolytes simultaneously.
- Compare  $[\text{HCO}_3^-]$  on ABG and electrolytes to verify accuracy.
- Evaluate anion gap (AG); if not normal, correct to albumin concentration of 4.5 g/dL (see text).
- Know four causes of high-AG acidosis (ketoacidosis, lactic acid acidosis, renal failure, and toxins).
- Know two causes of hyperchlormic or nongap acidosis (bicarbonate loss from gastrointestinal tract, renal tubular acidosis).
- Estimate compensatory response (Table 55-1).
- Compare  $\Delta\text{AG}$  and  $\Delta\text{HCO}_3^-$ .
- Compare change in  $[\text{Cl}^-]$  with change in  $[\text{Na}^+]$ .

be corrected. For example, for each g/dL of serum albumin below the normal value (4.5 g/dL), 2.5 mmol/L should be added to the reported (uncorrected) AG. Thus, in a patient with a serum albumin of 2.5 g/dL (2 g/dL below the normal value) and an uncorrected AG of 15, the corrected AG is calculated by adding 5 mmol/L ( $2.5 \times 2 = 5; 5 + 15 = \text{corrected AG of } 20 \text{ mmol/L}$ ). Clinical laboratories do not correct the AG for coexisting hypoalbuminemia and typically report the uncorrected value, requiring the attention of the clinician to the prevailing serum albumin concentration. The clinical disorders that may cause a high-AG acidosis are displayed in Table 55-3.

A high AG is usually due to accumulation of non-chloride-containing acids that contain inorganic (phosphate, sulfate), organic (ketoacids, lactate, uremic organic anions), exogenous (salicylate or ingested toxins with organic acid production), or unidentified anions. The high AG is meaningful even if the  $[\text{HCO}_3^-]$  or pH is normal. Simultaneous metabolic acidosis of the high-AG variety plus either chronic respiratory acidosis or metabolic alkalosis represents a situation in which  $[\text{HCO}_3^-]$  may be normal or even high (Table 55-3). In cases of high-AG metabolic acidosis, it is valuable to compare the decline in  $[\text{HCO}_3^-]$  ( $\Delta\text{HCO}_3^- : 25 - \text{patient's } [\text{HCO}_3^-]$ ) with the increase in the AG ( $\Delta\text{AG: patient's AG} - 10$ ).

Similarly, normal values for  $[\text{HCO}_3^-]$ ,  $\text{Pa}_{\text{CO}_2}$ , and pH do not ensure the absence of an acid-base disturbance. For instance, an alcoholic who has been vomiting may develop a metabolic alkalosis with a pH of 7.55,  $\text{Pa}_{\text{CO}_2}$  of 47 mmHg,  $[\text{HCO}_3^-]$  of 40 mmol/L,  $[\text{Na}^+]$  of 135,  $[\text{Cl}^-]$  of 80, and  $[\text{K}^+]$  of 2.8. If such a patient were then to develop a superimposed alcoholic ketoacidosis with a  $\beta$ -hydroxybutyrate concentration of 15 mmol/L, arterial pH would fall to 7.40, the  $[\text{HCO}_3^-]$  to 25 mmol/L, and the  $\text{Pa}_{\text{CO}_2}$  to 40 mmHg. Although these blood gases are normal, the AG is elevated at 30 mmol/L, indicating a mixed metabolic alkalosis and metabolic acidosis is present. A mixture of high-gap acidosis and metabolic alkalosis is recognized easily by comparing the differences ( $\Delta$  values) in the normal to prevailing patient values. In this example, the  $\Delta\text{HCO}_3^-$  is 0 (25 – 25 mmol/L), but the  $\Delta\text{AG}$  is 20 (30 – 10 mmol/L). Therefore, 20 mmol/L is unaccounted for in the  $\Delta/\Delta$  value ( $\Delta\text{AG}$  to  $\Delta\text{HCO}_3^-$ ).

## METABOLIC ACIDOSIS

Metabolic acidosis can occur because of an increase in endogenous acid production (such as lactate and ketoacids), loss of bicarbonate (as in diarrhea), or accumulation of endogenous acids because of inappropriately low excretion of net acid by the kidney (as in chronic kidney disease). Metabolic acidosis has profound effects on the respiratory, cardiac, and nervous systems. The fall in blood pH is accompanied by a characteristic increase in ventilation, especially the tidal volume (Kussmaul respiration). Intrinsic cardiac contractility may be depressed, but inotropic function can be normal because of catecholamine release. Both peripheral arterial vasodilation and central vasoconstriction may be present; the decrease in central and pulmonary vascular compliance predisposes to pulmonary edema with even minimal volume overload. CNS function is depressed, with headache, lethargy, stupor, and, in some cases, even coma. Glucose intolerance may also occur.

There are two major categories of clinical metabolic acidosis: high-AG and non-AG acidosis (Table 55-3 and Table 55-4). The presence of metabolic acidosis, a normal AG, and hyperchloremia denotes the presence of a non-AG metabolic acidosis.

TABLE 55-4 Causes of High-Anion Gap Metabolic Acidosis

Lactic acidosis	Toxins
Ketoacidosis	Ethylene glycol
Diabetic	Methanol
Alcoholic	Salicylates
Starvation	Propylene glycol
	Pyroglutamic acid (5-oxoproline)
	Renal failure (acute and chronic)

## TREATMENT

### Metabolic Acidosis

Treatment of metabolic acidosis with alkali should be reserved for severe acidemia except when the patient has no “potential  $\text{HCO}_3^-$ ” in plasma. The potential  $[\text{HCO}_3^-]$  can be estimated from the increment ( $\Delta$ ) in the AG ( $\Delta\text{AG} = \text{patient's AG} - 10$ ), only if the acid anion that has accumulated in plasma is metabolizable (i.e.,  $\beta$ -hydroxybutyrate, acetooacetate, and lactate). Conversely, nonmetabolizable anions that may accumulate in advanced-stage chronic kidney disease or after toxin ingestion are not metabolizable and do not represent “potential”  $\text{HCO}_3^-$ . In patients with acute kidney failure or acute-on-chronic kidney failure, improvement in kidney function after volume resuscitation may improve the serum  $[\text{HCO}_3^-]$ , but this is a slow and unpredictable process. Consequently, patients with a non-AG acidosis (hyperchloremic acidosis) or an AG acidosis attributable to a nonmetabolizable anion due to advanced kidney failure (“uremic” acidosis) should receive alkali therapy, either PO (NaHCO<sub>3</sub> tablets or Shohl’s solution) or IV (NaHCO<sub>3</sub>), in an amount necessary to slowly increase the plasma  $[\text{HCO}_3^-]$  to a target value of 22 mmol/L. Importantly, overcorrection should be avoided.

Bicarbonate therapy in diabetic ketoacidosis (DKA) is reserved for adult patients with severe acidemia (pH < 7.00) and/or evidence of shock. In such circumstances, bicarbonate may be administered IV, as a slow infusion of 50 meq of NaHCO<sub>3</sub> diluted in 300 mL of a saline solution, over 30–45 min, during the initial 1–2 h of therapy. Bolus administration should be avoided. Administration of NaHCO<sub>3</sub> requires careful monitoring of plasma electrolytes during the course of therapy because of the risk for hypokalemia as urine output is established. A reasonable initial goal in DKA is to increase the  $[\text{HCO}_3^-]$  to 10–12 mmol/L and the pH to approximately 7.20, but clearly not to increase these values to normal.

### HIGH ANION GAP ACIDOSES

#### APPROACH TO THE PATIENT

##### High-Anion Gap Acidoses

There are four principal causes of a high-AG acidosis: (1) lactic acidosis, (2) ketoacidosis, (3) ingested toxins, and (4) acute and chronic kidney failure (Table 55-4). Initial screening to differentiate the high-AG acidoses should include (1) a probe of the history for evidence of drug and toxin ingestion and measurement of arterial blood gas to detect coexistent respiratory alkalosis (salicylates); (2) determination of whether a history of diabetes mellitus is present (DKA); (3) a search for evidence of alcoholism or increased levels of  $\beta$ -hydroxybutyrate (alcoholic ketoacidosis); (4) observation for clinical signs of uremia and determination of the blood urea nitrogen (BUN) and creatinine (uremic acidosis); (5) inspection of the urine for oxalate crystals (ethylene glycol ingestion); and (6) recognition of the numerous clinical settings in which lactate levels may be increased (hypotension, shock, cardiac failure, leukemia, cancer, and drug or toxin ingestion).

**Lactic Acidosis** An increase in plasma lactate may be secondary to poor tissue perfusion (type A)—circulatory insufficiency (shock, cardiac failure), severe anemia, mitochondrial enzyme defects, and inhibitors (carbon monoxide, cyanide)—or to aerobic disorders (type B)—malignancies, nucleoside analogue reverse transcriptase inhibitors in HIV, diabetes mellitus, renal or hepatic failure, thiamine deficiency, severe infections (cholera, malaria), seizures, or drugs/toxins (biguanides, ethanol, and the toxic alcohols: ethylene glycol, methanol, or propylene glycol). Unrecognized bowel ischemia or infarction in a patient with severe atherosclerosis or cardiac decompensation receiving vasopressors is a common cause of lactic acidosis in elderly patients. Pyroglutamic acidemia may occur in critically ill patients.

receiving acetaminophen, which causes depletion of glutathione and accumulation of 5-oxoprolene. -Lactic acid acidosis, which may be associated with jejunoileal bypass, short bowel syndrome, or intestinal obstruction, is due to formation of -lactate by gut bacteria.

## APPROACH TO THE PATIENT

### -Lactic Acid Acidosis

The overarching goal of treatment is to correct the underlying condition that disrupts lactate metabolism; tissue perfusion should be restored when inadequate, but vasoconstrictors should be avoided, or used cautiously, because they may worsen tissue perfusion. Alkali therapy is generally advocated for acute, severe acidemia ( $\text{pH} < 7.00$ ) to improve cardiovascular function. However,  $\text{NaHCO}_3$  therapy may paradoxically depress cardiac performance and exacerbate acidosis by enhancing lactate production ( $\text{HCO}_3^-$  stimulates phosphofructokinase). While the use of alkali in moderate lactic acidosis is controversial, it is generally agreed that attempts to return the pH or  $[\text{HCO}_3^-]$  to normal by administration of exogenous  $\text{NaHCO}_3$  are deleterious. A reasonable approach with severe acidemia is to infuse sufficient  $\text{NaHCO}_3$  to raise arterial pH to no more than 7.2 or the  $[\text{HCO}_3^-]$  to no more than 12 mmol/L.

$\text{NaHCO}_3$  therapy can cause fluid overload, hypercapnia, and hypertension because the amount required can be massive when accumulation of lactic acid is relentless. Fluid administration is poorly tolerated, especially in the oliguric patient, when central venoconstriction coexists. If the underlying cause of the lactic acidosis can be remedied, blood lactate will be converted to  $\text{HCO}_3^-$  and may result in an overshoot alkalosis if exogenous  $\text{NaHCO}_3$  has been administered excessively.

**Ketoacidosis • DIABETIC KETOACIDOSIS (DKA)** This condition is caused by increased fatty acid metabolism and the accumulation of ketoacids (acetooacetate and  $\beta$ -hydroxybutyrate). DKA usually occurs in insulin-dependent diabetes mellitus in association with cessation of insulin or an intercurrent illness such as an infection, gastroenteritis, pancreatitis, or myocardial infarction, which increases insulin requirements temporarily and acutely, and is characterized by hyperglycemia, ketonemia, and a high-AG acidosis. Nevertheless, the plasma glucose may be normal or only slightly elevated in the setting of starvation ketoacidosis or in diabetics receiving antagonists of the proximal tubule sodium-glucose co-transporter 2 (SGLT2). These agents cause glycosuria, an osmotic diuresis, and lower the plasma glucose. Ketoacidosis can occur in patients receiving SGLT2 antagonists for the same reasons as in classical DKA, but the plasma glucose is typically normal or only slightly elevated. The accumulation of ketoacids in plasma accounts for the increment in the AG in both classical DKA and euglycemic DKA. Measurement of urine ketones (by the dipstick nitroprusside reaction) does not detect  $\beta$ -hydroxybutyrate and may underestimate the degree of ketosis (see below). Excretion of ketoacids obliges the excretion of cations, such as  $\text{Na}^+$  and  $\text{K}^+$ , contributing to volume depletion and  $\text{Cl}^-$  retention. In some circumstances, a mixed non-AG-high-AG acidosis may occur simultaneously and is recognized when the  $\Delta\text{HCO}_3^-$  exceeds the  $\Delta\text{AG}$ . It should be noted that bicarbonate therapy is rarely necessary in DKA except with extreme acidemia ( $\text{pH} < 7.00$ ) or if the patient is in shock. If administered,  $\text{NaHCO}_3$  should be administered in only limited amounts because of the risk for cerebral edema. Patients with DKA are typically volume depleted and require fluid resuscitation with isotonic saline. Volume overexpansion should be avoided, however, because overly aggressive saline administration may cause hyperchloremic acidosis during or following treatment of DKA. Regular insulin should be administered IV as an initial bolus of 0.1 U/kg followed by an infusion of 0.1 U/kg/h until the AG returns to normal; see Chap. 403 for more detail.

**ALCOHOLIC KETOACIDOSIS AKA** AKA is usually associated with chronic alcoholism, binge drinking, vomiting, abdominal pain, poor

nutrition, and volume depletion. The glucose concentration is variable, and acidosis may be severe because of elevated ketones, predominantly  $\beta$ -hydroxybutyrate. The presence of a high-AG acidosis, in the absence of hyperglycemia, in a patient with chronic alcoholism suggests the diagnosis of AKA. Mixed acid-base disorders are common in AKA. Hypoperfusion may enhance lactic acid production (mixed high-AG acidosis), chronic respiratory alkalosis may accompany liver disease (mixed high-AG acidosis and respiratory alkalosis), and metabolic alkalosis can result from vomiting (mixed high-AG acidosis and metabolic alkalosis:  $\Delta\text{AG}$  exceeds  $\Delta\text{HCO}_3^-$ ). As the circulation is restored by administration of IV fluids, the preferential accumulation of  $\beta$ -hydroxybutyrate is then shifted to acetoacetate. This explains the common clinical observation of an increasingly positive nitroprusside reaction (ketones) as the circulation is restored. The nitroprusside reaction can detect acetoacetic acid but not  $\beta$ -hydroxybutyrate, so that the degree of ketosis and ketonuria can not only change with therapy, but can be underestimated initially. Therefore, the plasma  $\beta$ -hydroxybutyrate level should be measured. Patients with AKA usually present with relatively normal renal function, as opposed to DKA, where renal function is often compromised because of volume depletion (osmotic diuresis) or diabetic nephropathy. The AKA patient with normal renal function may excrete relatively large quantities of ketoacids and retain  $\text{Cl}^-$  and, therefore, may have a mixed high-AG-non-AG metabolic acidosis ( $\Delta\text{HCO}_3^-$  exceeds  $\Delta\text{AG}$ ).

## TREATMENT

### Alcoholic Ketoacidosis

Extracellular fluid deficits almost always accompany AKA and should be repaired by IV administration, initially, of saline and glucose (5% dextrose in 0.9% NaCl). Hypophosphatemia, hypokalemia, and hypomagnesemia may coexist and should be monitored carefully and corrected when indicated. Hypophosphatemia may emerge 12–24 h after admission, exacerbated by glucose infusion, and, if severe, may induce marked muscle weakness, hemolysis, rhabdomyolysis, or respiratory arrest. Upper gastrointestinal hemorrhage, pancreatitis, and pneumonia may accompany this disorder.

**Drug- and Toxin-Induced Acidosis • SALICYLATES (See also Chap. 458)** Salicylate intoxication in adults usually causes respiratory alkalosis or a mixture of high-AG metabolic acidosis and respiratory alkalosis. Only a portion of the AG is due to salicylates. Lactic acid production is also often increased.

## TREATMENT

### Salicylate-Induced Acidosis

Vigorous gastric lavage with isotonic saline (not  $\text{NaHCO}_3$ ) should be initiated immediately. All patients should receive at least one round of activated charcoal per nasogastric tube (1 g/kg up to 50 g). To facilitate excretion of salicylate in the acidotic patient, IV  $\text{NaHCO}_3$  is administered in amounts adequate to alkalinize the urine (urine  $\text{pH} > 7.5$ ) and to maintain urine output. Raising urine pH from 6.5 to 7.5 increases salicylate clearance fivefold. Patients with coexisting respiratory alkalosis should also receive  $\text{NaHCO}_3$  cautiously to avoid excessive alkalemia. Acetazolamide may be administered in the face of alkalemia, when an alkaline diuresis cannot be achieved, or to ameliorate volume overload associated with  $\text{NaHCO}_3$  administration. Acetazolamide may cause systemic metabolic acidosis if the excreted  $\text{HCO}_3^-$  is not replaced, a circumstance that can markedly reduce salicylate clearance. Hypokalemia should be anticipated with vigorous bicarbonate therapy and should be treated promptly and aggressively. Glucose-containing fluids should be administered because of the danger of hypoglycemia. Excessive insensible fluid losses may cause severe volume depletion and

hypernatremia. If renal failure prevents rapid clearance of salicylate, hemodialysis should be performed against a standard bicarbonate dialysate ( $[HCO_3^-] = 30\text{--}35 \text{ meq/L}$ ).

**ALCOHOLS** Under most physiologic conditions, sodium, urea, and glucose generate the osmotic pressure of blood. Plasma osmolality is calculated according to the following expression:  $P_{osm} = 2Na^+ + Glu + BUN$  (all in mmol/L), or, using conventional laboratory values in which glucose and BUN are expressed in mg/dL:  $P_{osm} = 2Na^+ + Glu/18 + BUN/2.8$ . The calculated and determined osmolality should agree within 10–15 mmol/kg H<sub>2</sub>O. When the measured osmolality exceeds the calculated osmolality by >10–15 mmol/kg H<sub>2</sub>O, one of two circumstances prevails. Either the serum sodium is spuriously low, as with hyperlipidemia or hyperproteinemia (pseudohyponatremia), or osmolytes other than sodium salts, glucose, or urea have accumulated in plasma. Examples of such osmolytes include mannitol, radiocontrast media, ethanol, isopropyl alcohol, ethylene glycol, propylene glycol, methanol, and acetone. In this situation, the difference between the calculated osmolality and the measured osmolality (*osmolar gap*) is proportional to the concentration of the unmeasured solute. With an appropriate clinical history and index of suspicion, identification of an osmolar gap is helpful in identifying the presence of toxic alcohol-associated AG acidosis. Three alcohols may cause fatal intoxications: ethylene glycol, methanol, and isopropyl alcohol. All cause an elevated osmolal gap, but only the first two cause a high-AG acidosis. Isopropyl alcohol ingestion does not typically elevate the AG unless extreme overdose causes hypotension and lactic acid acidosis.

**ETHYLENE GLYCOL** (See also Chap. 458) Ethylene glycol (EG) (commonly used in antifreeze, but also in brake fluid and windshield washer fluid deicers) is metabolized by alcohol dehydrogenase, and ingestion of EG leads to a metabolic acidosis and severe damage to the CNS, heart, lungs, and kidneys. The combination of both a high AG and osmolar gap is highly suspicious for EG or methanol intoxication. The combination of a high AG and high osmolar gap in a patient suspected of EG ingestion should be taken as evidence of EG toxicity prior to measurement of EG levels, and treatment should not be delayed. The osmolar gap may be elevated earlier than the AG, and as the osmolar gap declines, the AG increases. The increased AG and osmolar gap in EG intoxication are attributable to EG and its metabolites, glycolate, oxalate, and other organic acids. Lactic acid production increases secondary to inhibition of the tricarboxylic acid cycle and altered intracellular redox state and may contribute to the high AG. Acute tubule injury is caused initially by glycolate and later is amplified by tubule obstruction from oxalate crystals.

## TREATMENT

### Ethylene Glycol Intoxication

This includes the prompt institution of IV isotonic fluids, thiamine and pyridoxine supplements, fomepizole, and usually, hemodialysis. Both fomepizole and ethanol compete with EG for metabolism by alcohol dehydrogenase. Fomepizole (4-methylpyrazole; 15 mg/kg IV over 30 min as a loading dose, then 10 mg/kg for four doses every 12 h) is the agent of choice and offers the advantages of a predictable decline in EG levels without excessive obtundation, as seen during ethyl alcohol infusion. Fomepizole should be continued until blood pH is normal or the osmolar gap is <10 mOsm/kg H<sub>2</sub>O. Hemodialysis is indicated when the arterial pH is <7.3, a high-AG acidosis is present, the osmolar gap exceeds 20 mOsm/kg H<sub>2</sub>O, or there is evidence of end organ damage such as CNS manifestations and kidney failure.

**METHANOL** (See also Chap. 458) The ingestion of methanol (wood alcohol) causes metabolic acidosis, and its metabolites formaldehyde and formic acid cause severe optic nerve and CNS damage. Lactic acid, ketoacids, and other unidentified organic acids may contribute to the acidosis. Due to its low molecular mass (32 Da), an osmolar gap is present and may precede the elevation of the AG.

## TREATMENT

### Methanol Intoxication

Treatment of methanol intoxication is similar to that for EG intoxication, including general supportive measures, fomepizole, and hemodialysis.

**PROPYLENE GLYCOL** Propylene glycol is the vehicle used in IV administration of diazepam, lorazepam, phenobarbital, nitroglycerine, etomidate, enoximone, and phenytoin. Propylene glycol is generally safe for limited use in these IV preparations, but toxicity has been reported in the setting of the intensive care unit in patients receiving frequent or continuous therapy, where the propylene glycol vehicle may accumulate in the plasma. This form of high-gap acidosis should be considered in patients with unexplained high-gap acidosis, hyperosmolality, and clinical deterioration, especially in the setting of treatment for alcohol withdrawal. Propylene glycol, like EG and methanol, is metabolized by alcohol dehydrogenase. With intoxication by propylene glycol, the first response is to stop the offending infusion. Additionally, fomepizole should also be administered in acidotic patients.

**ISOPROPYL ALCOHOL** Ingested isopropanol is absorbed rapidly and may be fatal when as little as 150 mL of rubbing alcohol, solvent, or deicer is consumed. A plasma level >400 mg/dL is life-threatening. Isopropyl alcohol is metabolized by alcohol dehydrogenase to acetone. The characteristic features differ significantly from EG and methanol intoxication in that the parent compound, not the metabolites, causes toxicity, and a high-AG acidosis is *not* present because acetone is rapidly excreted. Both isopropyl alcohol and acetone increase the osmolar gap, and hypoglycemia is common. Alternative diagnoses should be considered if the patient does not improve significantly within a few hours. Patients with hemodynamic instability with plasma levels above 400 mg/dL should be considered for hemodialysis.

## TREATMENT

### Isopropyl Alcohol Toxicity

Isopropanol alcohol toxicity is treated by supportive therapy, IV fluids, pressors, ventilatory support if needed, and acute hemodialysis for prolonged coma, hemodynamic instability, or levels >400 mg/dL.

**PYROGLUTAMIC ACID** Acetaminophen-induced high-AG metabolic acidosis is uncommon but is recognized in either patients with acetaminophen overdose or malnourished or critically ill patients receiving acetaminophen in typical dosage. 5-Oxoproline accumulation after acetaminophen should be suspected in the setting of an unexplained high-AG acidosis without elevation of the osmolar gap in patients receiving acetaminophen. The first step in treatment is to immediately discontinue acetaminophen. Additionally, sodium bicarbonate IV should be given. Although N-acetylcysteine has been suggested, it is not proven that it hastens the metabolism of 5-oxoproline by increasing intracellular glutathione concentrations in this setting, as assumed.

**Chronic Kidney Disease** (See also Chap. 311) The hyperchloremic acidosis of moderate chronic kidney disease (CKD; stage 3) is eventually converted to the high-AG acidosis of advanced renal failure (stages 4 and 5 CKD). Poor filtration and reabsorption of organic anions contribute to the pathogenesis. As renal disease progresses, the number of functioning nephrons eventually becomes insufficient to keep pace with net acid production. Uremic acidosis in advanced CKD is characterized, therefore, by a reduced rate of NH<sub>4</sub><sup>+</sup> production and excretion. Alkaline salts from bone buffer the acid retained in CKD. Despite significant retention of acid (up to 20 mmol/d), the serum [HCO<sub>3</sub><sup>-</sup>] does not typically decrease further, indicating participation of buffers outside the extracellular compartment. Therefore, the trade-off in untreated chronic metabolic acidosis of CKD stages 3 and 4 is significant loss of bone mass due to reduction in bone calcium carbonate.

Chronic acidosis also contributes significantly to muscle wasting and disability in advancing CKD.

## TREATMENT

### Metabolic Acidosis of Chronic Kidney Disease

Because of the association of metabolic acidosis in advanced CKD with muscle catabolism, bone disease, and more rapid progression of CKD, both the “uremic acidosis” of end-stage renal disease and the non-AG metabolic acidosis of stages 3 and 4 CKD require oral alkali replacement to increase and maintain the  $[HCO_3^-]$  to a value >22 mmol/L. This can be accomplished with relatively modest amounts of alkali (1.0–1.5 mmol/kg body weight per day) and has been shown to slow the progression of CKD. Either NaHCO<sub>3</sub> tablets (650-mg tablets contain 7.8 meq) or oral sodium citrate (Shohl's solution) is effective. Moreover, addition of fruits and vegetables (citrate) to the diet may increase the plasma  $[HCO_3^-]$  and slow progression.

### NON ANION GAP METABOLIC ACIDOSES

Alkali can be lost from the gastrointestinal tract as a result of diarrhea or from the kidneys due to renal tubular abnormalities (e.g., renal tubular acidosis [RTA]). In these disorders (Table 55-5), reciprocal

TABLE 55-5 Causes of Non-Anion Gap Acidosis

- I. Gastrointestinal bicarbonate loss
  - A. Diarrhea
  - B. External pancreatic or small-bowel drainage
  - C. Ureterosigmoidostomy, jejunal loop, ileal loop
  - D. Drugs
    - 1. Calcium chloride (acidifying agent)
    - 2. Magnesium sulfate (diarrhea)
    - 3. Cholestyramine (bile acid diarrhea)
- II. Renal acidosis
  - A. Hypokalemia
    - 1. Proximal RTA (type 2)
      - Drug-induced: acetazolamide, topiramate
    - 2. Distal (classic) RTA (type 1)
      - Drug-induced: amphotericin B, ifosfamide
  - B. Hyperkalemia
    - 1. Generalized distal nephron dysfunction (type 4 RTA)
      - a. Selective aldosterone deficiency
      - b. Mineralocorticoid resistance (PHA I, autosomal dominant)
      - c. Voltage defect (PHA I, autosomal recessive, and PHA II)
      - d. Hyporeninemic hypoaldosteronism
      - e. Tubulointerstitial disease
  - C. Normokalemia
    - 1. Chronic progressive kidney disease
- III. Drug-induced hyperkalemia (with renal insufficiency)
  - A. Potassium-sparing diuretics (amiloride, triamterene, spironolactone, eplerenone)
  - B. Trimethoprim
  - C. Pentamidine
  - D. ACE-Is and ARBs
  - E. Nonsteroidal anti-inflammatory drugs
  - F. Calcineurin inhibitors
  - G. Heparin in critically ill patients
- IV. Other
  - A. Acid loads (ammonium chloride, hyperalimentation)
  - B. Loss of potential bicarbonate: ketosis with ketone excretion
  - C. Expansion acidosis (rapid saline administration)
  - D. Hippurate
  - E. Cation exchange resins

**Abbreviations:** ACE-I, angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blocker; PHA, pseudohypoaldosteronism; RTA, renal tubular acidosis.

changes in  $[Cl^-]$  and  $[HCO_3^-]$  result in a normal AG. In non-AG acidosis, therefore, the increase in  $[Cl^-]$  above the normal value approximates the decrease in  $[HCO_3^-]$ . The absence of such a relationship suggests a mixed disturbance.

Stool contains a higher concentration of  $HCO_3^-$  and decomposed  $HCO_3^-$  than plasma so that metabolic acidosis develops in diarrhea. Instead of an acid urine pH (as anticipated with systemic acidosis), urine pH is usually >6 because metabolic acidosis and hypokalemia increase renal synthesis and excretion of  $NH_4^+$ , thus providing a urinary buffer that increases urine pH. Metabolic acidosis due to gastrointestinal losses with a high urine pH can be differentiated from RTA because urinary  $NH_4^+$  excretion is typically low in RTA and high with diarrhea. Urinary  $NH_4^+$  levels are not routinely measured by clinical laboratories but can be estimated by calculating the urine anion gap (UAG):  $UAG = [Na^+ + K^+]_u - [Cl^-]_u$ . When  $[Cl^-]_u > [Na^+ + K^+]_u$ , the UAG is negative by definition. This suggests that the urine ammonium level is appropriately increased, suggesting an extrarenal cause of the acidosis. Conversely, when the UAG is positive, the urine ammonium level is predictably low, suggesting a renal tubular origin of the acidosis. Recent studies have shown a poor correlation between the UAG and the measured urine ammonium, thus calling the estimation of urine ammonium by calculation of the UAG into question. Therefore, clinical laboratories should be encouraged to measure urine ammonium by adaptation of automated plasma ammonium assays, using the enzymatic method, if the urine sample is diluted 1:200 in normal saline.

Proximal RTA (type 2 RTA) (Chap. 315) is most often due to generalized proximal tubular dysfunction manifested by glycosuria, generalized aminoaciduria, and phosphaturia (Fanconi syndrome). When the plasma  $[HCO_3^-]$  is low, the urine pH is acid ( $pH < 5.5$ ) but exceeds 5.5 with alkali therapy. The fractional excretion of  $[HCO_3^-]$  may exceed 10–15% when the serum  $HCO_3^-$  is >20 mmol/L. Because of the defect in  $HCO_3^-$  reabsorption by the proximal tubule, therapy with NaHCO<sub>3</sub> will enhance delivery of  $HCO_3^-$  to the distal nephron and enhance renal potassium secretion, thereby causing hypokalemia.

The typical findings in acquired or inherited forms of classic distal RTA (type 1 RTA) include hypokalemia, a non-AG metabolic acidosis, low urinary  $NH_4^+$  excretion (positive UAG, low urine  $[NH_4^+]$ ), and inappropriately high urine pH ( $pH > 5.5$ ). Most patients have hypocitraturia and hypercalciuria; nephrolithiasis, nephrocalcinosis, and bone disease are common. In generalized distal RTA (type 4 RTA), hyperkalemia is disproportionate to the reduction in glomerular filtration rate (GFR) because of coexisting dysfunction of potassium and acid secretion. Urinary ammonium excretion is invariably depressed, and kidney function may be compromised secondary to diabetic nephropathy, obstructive uropathy, or chronic tubulointerstitial disease.

Hyporeninemic hypoaldosteronism typically presents as a non-AG metabolic acidosis in older adults with diabetes mellitus or tubulointerstitial disease and CKD (estimated GFR 20–50 mL/min) with hyperkalemia ( $[K^+] 5.2$ –6.0 mmol/L), concurrent hypertension, and congestive heart failure. Both the metabolic acidosis and the hyperkalemia are out of proportion to impairment in GFR. Nonsteroidal anti-inflammatory drugs, trimethoprim, pentamidine, angiotensin-converting enzyme (ACE) inhibitors, and angiotensin receptor blockers (ARBs) can also increase the risk for hyperkalemia and a non-AG metabolic acidosis in patients with CKD, especially from diabetic nephropathy (Table 55-5).

## TREATMENT

### Non-Anion Gap Metabolic Acidoses

For non-AG acidosis due to gastrointestinal losses of bicarbonate, NaHCO<sub>3</sub> may be administered intravenously or orally, as determined by the severity of both the acidosis and the accompanying volume depletion. Proximal RTA is the most challenging of the RTAs to treat if the goal is to restore the serum  $[HCO_3^-]$  to normal because administration of oral alkali increases urinary excretion of bicarbonate and potassium. In patients with proximal RTA (type 2), potassium

administration is typically required. An oral solution of sodium and potassium citrate (citric acid 334 mg, sodium citrate 500 mg, and potassium citrate 550 mg per 5 mL) may be prescribed for this purpose (Virtrate or Cytra-3). In classical distal RTA (type 1), hypokalemia should be corrected first. When accomplished, alkali therapy with either sodium citrate (Shohl's solution) or NaHCO<sub>3</sub> tablets (650-mg tablets contain 7.8 meq) should be initiated to correct and maintain the serum [HCO<sub>3</sub><sup>-</sup>] in the range of 24–26 meq/L. Type 1 RTA patients typically respond to chronic alkali therapy readily, and the benefits of adequate alkali therapy include a decrease in the frequency of nephrolithiasis, improvement in bone density, resumption of normal growth patterns in children, and preservation of kidney function in both adults and children. For type 4 RTA, attention must be paid to the dual goals of correction of the metabolic acidosis, using the same approach as for classical distal renal tubular acidosis (type 1 RTA), and also correction of the plasma [K<sup>+</sup>]. Restoration of normokalemia increases urinary net acid excretion and consequently can greatly improve the metabolic acidosis. Chronic administration of oral sodium polystyrene sulfonate (15 g of power prepared as an oral solution, without sorbitol, once daily 2–3 times per week) is sometimes used but is unpalatable, and patient compliance is low. The nonabsorbed, calcium-potassium cation exchange polymer, patiromer, may be considered for type 4 RTA patients with hyperkalemia because it is more palatable. It is administered as 8.4-g packets of powder for suspension PO twice daily with dose adjustment at weekly intervals, based on the plasma [K<sup>+</sup>], not to exceed 25.2 g/d. Additionally, the diet should be low in potassium-containing foods or supplements (salt substitute), all potassium-retaining medications should be discontinued, and a loop diuretic may be administered. Finally, patients with documented isolated hypoaldosteronism should receive fludrocortisone, but the dose varies with the cause of the hormone deficiency. This agent should be administered very cautiously and in combination with furosemide in patients with edema and hypertension because of possible aggravation of these conditions.

## METABOLIC ALKALOSIS

Metabolic alkalosis is established by an elevated arterial pH, an increase in the serum [HCO<sub>3</sub><sup>-</sup>], and an increase in Pa<sub>O<sub>2</sub></sub>, as a result of compensatory alveolar hypoventilation (Table 55-1). It is often accompanied by hypochloremia and hypokalemia. The elevation in arterial pH establishes the diagnosis because pH is decreased in respiratory acidosis, even though both have an elevated Pa<sub>O<sub>2</sub></sub>. Metabolic alkalosis frequently occurs as a mixed acid-base disorder in association with either respiratory acidosis, respiratory alkalosis, or metabolic acidosis.

### ■ ETIOLOGY AND PATHOGENESIS

Metabolic alkalosis occurs as a result of net gain of [HCO<sub>3</sub><sup>-</sup>] or loss of nonvolatile acid (usually HCl by vomiting) from the extracellular fluid. When vomiting causes loss of HCl from the stomach, HCO<sub>3</sub><sup>-</sup> secretion cannot be initiated in the small bowel, and thus, HCO<sub>3</sub><sup>-</sup> is retained in the extracellular fluid. Thus, vomiting or nasogastric suction is an example of the *generation stage* of metabolic alkalosis, in which the loss of acid typically causes alkalosis. Upon cessation of vomiting, the *maintenance stage* ensues because secondary factors prevent the kidneys from excreting HCO<sub>3</sub><sup>-</sup> appropriately.

Maintenance of metabolic alkalosis, therefore, represents a failure of the kidneys to eliminate excess HCO<sub>3</sub><sup>-</sup> from the extracellular compartment. The kidneys will retain, rather than excrete, the excess alkali and maintain the alkalosis if (1) volume deficiency, chloride deficiency, and K<sup>+</sup> deficiency exist in combination with a reduced GFR (associated with a low urine [Cl<sup>-</sup>]) or (2) hypokalemia exists because of autonomous hyperaldosteronism (normal urine [Cl<sup>-</sup>]). In the first example, saline-responsive metabolic alkalosis is corrected by extracellular fluid volume (ECFV) restoration (IV administration of NaCl and KCl), whereas, in the latter, it may be necessary to repair the alkalosis by pharmacologic or surgical intervention, not with saline administration (saline-unresponsive metabolic alkalosis).

TABLE 55-6 Causes of Metabolic Alkalosis

- I. Exogenous HCO<sub>3</sub><sup>-</sup> loads
  - A. Acute alkali administration
  - B. Milk-alkali syndrome
- II. Effective ECFV contraction, normotension, K<sup>+</sup> deficiency, and secondary hyperreninemic hyperaldosteronism
  - A. Gastrointestinal origin
    - 1. Vomiting
    - 2. Gastric aspiration
    - 3. Congenital chlорidorrhea
    - 4. Gastrocystoplasty
    - 5. Villous adenoma
  - B. Renal origin
    - 1. Diuretic use (thiazides and loop diuretics)
    - 2. Posthypercapnic state
    - 3. Hypercalcemia/hypoparathyroidism
    - 4. Recovery from lactic acidosis or ketoacidosis
    - 5. Nonreabsorbable anions including penicillin, carbenicillin
    - 6. Mg<sup>2+</sup> deficiency
    - 7. K<sup>+</sup> depletion
    - 8. Bartter's syndrome (loss-of-function mutations of transporters and ion channels in TALH)
    - 9. Gitelman's syndrome (loss-of-function mutation of Na<sup>+</sup>-Cl<sup>-</sup> cotransporter in DCT)
- III. ECFV expansion, hypertension, K<sup>+</sup> deficiency, and mineralocorticoid excess
  - A. High renin
    - 1. Renal artery stenosis
    - 2. Accelerated hypertension
    - 3. Renin-secreting tumor
    - 4. Estrogen therapy
  - B. Low renin
    - 1. Primary aldosteronism
      - a. Adenoma
      - b. Hyperplasia
      - c. Carcinoma
    - 2. Adrenal enzyme defects
      - a. 11β-Hydroxylase deficiency
      - b. 17α-Hydroxylase deficiency
    - 3. Cushing's syndrome or disease
    - 4. Other
      - a. Licorice
      - b. Carbenoxolone
      - c. Chewer's tobacco
- IV. Gain-of-function mutation of sodium channel in DCT with ECFV expansion, hypertension, K<sup>+</sup> deficiency, and hyporeninemic-hypoaldosteronism
  - A. Liddle's syndrome

Abbreviations: DCT, distal convoluted tubule; ECFV, extracellular fluid volume; TALH, thick ascending limb of Henle's loop.

### ■ DIFFERENTIAL DIAGNOSIS

To establish the cause of metabolic alkalosis (Table 55-6), it is necessary to assess the status of the ECFV, the recumbent and upright blood pressure (to determine if orthostasis is present), the serum [K<sup>+</sup>], the urine [Cl<sup>-</sup>], and in some circumstances, the renin-aldosterone system. For example, the presence of chronic hypertension and chronic hypokalemia in an alkalemic patient suggests either mineralocorticoid excess or that the hypertensive patient is receiving diuretics. Low plasma renin activity and values for urine [Cl<sup>-</sup>] >20 meq/L in a patient who is not taking diuretics suggest primary mineralocorticoid excess. The combination of hypokalemia and alkalosis in a normotensive, nonedematous patient can be due to Bartter's or Gitelman's syndrome, magnesium deficiency, vomiting, exogenous alkali, or diuretic ingestion. Measurement of urine electrolytes (especially the urine [Cl<sup>-</sup>]) and screening of the urine for diuretics are recommended. If the urine is alkaline, with an elevated [Na<sup>+</sup>]<sub>u</sub> and [K<sup>+</sup>]<sub>u</sub> but low [Cl<sup>-</sup>]<sub>u</sub>, the diagnosis is usually

either vomiting (overt or surreptitious) or alkali ingestion. If the urine is relatively acid with low concentrations of  $\text{Na}^+$ ,  $\text{K}^+$ , and  $\text{Cl}^-$ , the most likely possibilities are prior vomiting, the posthypercapnic state, or prior diuretic ingestion. If the urine sodium, potassium, and chloride concentrations are not depressed, magnesium deficiency, Bartter's or Gitelman's syndrome, or current diuretic ingestion should be considered. Bartter's syndrome is distinguished from Gitelman's syndrome by the presence of hypocalciuria in the latter disorder.

**Alkali Administration** Chronic administration of alkali to individuals with normal renal function rarely causes alkalosis. However, in patients with coexistent hemodynamic disturbances associated with effective ECFV depletion (e.g., heart failure), alkalosis can develop because of diminished capacity to excrete  $\text{HCO}_3^-$  or enhanced reabsorption of  $\text{HCO}_3^-$ . Such patients include those who receive  $\text{NaHCO}_3$  (PO or IV), citrate loads IV (transfusions of whole blood, or therapeutic apheresis), or antacids plus cation-exchange resins (aluminum hydroxide and sodium polystyrene sulfonate). Nursing home patients receiving enteral tube feedings have a higher incidence of metabolic alkalosis than nursing home patients receiving regular diets.

### METABOLIC ALKALOSIS ASSOCIATED WITH ECFV CONTRACTION, $\text{K}^+$ DEPLETION, AND SECONDARY HYPERRENINEMIC HYPERALDOSTERONISM

**Gastrointestinal Origin** Gastrointestinal loss of  $\text{H}^+$  from vomiting or gastric aspiration causes simultaneous addition of  $\text{HCO}_3^-$  into the extracellular fluid. During active vomiting, the filtered load of bicarbonate reaching the kidneys is acutely increased and will exceed the reabsorptive capacity of the proximal tubule for  $\text{HCO}_3^-$  absorption. Subsequently, enhanced delivery of  $\text{HCO}_3^-$  to the distal nephron, where the capacity for  $\text{HCO}_3^-$  reabsorption is lower, will result in excretion of alkaline urine that stimulates potassium secretion. When vomiting ceases, the persistence of volume, potassium, and chloride depletion triggers maintenance of the alkalosis because these conditions promote  $\text{HCO}_3^-$  reabsorption. Correction of the contracted ECFV with  $\text{NaCl}$  and repair of  $\text{K}^+$  deficits with  $\text{KCl}$  corrects the acid-base disorder by restoring the ability of the kidney to excrete the excess bicarbonate.

**Renal Origin • DIURETICS** (See also Chap. 258) Diuretics such as thiazides and loop diuretics (furosemide, bumetanide, torsemide) increase excretion of salt and acutely diminish the ECFV without altering the total body bicarbonate content. The serum  $[\text{HCO}_3^-]$  increases because the reduced ECFV "contracts" around the  $[\text{HCO}_3^-]$  in plasma (contraction alkalosis). The chronic administration of diuretics tends to generate an alkalosis by increasing distal salt delivery so that both  $\text{K}^+$  and  $\text{H}^+$  secretion are stimulated. The alkalosis is maintained by persistence of the contraction of the ECFV, secondary hyperaldosteronism,  $\text{K}^+$  deficiency, and the direct effect of the diuretic (as long as diuretic administration continues). Discontinuing the diuretic and providing isotonic saline to correct the ECFV deficit will repair the alkalosis.

**SOLUTE LOSING DISORDERS: BARTTER'S SYNDROME AND GITELMAN'S SYNDROME** See Chap. 315.

**NON REABSORBABLE ANIONS AND MAGNESIUM DEFICIENCY** Administration of large quantities of the penicillin derivatives carbencillin or ticarcillin cause their non-reabsorbable anions to appear in the distal tubule. This increases the transepithelial potential difference in the collecting tubule and thereby enhances  $\text{H}^+$  and  $\text{K}^+$  secretion.  $\text{Mg}^{2+}$  deficiency may occur with chronic administration of thiazide diuretics, alcoholism, and malnutrition, and in Gitelman's syndrome, it potentiates the development of hypokalemic alkalosis by enhancing distal acidification through stimulation of renin and hence aldosterone secretion.

**POTASSIUM DEPLETION** Chronic  $\text{K}^+$  depletion as a result of extreme dietary potassium insufficiency, diuretics, or alcohol abuse may initiate metabolic alkalosis by increasing urinary net acid excretion. The

renal generation of  $\text{NH}_4^+$  (ammoniagenesis) is upregulated directly by hypokalemia. Chronic  $\text{K}^+$  deficiency also upregulates the  $\text{H}^+$ ,  $\text{K}^+$ -ATPases in the distal tubule and collecting duct to increase  $\text{K}^+$  absorption while simultaneously increasing  $\text{H}^+$  secretion. Alkalosis associated with severe  $\text{K}^+$  depletion is resistant to salt administration, but repair of the  $\text{K}^+$  deficiency corrects the alkalosis. Potassium depletion often occurs concurrent with magnesium deficiency in alcoholics with malnutrition.

**AFTER TREATMENT OF LACTIC ACIDOSIS OR KETOACIDOSIS** When an underlying stimulus for the generation of lactic acid or ketoacid is corrected, such as shock or severe volume depletion by volume restoration, or with insulin therapy, the lactate or ketones are metabolized to yield an equivalent amount of  $\text{HCO}_3^-$ . Exogenous sources of  $\text{HCO}_3^-$  will be additive to that amount generated by organic anion metabolism and may create a surfeit of  $\text{HCO}_3^-$  ("rebound alkalosis").

**POSTHYPERCAPNIA** Prolonged  $\text{CO}_2$  retention with chronic respiratory acidosis enhances renal  $\text{HCO}_3^-$  absorption and the generation of new  $\text{HCO}_3^-$  (increased net acid excretion). Metabolic alkalosis results from the persistently elevated  $[\text{HCO}_3^-]$  when the elevated  $\text{Pa}_\text{CO}_2$  is abruptly returned toward normal.

### METABOLIC ALKALOSIS ASSOCIATED WITH ECFV EXPANSION, HYPERTENSION, AND MINERALOCORTICOID EXCESS

Increased aldosterone levels may be the result of autonomous primary adrenal overproduction or of secondary aldosterone release due to renal overproduction of renin. Mineralocorticoid excess increases net acid excretion and may result in metabolic alkalosis, which is typically exacerbated by associated  $\text{K}^+$  deficiency. Salt retention and hypertension are due to upregulation of the epithelial  $\text{Na}^+$  channel (ENaC) in the collecting tubule in response to aldosterone. The kaliuresis persists because of mineralocorticoid excess and stimulation of ENaC, causing an increase in transepithelial voltage, which enhances  $\text{K}^+$  excretion. Persistent  $\text{K}^+$  depletion may cause polydipsia and polyuria.

Liddle's syndrome (Chap. 315) results from an inherited gain-of-function mutation of genes that regulate the collecting duct  $\text{Na}^+$  channel, ENaC. This rare monogenic form of hypertension is the result of volume expansion that secondarily suppresses aldosterone elaboration. Patients typically present with hypertension, hypokalemia, and metabolic alkalosis.

**Symptoms** With metabolic alkalosis, changes in CNS and peripheral nervous system function are similar to those of hypocalcemia (Chap. 409); symptoms include mental confusion; obtundation; and a predisposition to seizures, paresthesias, muscular cramping, tetany, aggravation of arrhythmias, and hypoxemia in chronic obstructive pulmonary disease. Related electrolyte abnormalities include hypokalemia and hypophosphatemia.

## TREATMENT

### Metabolic Alkalosis

The first goal of therapy is to correct the underlying stimulus for  $\text{HCO}_3^-$  generation. If primary aldosteronism or Cushing's syndrome is present, correction of the underlying cause will reverse the hypokalemia and alkalosis.  $[\text{H}^+]$  loss by the stomach or kidneys can be mitigated by the use of proton pump inhibitors or the discontinuation of diuretics. The second aspect of treatment is to eliminate factors that sustain the inappropriate increase in  $\text{HCO}_3^-$  reabsorption, such as ECFV contraction or  $\text{K}^+$  deficiency.  $\text{K}^+$  deficits should always be repaired. Isotonic saline is recommended to reverse the alkalosis when ECFV contraction is present. If associated conditions, such as congestive heart failure, preclude infusion of isotonic saline, renal  $\text{HCO}_3^-$  loss can be accelerated by administration of acetazolamide (125–250 mg IV), a carbonic anhydrase inhibitor, which is usually effective in patients with adequate renal function. However, acetazolamide triggers urinary  $\text{K}^+$

losses and may cause hypokalemia that should be corrected. Dilute hydrochloric acid IV (0.1 N HCl) has been advocated in extreme cases of metabolic alkalosis but causes hemolysis and must be delivered slowly in a central vein. This preparation is not available generally and must be prepared in the pharmacy. Because serious errors or harm may occur, its use is not advised. Therapy in Liddle's syndrome should include a potassium-sparing diuretic (amiloride or triamterene) to inhibit ENaC and correct both the hypertension and the hypokalemia.

## RESPIRATORY ACIDOSIS

Respiratory acidosis occurs as a result of severe pulmonary disease, respiratory muscle fatigue, or abnormalities in ventilatory control and is recognized by an increase in  $\text{PaCO}_2$  and decrease in pH ([Table 55-7](#)). In acute respiratory acidosis, there is a compensatory elevation in  $\text{HCO}_3^-$  (due to cellular buffering mechanisms) that increases 1 mmol/L for every 10-mmHg increase in  $\text{PaCO}_2$ . In chronic respiratory acidosis (>24 h), renal adaptation increases the  $[\text{HCO}_3^-]$  by 4 mmol/L for every 10-mmHg increase in  $\text{PaCO}_2$ . The serum  $\text{HCO}_3^-$  usually does not increase above 38 mmol/L.

The clinical features vary according to the severity and duration of the respiratory acidosis, the underlying disease, and whether there is accompanying hypoxemia. A rapid increase in  $\text{PaCO}_2$  (acute hypercapnia) may cause anxiety, dyspnea, confusion, psychosis, and hallucinations and may progress to coma. However, chronic hypercapnia may cause sleep disorders; loss of memory; daytime somnolence; personality changes; impairment of coordination; and motor disturbances such as tremor, myoclonic jerks, and asterixis. Headaches and other signs that mimic raised intracranial pressure, such as papilledema, abnormal reflexes, and focal muscle weakness, are also seen.

Depression of the respiratory center by a variety of drugs, injury, or disease can produce respiratory acidosis. This may occur acutely with general anesthetics, sedatives, and head trauma or chronically with sedatives, alcohol, intracranial tumors, and the syndromes of sleep-disordered breathing including the primary alveolar and obesity-hypoventilation syndromes ([Chaps. 296 and 297](#)). Abnormalities or disease in the motor neurons, neuromuscular junction, and skeletal muscle can cause hypoventilation via respiratory muscle fatigue. Mechanical ventilation, when not properly adjusted, may result in respiratory acidosis, particularly if  $\text{CO}_2$  production suddenly rises (because of fever, agitation, sepsis, or overfeeding) or alveolar ventilation decreases because of worsening pulmonary function. High levels of positive end-expiratory pressure in the presence of reduced cardiac output may cause hypercapnia as a result of large increases in alveolar dead space ([Chap. 285](#)). Permissive hypercapnia may be used to minimize intrinsic positive end-expiratory pressure in respiratory distress syndrome, but the consequential respiratory acidosis may require administration of  $\text{NaHCO}_3$  to increase the arterial pH to approximately 7.20, but not to the normal value.

Acute hypercapnia follows sudden occlusion of the upper airway or generalized bronchospasm as in severe asthma, anaphylaxis, inhalational burn, or toxin injury. Chronic hypercapnia and respiratory acidosis occur in end-stage obstructive lung disease. Restrictive disorders involving both the chest wall and the lungs can cause respiratory acidosis because the high metabolic cost of respiration causes ventilatory muscle fatigue. Advanced stages of intrapulmonary and extrapulmonary restrictive defects present as chronic respiratory acidosis.

The diagnosis of respiratory acidosis requires the measurement of  $\text{PaCO}_2$  and arterial pH. A detailed history and physical examination often indicate the cause. Pulmonary function studies ([Chap. 285](#)), including spirometry, diffusion capacity for carbon monoxide, lung volumes, and arterial  $\text{PaCO}_2$  and  $\text{O}_2$  saturation, usually make it possible to determine if respiratory acidosis is secondary to lung disease. The workup for nonpulmonary causes should include a detailed drug history, measurement of hematocrit, and assessment of upper airway, chest wall, pleura, and neuromuscular function.

TABLE 55-7 Respiratory Acid-Base Disorders

- I. Alkalosis
  - A. Central nervous system stimulation
    - 1. Pain
    - 2. Anxiety, psychosis
    - 3. Fever
    - 4. Cerebrovascular accident
    - 5. Meningitis, encephalitis
    - 6. Tumor
    - 7. Trauma
  - B. Hypoxemia or tissue hypoxia
    - 1. High altitude
    - 2. Pneumonia, pulmonary edema
    - 3. Aspiration
    - 4. Severe anemia
  - C. Drugs or hormones
    - 1. Pregnancy, progesterone
    - 2. Salicylates
    - 3. Cardiac failure
  - D. Stimulation of chest receptors
    - 1. Hemothorax
    - 2. Flail chest
    - 3. Cardiac failure
    - 4. Pulmonary embolism
  - E. Miscellaneous
    - 1. Septicemia
    - 2. Hepatic failure
    - 3. Mechanical hyperventilation
    - 4. Heat exposure
    - 5. Recovery from metabolic acidosis
- II. Acidosis
  - A. Central
    - 1. Drugs (anesthetics, morphine, sedatives)
    - 2. Stroke
    - 3. Infection
  - B. Airway
    - 1. Obstruction
    - 2. Asthma
  - C. Parenchyma
    - 1. Emphysema
    - 2. Pneumoconiosis
    - 3. Bronchitis
    - 4. Adult respiratory distress syndrome
    - 5. Barotrauma
  - D. Neuromuscular
    - 1. Poliomyelitis
    - 2. Kyphoscoliosis
    - 3. Myasthenia
    - 4. Muscular dystrophies
  - E. Miscellaneous
    - 1. Obesity
    - 2. Hypoventilation
    - 3. Permissive hypercapnia

## TREATMENT

### Respiratory Acidosis

The management of respiratory acidosis depends on its severity and rate of onset. Acute respiratory acidosis can be life-threatening, and measures to reverse the underlying cause should be undertaken simultaneously with restoration of adequate alveolar ventilation. This

may necessitate tracheal intubation and assisted mechanical ventilation. Oxygen administration should be titrated carefully in patients with severe obstructive pulmonary disease and chronic CO<sub>2</sub> retention who are breathing spontaneously (Chap. 292). When oxygen is used injudiciously, these patients may experience progression of the respiratory acidosis causing severe acidemia. Aggressive and rapid correction of hypercapnia should be avoided, because the falling Pa<sub>CO<sub>2</sub></sub> may provoke the same complications noted with acute respiratory alkalosis (i.e., cardiac arrhythmias, reduced cerebral perfusion, and seizures). The Pa<sub>CO<sub>2</sub></sub> should be lowered gradually in chronic respiratory acidosis, aiming to restore the Pa<sub>CO<sub>2</sub></sub> to baseline levels and to provide sufficient Cl<sup>-</sup> and K<sup>+</sup> to enhance the renal excretion of HCO<sub>3</sub><sup>-</sup>.

Chronic respiratory acidosis is frequently difficult to correct, but the primary goal is to institute measures that may improve lung function (Chap. 292).

## RESPIRATORY ALKALOSIS

Alveolar hyperventilation decreases Pa<sub>CO<sub>2</sub></sub> and increases the HCO<sub>3</sub><sup>-</sup>/Pa<sub>CO<sub>2</sub></sub> ratio, thus increasing pH (Table 55–7). Nonbicarbonate cellular buffers respond by consuming HCO<sub>3</sub><sup>-</sup>. Hypocapnia develops when a sufficiently strong ventilatory stimulus causes CO<sub>2</sub> output in the lungs to exceed its metabolic production by tissues. Plasma pH and [HCO<sub>3</sub><sup>-</sup>] appear to vary proportionately with Pa<sub>CO<sub>2</sub></sub> over a range from 40–15 mmHg. The relationship between arterial [H<sup>+</sup>] concentration and Pa<sub>CO<sub>2</sub></sub> is 0.7 mmol/L per mmHg (or 0.01 pH unit/mmHg), and that for plasma [HCO<sub>3</sub><sup>-</sup>] is 0.2 mmol/L per mmHg. Hypocapnia sustained for >2–6 h is further compensated by a decrease in renal ammonium and titratable acid excretion and a reduction in filtered HCO<sub>3</sub><sup>-</sup> reabsorption. Full renal adaptation to respiratory alkalosis may take several days and requires normal volume status and renal function. The kidneys appear to respond directly to the lowered Pa<sub>CO<sub>2</sub></sub> rather than to alkalosis per se. In chronic respiratory alkalosis, a 1-mmHg decrease in Pa<sub>CO<sub>2</sub></sub> causes a 0.4-to 0.5-mmol/L drop in [HCO<sub>3</sub><sup>-</sup>] and a 0.3-mmol/L decrease in [H<sup>+</sup>] (or 0.003 increase in pH).

The effects of respiratory alkalosis vary according to duration and severity but are primarily those of the underlying disease. Reduced cerebral blood flow as a consequence of a rapid decline in Pa<sub>CO<sub>2</sub></sub> may cause dizziness, mental confusion, and seizures, even in the absence of hypoxemia. The cardiovascular effects of acute hypocapnia in the conscious human are generally minimal, but in the anesthetized or mechanically ventilated patient, cardiac output and blood pressure may fall because of the depressant effects of anesthesia and positive-pressure ventilation on heart rate, systemic resistance, and venous return. Cardiac arrhythmias may occur in patients with heart disease as a result of changes in oxygen unloading by blood from a left shift in the hemoglobin-oxygen dissociation curve (Bohr effect). Acute respiratory alkalosis causes intracellular shifts of Na<sup>+</sup>, K<sup>+</sup>, and PO<sub>4</sub><sup>2-</sup> and reduces free [Ca<sup>2+</sup>] by increasing the protein-bound fraction. Hypocapnia-induced hypokalemia is usually minor.

Chronic respiratory alkalosis is the most common acid-base disturbance in critically ill patients and, when severe, portends a poor prognosis. Many cardiopulmonary disorders manifest respiratory alkalosis in their early to intermediate stages, and the finding of normocapnia and hypoxemia in a patient with hyperventilation may herald the onset of rapid respiratory failure and should prompt an assessment to determine if the patient is becoming fatigued. Respiratory alkalosis is common during mechanical ventilation.

The hyperventilation syndrome may be disabling. Paresthesia; circumoral numbness; chest wall tightness or pain; dizziness; inability to take an adequate breath; and, rarely, tetany may be sufficiently stressful to perpetuate the disorder. Arterial blood-gas analysis demonstrates an acute or chronic respiratory alkalosis, often with hypocapnia in the range of 15–30 mmHg and no hypoxemia. CNS diseases or injury can produce several patterns of hyperventilation and sustained Pa<sub>CO<sub>2</sub></sub>

levels of 20–30 mmHg. Hyperthyroidism, high caloric loads, and exercise raise the basal metabolic rate, but ventilation usually rises in proportion so that arterial blood gases are unchanged and respiratory alkalosis does not develop. Salicylates are the most common cause of drug-induced respiratory alkalosis because of direct stimulation of the medullary chemoreceptor (Chap. 458). In addition, the methylxanthines, theophylline, and aminophylline stimulate ventilation and increase the ventilatory response to CO<sub>2</sub>. Progesterone increases ventilation and lowers arterial Pa<sub>CO<sub>2</sub></sub> by as much as 5–10 mmHg. Therefore, chronic respiratory alkalosis is a common feature of pregnancy. Respiratory alkalosis is also prominent in liver failure, and the severity correlates with the degree of hepatic insufficiency. Respiratory alkalosis is often an early finding in gram-negative septicemia, before fever, hypoxemia, or hypotension develops.

The diagnosis of respiratory alkalosis depends on measurement of arterial pH and Pa<sub>CO<sub>2</sub></sub>. The plasma [K<sup>+</sup>] is often reduced and the [Cl<sup>-</sup>] increased. In the acute phase, respiratory alkalosis is not associated with increased renal HCO<sub>3</sub><sup>-</sup> excretion, but within hours, net acid excretion is reduced. In general, the HCO<sub>3</sub><sup>-</sup> concentration falls by 2.0 mmol/L for each 10-mmHg decrease in Pa<sub>CO<sub>2</sub></sub>. Chronic respiratory alkalosis occurs when hypocapnia persists for greater than 3–5 days. The decline in Pa<sub>CO<sub>2</sub></sub> reduces the serum [HCO<sub>3</sub><sup>-</sup>] by 4.0–5 mmol/L for each 10-mmHg decrease in Pa<sub>CO<sub>2</sub></sub>. It is unusual to observe a plasma HCO<sub>3</sub><sup>-</sup> <12 mmol/L as a result of a pure respiratory alkalosis. The compensatory reduction in plasma [HCO<sub>3</sub><sup>-</sup>] is so effective in chronic respiratory alkalosis that the pH may not decline significantly from the normal value. Therefore, chronic respiratory alkalosis is the only acid-base disorder for which compensation can return the pH to the normal value.

When the diagnosis of respiratory alkalosis is made, its cause should be investigated. The diagnosis of hyperventilation syndrome is made by exclusion. In difficult cases, it may be important to rule out other conditions such as pulmonary embolism, coronary artery disease, and hyperthyroidism.

## TREATMENT

### Respiratory Alkalosis

The management of respiratory alkalosis is directed toward alleviation of the underlying disorder. If respiratory alkalosis complicates ventilator management, changes in dead space and tidal volume can minimize the hypocapnia. Patients with the hyperventilation syndrome may benefit from reassurance, rebreathing from a paper bag during symptomatic attacks, and attention to underlying psychological stress. Antidepressants and sedatives are not recommended.  $\beta$ -Adrenergic blockers may ameliorate peripheral manifestations of the hyperadrenergic state.

## REFERENCES

- B K et al: Physiological approach to assessment of acid-base disturbances. *N Engl J Med* 371:1434, 2014.
- D TD: Etiologic causes of metabolic acidosis II: The normal anion gap acidosis. In *Metabolic Acidosis*. Wesson DE (ed). New York, Springer, 2016, pp. 27–38.
- H LL, D TD: Disorders of acid-base balance. In *Brenner and Rector's The Kidney*, 11th ed. Yu A et al (eds). Philadelphia, Elsevier, 2020, pp 496–536.
- K JA, M NE: Metabolic acidosis of CKD: An update. *Am J Kidney Dis* 67:307, 2016.
- K JA, M NE: Re-evaluation of the normal range of serum total CO<sub>2</sub> concentration. *Clin J Am Soc Nephrol* 13:343, 2018.
- P BF, C DJ: Electrolyte and acid-base disturbances in patients with diabetes mellitus. *N Engl J Med* 373:548, 2015.
- W DE et al: Mechanisms of metabolic acidosis-induced kidney injury in chronic kidney disease. *J Am Soc Nephrol* 31:469, 2020.

## Section 8 Alterations in the Skin

# 56

## Approach to the Patient with a Skin Disorder

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The challenge of examining the skin lies in distinguishing normal from abnormal findings, distinguishing significant findings from trivial ones, and integrating pertinent signs and symptoms into an appropriate differential diagnosis. The fact that the largest organ in the body is visible is both an advantage and a disadvantage to those who examine it. It is advantageous because no special instrumentation is necessary and because the skin can be biopsied with little morbidity. However, the casual observer can be misled by a variety of stimuli and overlook important, subtle signs of skin or systemic disease. For instance, the sometimes minor differences in color and shape that distinguish a melanoma (Fig. 56-1) from a benign nevomelanocytic nevus (Fig. 56-2) can be difficult to recognize. A variety of descriptive terms have been developed that characterize cutaneous lesions (Tables 56-1, 56-2, and 56-3; Fig. 56-3), thereby aiding in their interpretation and in the formulation of a differential diagnosis (Table 56-4). For example, the finding of scaling papules, which are present in psoriasis or atopic dermatitis, places the patient in a different diagnostic category than would hemorrhagic papules, which may indicate vasculitis or sepsis (Figs. 56-4 and 56-5, respectively). It is also important to differentiate primary from secondary skin lesions. If the examiner focuses on linear erosions overlying an area of erythema and scaling, he or she may incorrectly assume that the erosion is the primary lesion and that the redness and scale are secondary, whereas the correct interpretation would be that the patient has a pruritic eczematous dermatitis with erosions caused by scratching.

### APPROACH TO THE PATIENT

#### Skin Disorder

In examining the skin, it is usually advisable to assess the patient before taking an extensive history. This approach ensures that the entire cutaneous surface will be evaluated, and objective findings can be integrated with relevant historical data. Four basic features of a skin problem must be noted and considered during a physical examination: the *distribution* of the eruption, the *types* of primary



FIGURE 56-1 Superficial spreading melanoma. This is the most common type of melanoma. Such lesions usually demonstrate asymmetry, border irregularity, color variegation (black, blue, brown, pink, and white), a diameter  $>6$  mm, and a history of change (e.g., an increase in size or development of associated symptoms such as pruritus or pain).



FIGURE 56-2 Nevomelanocytic nevus. Nevi are benign proliferations of nevomelanocytes characterized by regularly shaped hyperpigmented macules or papules of a uniform color.

TABLE 56-1 Description of Primary Skin Lesions

**Macule:** A flat, colored lesion,  $<2$  cm in diameter, not raised above the surface of the surrounding skin. A “freckle,” or ephelid, is a prototypical pigmented macule.

**Patch:** A large ( $>2$  cm) flat lesion with a color different from the surrounding skin. This differs from a macule only in size.

**Papule:** A small, solid lesion,  $<0.5$  cm in diameter, raised above the surface of the surrounding skin and thus palpable (e.g., a closed comedone, or whitehead, in acne).

**Nodule:** A larger (0.5–5.0 cm), firm lesion raised above the surface of the surrounding skin. This differs from a papule only in size (e.g., a large dermal nevomelanocytic nevus).

**Tumor:** A solid, raised growth  $>5$  cm in diameter.

**Plaque:** A large ( $>1$  cm), flat-topped, raised lesion; edges may either be distinct (e.g., in psoriasis) or gradually blend with surrounding skin (e.g., in eczematous dermatitis).

**Vesicle:** A small, fluid-filled lesion,  $<0.5$  cm in diameter, raised above the plane of surrounding skin. Fluid is often visible, and the lesions are translucent (e.g., vesicles in allergic contact dermatitis caused by *Toxicodendron* [poison ivy]).

**Pustule:** A vesicle filled with leukocytes. Note: The presence of pustules does not necessarily signify the existence of an infection.

**Bulla:** A fluid-filled, raised, often translucent lesion  $>0.5$  cm in diameter.

**Wheal:** A raised, erythematous, edematous papule or plaque, usually representing short-lived vasodilation and vasopermeability.

**Telangiectasia:** A dilated, superficial blood vessel.

TABLE 56-2 Description of Secondary Skin Lesions

**Lichenification:** A distinctive thickening of the skin that is characterized by accentuated skinfold markings.

**Scale:** Excessive accumulation of stratum corneum.

**Crust:** Dried exudate of body fluids that may be either yellow (i.e., serous crust) or red (i.e., hemorrhagic crust).

**Erosion:** Loss of epidermis without an associated loss of dermis.

**Ulcer:** Loss of epidermis and at least a portion of the underlying dermis.

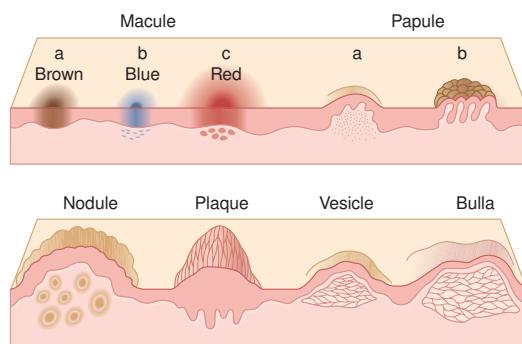
**Excoriation:** Linear, angular erosions that may be covered by crust and are caused by scratching.

**Atrophy:** An acquired loss of substance. In the skin, this may appear as a depression with intact epidermis (i.e., loss of dermal or subcutaneous tissue) or as sites of shiny, delicate, wrinkled lesions (i.e., epidermal atrophy).

**Scar:** A change in the skin secondary to trauma or inflammation. Sites may be erythematous, hypopigmented, or hyperpigmented depending on their age or character. Sites on hair-bearing areas may be characterized by destruction of hair follicles.

**TABLE 56-3** Common Dermatologic Terms

Alopecia: Hair loss, partial or complete.
Anular: Ring-shaped.
Cyst: A soft, raised, encapsulated lesion filled with semisolid or liquid contents.
Herpetiform: In a grouped configuration.
Lichenoid eruption: Violaceous to purple, polygonal lesions that resemble those seen in lichen planus.
Milia: Small, firm, white papules filled with keratin.
Morbilliform rash: Generalized, small erythematous macules and/or papules that resemble lesions seen in measles.
Nummular: Coin-shaped.
Poikiloderma: Skin that displays variegated pigmentation, atrophy, and telangiectasias.
Polycyclic lesions: A configuration of skin lesions formed from coalescing rings or incomplete rings.
Pruritus: A sensation that elicits the desire to scratch. Pruritus is often the predominant symptom of inflammatory skin diseases (e.g., atopic dermatitis, allergic contact dermatitis); it is also commonly associated with xerosis and aged skin. Systemic conditions that can be associated with pruritus include chronic renal disease, cholestasis, pregnancy, malignancy, thyroid disease, polycythemia vera, and delusions of parasitosis.

**FIGURE 56-3** A schematic representation of several common primary skin lesions (see Table 56-1).**TABLE 56-4** Selected Common Dermatologic Conditions

DIAGNOSIS	COMMON DISTRIBUTION	USUAL MORPHOLOGY	DIAGNOSIS	COMMON DISTRIBUTION	USUAL MORPHOLOGY
Acne vulgaris	Face, upper back, chest	Open and closed comedones, erythematous papules, pustules, cysts	Seborrheic keratosis	Trunk, face, extremities	Brown plaques with adherent, greasy scale; "stuck on" appearance
Rosacea	Blush area of cheeks, nose, forehead, chin	Erythema, telangiectasias, papules, pustules	Folliculitis Impetigo	Any hair-bearing area Anywhere	Follicular pustules Papules, vesicles, pustules, often with honey-colored crusts
Seborrheic dermatitis	Scalp, eyebrows, perinasal areas	Erythema with greasy yellow-brown scale	Herpes simplex	Lips, genitalia	Grouped vesicles progressing to crusted erosions
Atopic dermatitis	Antecubital and popliteal fossae; may be widespread	Patches and plaques of erythema, scaling, and lichenification; pruritus	Herpes zoster	Dermatomal, usually trunk but may be anywhere	Vesicles limited to a dermatome (often painful)
Stasis dermatitis	Ankles, lower legs over medial malleoli	Patches of erythema and scaling on background of hyperpigmentation associated with signs of venous insufficiency	Varicella	Face, trunk, relative sparing of extremities	Lesions arise in crops and quickly progress from erythematous macules, to papules, to vesicles, to pustules, to crusted sites
Dyshidrotic eczema	Palms, soles, sides of fingers, and toes	Deep vesicles	Pityriasis rosea	Trunk (Christmas tree pattern); herald patch followed by multiple smaller lesions	Symmetric erythematous papules and plaques with a collarette of scale
Allergic contact dermatitis	Anywhere	Localized erythema, vesicles, scale, and pruritus (e.g., fingers, earlobes—nickel; dorsal aspect of foot—shoe; exposed surfaces—poison ivy)	Tinea versicolor	Chest, back, abdomen, proximal extremities	Scaly hyper- or hypopigmented macules
Psoriasis	Elbows, knees, scalp, lower back, fingernails (may be generalized)	Papules and plaques covered with silvery scale; nails have pits	Candidiasis	Groin, beneath breasts, vagina, oral cavity	Erythematous macerated areas with satellite pustules; white, friable patches on mucous membranes
Lichen planus	Wrists, ankles, mouth (may be widespread)	Violaceous flat-topped papules and plaques	Dermatophytosis	Feet, groin, beard, or scalp	Varies with site (e.g., tinea corporis—scaly annular plaque)
Keratosis pilaris	Extensor surfaces of arms and thighs, buttocks	Keratotic follicular papules with surrounding erythema	Scabies	Groin, axillae, between fingers and toes, beneath breasts	Excoriated papules, burrows, pruritus
Melasma	Forehead, cheeks, temples, upper lip	Tan to brown patches	Insect bites	Anywhere	Erythematous papules with central puncta
Vitiligo	Periorificial, trunk, extensor surfaces of extremities, flexor wrists, axillae	Chalk-white macules	Cherry angioma Keloid Dermatofibroma	Trunk Anywhere (site of previous injury) Anywhere	Red, blood-filled papules Firm tumor, pink, purple, or brown Firm red to brown nodule that shows dimpling of overlying skin with lateral compression

(Continued)

TABLE 56-4 Selected Common Dermatologic Conditions (Continued)

DIAGNOSIS	COMMON DISTRIBUTION	USUAL MORPHOLOGY	DIAGNOSIS	COMMON DISTRIBUTION	USUAL MORPHOLOGY
Actinic keratosis	Sun-exposed areas	Skin-colored or red-brown macule or papule with dry, rough, adherent scale	Acrochordons (skin tags)	Groin, axilla, neck	Fleshy papules
Basal cell carcinoma	Face	Papule with pearly, telangiectatic border on sun-damaged skin	Urticaria	Anywhere	Wheals, sometimes with surrounding flare; pruritus
Squamous cell carcinoma	Face, especially lower lip, ears	Indurated and possibly hyperkeratotic lesions often showing ulceration and/or crusting	Transient acantholytic dermatosis Xerosis	Trunk, especially anterior chest Extensor extremities, especially legs	Erythematous papules Dry, erythematous, scaling patches; pruritus

and secondary lesions, the *shape* of individual lesions, and the *arrangement* of the lesions. An ideal skin examination includes evaluation of the skin, hair, and nails as well as the mucous membranes of the mouth, eyes, nose, nasopharynx, and anogenital region. In the initial examination, it is important that the patient be disrobed as completely as possible to minimize chances of missing important individual skin lesions and permit accurate assessment of the distribution of the eruption. The patient should first be viewed from a distance of about 1.5–2 m (4–6 ft) so that the general character of the skin and the distribution of lesions can be evaluated. Indeed, the distribution of lesions often correlates highly with diagnosis (Fig. 56-6). For example, a hospitalized patient with a generalized erythematous exanthem is more likely to have a drug eruption than is a patient with a similar rash limited to the sun-exposed portions of the face. Once the distribution of the lesions has been established, the nature of the primary lesion must be determined. Thus, when lesions are distributed on elbows, knees, and scalp, the most likely possibility based solely on distribution is psoriasis or dermatitis herpetiformis (Figs. 56-7 and 56-8, respectively). The primary lesion in psoriasis is a scaly papule that soon forms erythematous plaques covered with a white scale, whereas that of dermatitis herpetiformis is an urticarial papule that quickly becomes a small vesicle. In this manner, identification of the primary lesion directs the examiner toward the proper diagnosis. Secondary changes in skin can also be quite helpful. For example, scale represents excessive epidermis, while crust is the result of a discontinuous epithelial cell layer. Palpation of skin lesions can yield insight into the character of an eruption. Thus, red papules on the lower extremities that blanch

with pressure can be a manifestation of many different diseases, but hemorrhagic red papules that do not blanch with pressure indicate palpable purpura characteristic of necrotizing vasculitis (Fig. 56-4).

The shape of lesions is also an important feature. Flat, round, erythematous papules and plaques are common in many cutaneous diseases. However, target-shaped lesions that consist in part of erythematous plaques are specific for erythema multiforme (Fig. 56-9). Likewise, the arrangement of individual lesions is important. Erythematous papules and vesicles can occur in many conditions, but their arrangement in a specific linear array suggests an external etiology such as allergic contact dermatitis (Fig. 56-10) or primary irritant dermatitis. In contrast, lesions with a generalized arrangement are common and suggest a systemic etiology.

As in other branches of medicine, a complete history should be obtained to emphasize the following features:

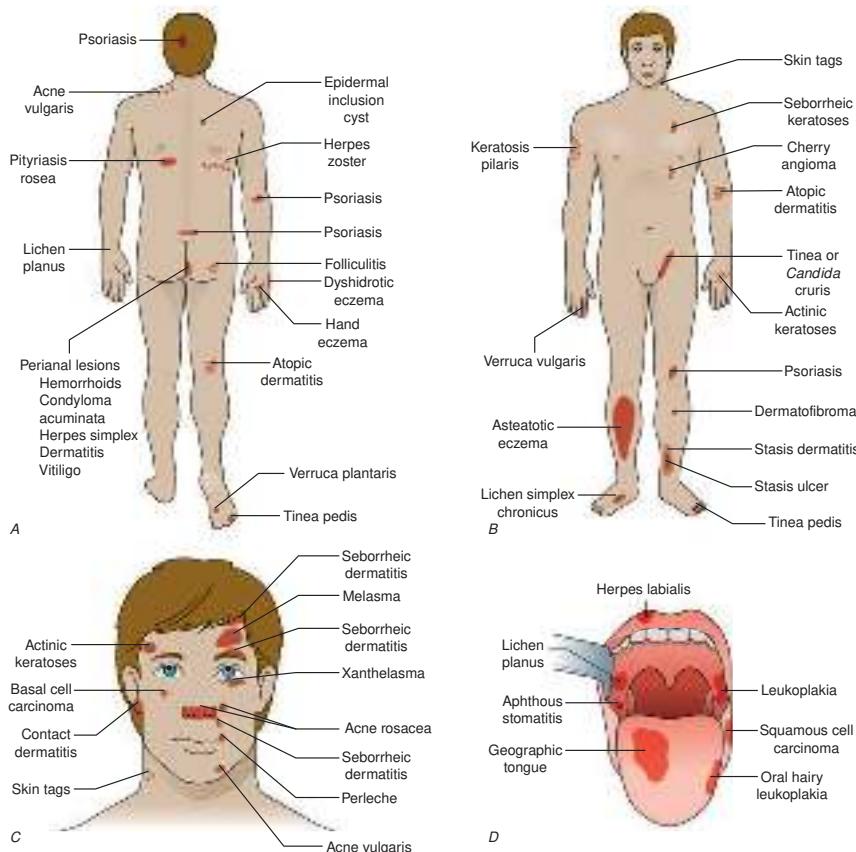
1. Evolution of lesions
  - a. Site of onset
  - b. Manner in which the eruption progressed or spread
  - c. Duration
  - d. Periods of resolution or improvement in chronic eruptions
2. Symptoms associated with the eruption
  - a. Itching, burning, pain, numbness
  - b. What, if anything, has relieved symptoms
  - c. Time of day when symptoms are most severe
3. Current or recent medications (prescribed as well as over-the-counter)
4. Associated systemic symptoms (e.g., malaise, fever, arthralgias)
5. Ongoing or previous illnesses
6. History of allergies
7. Presence of photosensitivity
8. Review of systems
9. Family history (particularly relevant for patients with melanoma, atopy, psoriasis, or acne)
10. Social, sexual, or travel history



FIGURE 56-4 Necrotizing vasculitis. Palpable purpuric papules on the lower legs are seen in this patient with cutaneous small-vessel vasculitis. (Courtesy of Robert Swerlick, MD; with permission.)



FIGURE 56-5 Meningococcemia. An example of fulminant meningococcemia with extensive angular purpuric patches. (Courtesy of Stephen E Gellis, MD; with permission.)



**FIGURE 56-6** Distribution of some common dermatologic diseases and lesions.

### ■ DIAGNOSTIC TECHNIQUES

Many skin diseases can be diagnosed on the basis of gross clinical appearance, but sometimes relatively simple diagnostic procedures can yield valuable information. In most instances, they can be performed at the bedside with a minimum of equipment.

**Skin Biopsy** A skin biopsy is a straightforward minor surgical procedure; however, it is important to biopsy a lesion that is most likely to yield diagnostic findings. This decision may require expertise in skin diseases and knowledge of superficial anatomic structures in selected areas of the body. In this procedure, a small area of skin is anesthetized with 1% lidocaine with or without epinephrine. The skin lesion in

question can be excised or saucerized with a scalpel or removed by punch biopsy. In the latter technique, a punch is pressed against the surface of the skin and rotated with downward pressure until it penetrates to the subcutaneous tissue. The circular biopsy is then lifted with forceps, and the bottom is cut with iris scissors. Biopsy sites may or may not need suture closure, depending on size and location.

**KOH Preparation** A potassium hydroxide (KOH) preparation is performed on scaling skin lesions where a fungal infection is suspected. The edge of such a lesion is scraped gently with a no. 15 scalpel blade. The removed scale is collected on a glass microscope slide, treated with 1 or 2 drops of a solution of 10–20% KOH, and placement of a cover



**FIGURE 56-7** Psoriasis. This papulosquamous skin disease is characterized by small and large erythematous papules and plaques with overlying adherent silvery scale.



**FIGURE 56-8** Dermatitis herpetiformis. This disorder typically displays pruritic, grouped papulovesicles on elbows, knees, buttocks, and posterior scalp. Vesicles are often excoriated due to associated pruritus.



**FIGURE 56-9** Erythema multiforme. This eruption is characterized by multiple erythematous plaques with a target or iris morphology. It usually represents a hypersensitivity reaction to drugs (e.g., sulfonamides) or infections (e.g., HSV). (Courtesy of the Yale Resident's Slide Collection; with permission.)

slip. KOH dissolves keratin and allows easier visualization of fungal elements. Brief heating of the slide accelerates dissolution of keratin. When the preparation is viewed under the microscope, the refractive hyphae are seen more easily when the light intensity is reduced and the condenser is lowered. This technique can be used to identify hyphae in dermatophyte infections, pseudohyphae and budding yeasts in *Candida* infections, and “spaghetti and meatballs” yeast forms in tinea versicolor. The same sampling technique can be used to obtain scale for culture of selected pathogenic organisms.

**Tzanck Smear** A Tzanck smear is a cytologic technique most often used in the diagnosis of herpesvirus infections (herpes simplex virus [HSV] or varicella-zoster virus [VZV]) (see Figs. 193-1 and 193-3). An early vesicle, not a pustule or crusted lesion, is unroofed, and the base of the lesion is scraped gently with a scalpel blade. The material is



**FIGURE 56-11** Urticaria. Discrete and confluent, edematous, erythematous papules and plaques are characteristic of this whealing eruption.

placed on a glass slide, air-dried, and stained with Giemsa or Wright's stain. Multinucleated epithelial giant cells suggest the presence of HSV or VZV; culture, immunofluorescence microscopy, or genetic testing must be performed to identify the specific virus.

**Diascopy** Diascopy is designed to assess whether a skin lesion will blanch with pressure as, for example, in determining whether a red lesion is hemorrhagic or simply blood-filled. Urticaria (Fig. 56-11) will blanch with pressure, whereas a purpuric lesion caused by necrotizing vasculitis (Fig. 56-4) will not. Diascopy is performed by pressing a microscope slide or magnifying lens against a lesion and noting the amount of blanching that occurs. Granulomas often have an opaque to transparent, brown-pink “apple jelly” appearance on diascopy.

**Dermoscopy** Dermoscopy is a noninvasive method of examining the skin surface that uses a high-quality magnifying lens and a specialized light source (i.e., a dermatoscope). Dermoscopy identifies skin structures, colors, and patterns that are not visible to the naked eye. It is particularly useful in the evaluation of pigmented skin lesions.

**Wood's Light** A Wood's lamp generates 360-nm ultraviolet (“black”) light that can be used to aid the evaluation of certain skin disorders. For example, a Wood's lamp will cause erythrasma (a superficial, intertriginous infection caused by *Corynebacterium minutissimum*) to show a characteristic coral pink color, and wounds colonized by *Pseudomonas* will appear pale blue. Tinea capitis caused by certain dermatophytes (e.g., *Microsporum canis* or *M. audouinii*) exhibits a yellow fluorescence. Pigmented lesions of the epidermis such as freckles are accentuated, while dermal pigment such as postinflammatory hyperpigmentation fades under a Wood's light. Vitiligo (Fig. 56-12)



**FIGURE 56-10** Allergic contact dermatitis (ACD). *A*, An example of ACD in its acute phase, with sharply demarcated, weeping, eczematous plaques in a perioral distribution. *B*, ACD in its chronic phase, with an erythematous, lichenified, weeping plaque on skin chronically exposed to nickel in a metal snap. (*B*, Courtesy of Robert Swerlick, MD; with permission.)



**FIGURE 56-12** Vitiligo. Characteristic lesions display an acral distribution and striking depigmentation as a result of loss of melanocytes.

appears totally white under a Wood's lamp, and previously unsuspected areas of involvement often become apparent. A Wood's lamp may also aid in the demonstration of tinea versicolor, detection of sites of depigmentation within and/or surrounding melanomas, and recognition of ash leaf spots in patients with tuberous sclerosis.

**Patch Tests** Patch testing is designed to document sensitivity to a specific antigen. In this procedure, a battery of suspected allergens is applied to the patient's back under occlusive dressings and allowed to remain in contact with the skin for 48 h. The dressings are removed, and the area is examined for evidence of delayed hypersensitivity reactions (e.g., erythema, edema, or papulovesicles). This test is best performed by physicians with special expertise in patch testing and is often helpful in the evaluation of patients with chronic dermatitis.

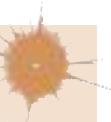
### FURTHER READING

- B JL et al (eds): *Dermatology*, 4th ed. Philadelphia, Elsevier, 2018.
- J WD: *Andrews' Diseases of the Skin: Clinical Dermatology*, 13th ed. Philadelphia, Elsevier, 2019.
- K S et al (eds): *Fitzpatrick's Dermatology in General Medicine*, 9th ed. New York, McGraw-Hill, 2019.

## 57

# Eczema, Psoriasis, Cutaneous Infections, Acne, and Other Common Skin Disorders

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### ECZEMA AND DERMATITIS

Eczema is a type of dermatitis, and these terms are often used synonymously (e.g., atopic eczema or atopic dermatitis [AD]). Eczema is a reaction pattern that presents with variable clinical findings and the common histologic finding of *spongiosis* (intercellular edema of the epidermis). Eczema is the final common expression for a number of disorders, including those discussed in the following sections. Primary lesions may include erythematous macules, papules, and vesicles, which can coalesce to form patches and plaques. In severe eczema, secondary lesions from infection or excoriation, marked by weeping and crusting, may predominate. In chronic eczematous conditions, *lichenification* (cutaneous hypertrophy and accentuation of normal skin markings) may alter the characteristic appearance of eczema.

### ATOPIC DERMATITIS

AD is the cutaneous expression of the atopic state, characterized by a family history of asthma, allergic rhinitis, or eczema. The prevalence of AD is increasing worldwide. Some of its features are shown in Table 57-1.

The etiology of AD is only partially defined, but there is a clear genetic predisposition. When both parents are affected by AD, >80% of their children manifest the disease. When only one parent is affected, the prevalence drops to slightly >50%. A characteristic defect in AD that contributes to the pathophysiology is an impaired epidermal barrier. In many patients, a mutation in the gene encoding filaggrin, a structural protein in the stratum corneum, is responsible. Patients with AD may display a variety of immunoregulatory abnormalities, including increased IgE synthesis; increased serum IgE levels; and impaired, delayed-type hypersensitivity reactions.

TABLE 57-1 Clinical Features of Atopic Dermatitis

1. Pruritus and scratching
2. Course marked by exacerbations and remissions
3. Lesions typical of eczematous dermatitis
4. Personal or family history of atopy (asthma, allergic rhinitis, food allergies, or eczema)
5. Clinical course lasting >6 weeks
6. Lichenification of skin
7. Presence of dry skin

The clinical presentation often varies with age. Half of patients with AD present within the first year of life, and 80% present by 5 years of age. About 80% ultimately coexpress allergic rhinitis or asthma. The infantile pattern is characterized by weeping inflammatory patches and crusted plaques on the face, neck, and extensor surfaces. The childhood and adolescent patterns are typified by dermatitis of flexural skin, particularly in the antecubital and popliteal fossae (Fig. 57-1). AD may resolve spontaneously, but approximately 40% of all individuals affected as children will have dermatitis in adult life. The distribution of lesions in adults may be similar to those seen in childhood; however, adults frequently have localized disease manifesting as lichen simplex chronicus or hand eczema (see below). In patients with localized disease, AD may be suspected because of a typical personal or family history or the presence of cutaneous stigmata of AD such as perioral pallor, an extra fold of skin beneath the lower eyelid (Dennie-Morgan folds), increased palmar skin markings, and an increased incidence of cutaneous infections, particularly with *Staphylococcus aureus*. Regardless of other manifestations, pruritus is a prominent characteristic of AD in all age groups and is exacerbated by dry skin. Many of the cutaneous findings in affected patients, such as lichenification, are secondary to rubbing and scratching.

### TREATMENT

#### Atopic Dermatitis

Therapy for AD should include avoidance of cutaneous irritants, adequate moisturization through the application of emollients, judicious use of topical anti-inflammatory agents, and prompt treatment of secondary infection. Patients should be instructed to bathe no more often than daily, using warm or cool water, and to use only mild bath soap. Immediately after bathing, while the skin is still moist, a topical anti-inflammatory agent in a cream or ointment base should be applied to areas of dermatitis, and all other skin areas should be lubricated with a moisturizer. Approximately 30 g of a topical agent is required to cover the entire body surface of an average adult.



FIGURE 57-1 Atopic dermatitis. Hyperpigmentation, lichenification, and scaling in the antecubital fossae are seen in this patient with atopic dermatitis. (Courtesy of Robert Swerlick, MD.)

Low- to mid-potency topical glucocorticoids are employed in most treatment regimens for AD. Skin atrophy and the potential for systemic absorption are constant concerns, especially with more potent agents. Low-potency topical glucocorticoids or nonglucocorticoid anti-inflammatory agents should be selected for use on the face and in intertriginous areas to minimize the risk of skin atrophy. Three nonglucocorticoid anti-inflammatory agents approved by the U.S. Food and Drug Administration (FDA) are available for topical use in AD: tacrolimus ointment, pimecrolimus cream, and crisaborole ointment. These agents do not cause skin atrophy, nor do they suppress the hypothalamic-pituitary-adrenal axis. The first two agents are topical calcineurin inhibitors (TCIs), whereas crisaborole is a phosphodiesterase-4 inhibitor. Concerns regarding the potential for lymphomas in patients treated with TCIs have largely been unfounded. Currently, all three agents are more costly than topical glucocorticoids. Barrier-repair products that attempt to restore the impaired epidermal barrier are also nonglucocorticoid agents and are gaining popularity in the treatment of AD.

Secondary infection of eczematous skin may lead to exacerbation of AD. Crusted and weeping skin lesions may be infected with *S. aureus*. When secondary infection is suspected, eczematous lesions should be cultured and patients treated with systemic antibiotics active against *S. aureus*. The initial use of penicillinase-resistant penicillins or cephalosporins is preferable. Dicloxacillin or cephalexin (250 mg qid for 7–10 days) is generally adequate for adults; however, antibiotic selection must be directed by culture results and clinical response. More than 50% of *S. aureus* isolates are now methicillin resistant in some communities. Current recommendations for the treatment of infection with these community-acquired methicillin-resistant *S. aureus* (CA-MRSA) strains in adults include trimethoprim-sulfamethoxazole (one double-strength tablet bid), minocycline (100 mg bid), doxycycline (100 mg bid), or clindamycin (300–450 mg qid). Duration of therapy should be 7–10 days. Inducible resistance may limit clindamycin's usefulness. Such resistance can be detected by the double-disk diffusion test, which should be ordered if the isolate is erythromycin resistant and clindamycin sensitive. As an adjunct, antibacterial washes or dilute sodium hypochlorite baths (0.005% bleach) and intermittent nasal mupirocin may be useful.

Control of pruritus is essential for treatment, as AD often represents “an itch that rashes.” Antihistamines are most often used to control pruritus. Diphenhydramine (25 mg every 4–6 h), hydroxyzine (10–25 mg every 6 h), and doxepin (10–25 mg at bedtime) are useful primarily due to their sedating action. Higher doses of these agents may be required, but sedation can become bothersome. Patients need to be counseled about driving or operating heavy equipment after taking these medications. When used at bedtime, sedating antihistamines may improve the patient's sleep. Although they are effective in urticaria, nonsedating antihistamines and selective H<sub>2</sub> blockers are of little use in controlling the pruritus of AD.

Treatment with systemic glucocorticoids should be limited to severe exacerbations unresponsive to topical therapy. In the patient with chronic AD, therapy with systemic glucocorticoids will generally clear the skin only briefly, and cessation of the systemic therapy will invariably be accompanied by a return, if not a worsening, of the dermatitis. For chronic severe AD poorly responsive to standard topical regimens, systemic agents may be considered. Cyclosporine is approved for treatment of severe recalcitrant AD in some European countries. Monitoring of renal function and secondary infections is required. Dupilumab, an interleukin 4 receptor blocker, is FDA approved for use in patients 6 years of age and older and provides more targeted immunomodulation and a better safety profile than cyclosporine. Patients who do not respond to conventional therapies should be considered for patch testing to rule out allergic contact dermatitis (ACD). The role of dietary allergens in AD is controversial, and there is little evidence that they play any role outside of infancy, during which a small percentage of patients with AD may be affected by food allergens.

## ■ LICHEN SIMPLEX CHRONICUS

Lichen simplex chronicus may represent the end stage of a variety of pruritic and eczematous disorders, including AD. It consists of a circumscribed plaque or plaques of lichenified skin due to chronic scratching or rubbing. Common areas involved include the posterior nuchal region, dorsum of the feet, and ankles. Treatment of lichen simplex chronicus centers on breaking the cycle of chronic itching and scratching. High-potency topical glucocorticoids are helpful in most cases, but, in recalcitrant cases, application of topical glucocorticoids under occlusion or intralesional injection of glucocorticoids may be required.

## ■ CONTACT DERMATITIS

Contact dermatitis is an inflammatory skin process caused by an exogenous agent or agents that directly or indirectly injure the skin. In *irritant* contact dermatitis (ICD), this injury is caused by an inherent characteristic of a compound—for example, a concentrated acid or base. Agents that cause *allergic* contact dermatitis (ACD) induce an antigen-specific immune response (e.g., poison ivy dermatitis). The clinical lesions of contact dermatitis may be acute (wet and edematous) or chronic (dry, thickened, and scaly), depending on the persistence of the insult (see Chap. 56, Fig. 56-10).

**Irritant Contact Dermatitis** ICD is generally well demarcated and often localized to areas of thin skin (eyelids, intertriginous areas) or areas where the irritant was occluded. Lesions may range from minimal skin erythema to areas of marked edema, vesicles, and ulcers. Prior exposure to the offending agent is not necessary, and the reaction develops in minutes to a few hours. Chronic low-grade irritant dermatitis is the most common type of ICD, and the most common area of involvement is the hands (see below). The most common irritants encountered are chronic wet work, soaps, and detergents. Treatment should be directed toward the avoidance of irritants and the use of protective gloves or clothing.

**Allergic Contact Dermatitis** ACD is a manifestation of delayed-type hypersensitivity mediated by memory T lymphocytes in the skin. Prior exposure to the offending agent is necessary to develop the hypersensitivity reaction, which may take as little as 12 h or as long as 72 h to develop. The most common cause of ACD is exposure to plants, especially to members of the family Anacardiaceae, including the genus *Toxicodendron*. Poison ivy, poison oak, and poison sumac are members of this genus and cause an allergic reaction marked by erythema, vesication, and severe pruritis. The eruption is often linear or angular, corresponding to areas where plants have touched the skin. The sensitizing antigen common to these plants is urushiol, an oleoresin containing the active ingredient pentadecylcatechol. The oleoresin may adhere to skin, clothing, tools, and pets, and contaminated articles may cause dermatitis even after prolonged storage. Blister fluid does not contain urushiol and is not capable of inducing skin eruption in exposed subjects.

## TREATMENT

### Contact Dermatitis

If contact dermatitis is suspected and an offending agent is identified and removed, the eruption will resolve. Usually, treatment with high-potency topical glucocorticoids is enough to relieve symptoms while the dermatitis runs its course. For patients who require systemic therapy, daily oral prednisone—beginning at 1 mg/kg, but usually ≤60 mg/d—is sufficient. The dose should be tapered over 2–3 weeks, and each daily dose should be taken in the morning with food.

Identification of a contact allergen can be a difficult and time-consuming task. ACD should be suspected in patients with dermatitis unresponsive to conventional therapy or with an unusual and patterned distribution. Patients should be questioned carefully regarding occupational exposures and topical medications. Common sensitizers include preservatives in topical preparations,



**FIGURE 57-2** Dyshidrotic eczema. This example is characterized by deep-seated vesicles and scaling on palms and lateral fingers, and the disease is often associated with an atopic diathesis.

nickel sulfate, potassium dichromate, thimerosal, neomycin sulfate, fragrances, formaldehyde, and rubber-curing agents. Patch testing is helpful in identifying these agents but should not be attempted when patients have widespread active dermatitis or are taking systemic glucocorticoids.

### HAND ECZEMA

Hand eczema is a very common, chronic skin disorder in which both exogenous and endogenous factors play important roles. It may be associated with other cutaneous disorders such as AD, and contact with various agents may be involved. Hand eczema represents a large proportion of cases of occupation-associated skin disease. Chronic, excessive exposure to water and detergents, harsh chemicals, or allergens may initiate or aggravate this disorder. It may present with dryness and cracking of the skin of the hands as well as with variable amounts of erythema and edema. Often, the dermatitis will begin under rings, where water and irritants are trapped. *Dyshidrotic* eczema, a variant of hand eczema, presents with multiple, intensely pruritic, small papules and vesicles on the thenar and hypothenar eminences and the sides of the fingers (Fig. 57-2). Lesions tend to occur in crops that slowly form crusts and then heal.

The evaluation of a patient with hand eczema should include an assessment of potential occupation-associated exposures. The history should be directed to identifying possible irritant or allergen exposures.

### TREATMENT

#### Hand Eczema

Therapy for hand eczema is directed toward avoidance of irritants, identification of possible contact allergens, treatment of coexistent infection, and application of topical glucocorticoids. Whenever possible, the hands should be protected by gloves, preferably vinyl. The use of rubber gloves (latex) to protect dermatitic skin is sometimes associated with the development of hypersensitivity reactions to components of the gloves, which could be either a type I hypersensitivity reaction to the latex (manifested by the development of hives, itching, angioedema, and possibly anaphylaxis within minutes to hours of exposure) or a type IV hypersensitivity reaction to rubber accelerators (with worsening of eczematous eruptions days after exposure). Patients can be treated with cool moist compresses followed by application of a mid- to high-potency topical glucocorticoid in a cream or ointment base. As in AD, treatment of secondary infection is essential for good control. In addition, patients with hand eczema should be examined for dermatophyte infection by potassium hydroxide (KOH) preparation and culture (see below).

### NUMMULAR ECZEMA

Nummular eczema is characterized by circular or oval “coinlike” lesions, beginning as small edematous papules that become crusted and scaly. The etiology of nummular eczema is unknown, but dry skin is a contributing factor. Common locations are the trunk or the extensor surfaces of the extremities, particularly on the pretibial areas or dorsum of the hands. Nummular eczema occurs more frequently in men and is most common in middle age. The treatment of nummular eczema is similar to that for AD.

### ASTEATOTIC ECZEMA

Asteatotic eczema, also known as *xerotic eczema* or “winter itch,” is a mildly inflammatory dermatitis that develops in areas of extremely dry skin, especially during the dry winter months. Clinically, there may be considerable overlap with nummular eczema. This form of eczema accounts for many physician visits because of the associated pruritus. Fine cracks and scale, with or without erythema, characteristically develop in areas of dry skin, especially on the anterior surfaces of the lower extremities in elderly patients. Asteatotic eczema responds well to topical moisturizers and the avoidance of cutaneous irritants. Over-bathing and the use of harsh soaps exacerbate asteatotic eczema.

### STASIS DERMATITIS AND STASIS ULCERATION

Stasis dermatitis develops on the lower extremities secondary to venous incompetence and chronic edema. Patients may give a history of deep venous thrombosis and may have evidence of vein removal or varicose veins. Early findings in stasis dermatitis consist of mild erythema and scaling associated with pruritus. The typical initial site of involvement is the medial aspect of the ankle, often over a distended vein (Fig. 57-3).

Stasis dermatitis may become acutely inflamed, with crusting and exudate. In this state, it is easily confused with cellulitis. Of note, symmetrical and bilateral involvement is more likely stasis dermatitis, whereas unilateral involvement may represent cellulitis. Chronic stasis dermatitis is often associated with dermal fibrosis that is recognized clinically as brawny edema of the skin. As the disorder progresses, the dermatitis becomes progressively pigmented due to chronic erythrocyte extravasation leading to cutaneous hemosiderin deposition. Stasis dermatitis may be complicated by secondary infection and contact dermatitis. Severe stasis dermatitis may precede the development of stasis ulcers.

### TREATMENT

#### Stasis Dermatitis and Stasis Ulceration

Patients with stasis dermatitis and stasis ulceration benefit greatly from leg elevation and the routine use of compression stockings with a gradient of at least 30–40 mmHg. Stockings providing less



**FIGURE 57-3** Stasis dermatitis. An example of stasis dermatitis showing erythematous, scaly, and oozing patches over the lower leg. Several stasis ulcers are also seen in this patient.



**FIGURE 57-4** Seborrheic dermatitis. Central facial erythema with overlying greasy, yellowish scale is seen in this patient. (Courtesy of Jean Bolognia, MD; with permission.)

compression, such as antiembolism hose, are poor substitutes. Use of emollients and/or mid-potency topical glucocorticoids and avoidance of irritants are also helpful in treating stasis dermatitis. Protection of the legs from injury, including scratching, and control of chronic edema are essential to prevent ulcers. Diuretics may be required to adequately control chronic edema.

Stasis ulcers are difficult to treat, and resolution is slow. It is extremely important to elevate the affected limb as much as possible. The ulcer should be kept clear of necrotic material by gentle debridement and covered with a semipermeable dressing and a compression dressing or compression stocking. Glucocorticoids should not be applied to ulcers, because they may retard healing; however, they may be applied to the surrounding skin to control itching, scratching, and additional trauma. Superficial bacterial cultures of chronic stasis ulcers often yield polymicrobial colonizers and are of little utility in determination of secondary infection. Care must be taken to exclude treatable causes of leg ulcers (hypercoagulation, vasculitis, arterial insufficiency) before beginning the chronic management outlined above.

### ■ SEBORRHEIC DERMATITIS

Seborrheic dermatitis is a common, chronic disorder characterized by greasy scales overlying erythematous patches or plaques. Induration and scale are generally less prominent than in psoriasis, but clinical overlap exists between these diseases (“sebopsoriasis”). The most common location is in the scalp, where it may be recognized as severe dandruff. On the face, seborrheic dermatitis affects the eyebrows, eyelids, glabella, and nasolabial folds (Fig. 57-4). Scaling of the external

auditory canal is common in seborrheic dermatitis. In addition, the postauricular areas often become macerated and tender. Seborrheic dermatitis may also develop in the central chest, axilla, groin, submammary folds, and gluteal cleft. Rarely, it may cause widespread generalized dermatitis. Pruritus is variable.

Seborrheic dermatitis may be evident within the first few weeks of life, and within this context, it typically occurs in the scalp (“cradle cap”), face, or groin. It is rarely seen in children beyond infancy but becomes evident again during adolescent and adult life. Although it is frequently seen in patients with Parkinson’s disease, in those who have had cerebrovascular accidents, and in those with HIV infection, the overwhelming majority of individuals with seborrheic dermatitis have no underlying disorder.

## TREATMENT

### Seborrheic Dermatitis

Treatment with low-potency topical glucocorticoids in conjunction with a topical antifungal agent, such as ketoconazole cream or ciclopirox cream, is often effective. The scalp and beard areas may benefit from antidandruff shampoos, which should be left in place 3–5 min before rinsing. High-potency topical glucocorticoid solutions (betamethasone or clobetasol) are effective for control of severe scalp involvement. High-potency glucocorticoids should not be used on the face because this treatment is often associated with steroid-induced rosacea or atrophy.

## PAPULOSQUAMOUS DISORDERS

### TABLE 57-2

#### ■ PSORIASIS

Psoriasis is one of the most common dermatologic diseases, affecting up to 2% of the world’s population. It is an immune-mediated disease clinically characterized by erythematous, sharply demarcated papules and rounded plaques covered by silvery micaceous scale. The skin lesions of psoriasis are variably pruritic. Traumatized areas often develop lesions of psoriasis (the *Koebner* or isomorphic phenomenon). In addition, other external factors may exacerbate psoriasis, including infections, stress, and medications (lithium, beta blockers, and antimarial drugs).

The most common variety of psoriasis is called *plaque-type*. Patients with plaque-type psoriasis have stable, slowly enlarging plaques, which remain basically unchanged for long periods of time. The most commonly involved areas are the elbows, knees, gluteal cleft, and scalp. Involvement tends to be symmetric. Plaque psoriasis generally develops slowly and runs an indolent course. It rarely remits spontaneously. *Inverse psoriasis* affects the intertriginous regions, including the axilla, groin, submammary region, and navel; it also tends to affect the scalp, palms, and soles. The individual lesions are sharply demarcated plaques (see Chap. 56, Fig. 56-7), but they may be moist and without scale due to their locations.

**TABLE 57-2** Papulosquamous Disorders

	CLINICAL FEATURES	OTHER NOTABLE FEATURES	HISTOLOGIC FEATURES
Psoriasis	Sharply demarcated, erythematous plaques with mica-like scale; predominantly on elbows, knees, and scalp; atypical forms may localize to intertriginous areas; eruptive forms may be associated with infection	May be aggravated by certain drugs, infection; severe forms seen in association with HIV	Acanthosis, vascular proliferation
Lichen planus	Purple polygonal papules marked by severe pruritus; lacy white markings, especially associated with mucous membrane lesions	Certain drugs may induce: thiazides, antimarial drugs	Interface dermatitis
Pityriasis rosea	Rash often preceded by herald patch; oval to round plaques with trailing scale; most often affects trunk; eruption lines up in skinfolds giving a “fir tree-like” appearance; generally spares palms and soles	Variable pruritus; self-limited, resolving in 2–8 weeks; may be imitated by secondary syphilis	Pathologic features often nonspecific
Dermatophytosis	Polymorphous appearance depending on dermatophyte, body site, and host response; sharply defined to ill-demarcated scaly plaques with or without inflammation; may be associated with hair loss	KOH preparation may show branching hyphae; culture helpful	Hyphae and neutrophils in stratum corneum

Abbreviations: HIV, human immunodeficiency virus; KOH, potassium hydroxide.

*Guttate psoriasis* (eruptive psoriasis) is most common in children and young adults. It develops acutely in individuals without psoriasis or in those with chronic plaque psoriasis. Patients present with many small erythematous, scaling papules, frequently after upper respiratory tract infection with  $\beta$ -hemolytic streptococci. The differential diagnosis should include pityriasis rosea and secondary syphilis.

In *pustular psoriasis*, patients may have disease localized to the palms and soles, or the disease may be generalized. Regardless of the extent of disease, the skin is erythematous, with pustules and variable scale. Localized to the palms and soles, it is easily confused with dyshidrotic eczema. When it is generalized, episodes are characterized by fever ( $39^{\circ}$ – $40^{\circ}$ C [ $102.2^{\circ}$ – $104.0^{\circ}$ F]) lasting several days, an accompanying generalized eruption of sterile pustules, and a background of intense erythema; patients may become erythrodermic. Episodes of fever and pustules are recurrent. Local irritants, pregnancy, medications, infections, and systemic glucocorticoid withdrawal can precipitate this form of psoriasis. Oral retinoids are the treatment of choice in nonpregnant patients.

Fingernail involvement, appearing as punctate pitting, onycholysis, nail thickening, or subungual hyperkeratosis, may be a clue to the diagnosis of psoriasis when the clinical presentation is not classic.

According to the National Psoriasis Foundation, up to 30% of patients with psoriasis have psoriatic arthritis (PsA). It develops most commonly between the ages of 30 and 50 years. There are five subtypes of PsA: symmetric PsA, asymmetric PsA, distal PsA, spondylitis, and arthritis mutilans. Approximately 50% of PsA is classified as symmetric, which may resemble rheumatoid arthritis. Asymmetric arthritis comprises about 35% of cases. It can involve any joint and may present as “sausage digits.” Distal PsA is the classic form; however, it occurs in only about 5% of patients with PsA. It can involve fingers and toes; fingernails and toenails are often dystrophic, including nail pitting. Spondylitis also occurs in ~5% of patients with PsA. Arthritis mutilans is severe and deforming and affects primarily the small joints of the hands and feet. It accounts for fewer than 5% of PsA cases.

An increased risk of metabolic syndrome, including increased morbidity and mortality from cardiovascular events, has been demonstrated in psoriasis patients. Appropriate screening tests should be performed. The etiology of psoriasis is still poorly understood, but there is clearly a genetic component to the disease. In various studies, 30–50% of patients with psoriasis report a positive family history. Psoriatic lesions contain infiltrates of activated T cells that are thought to elaborate cytokines responsible for keratinocyte hyperproliferation, which results in the characteristic clinical findings. Agents inhibiting T-cell activation, clonal expansion, or release of proinflammatory cytokines are often effective for the treatment of severe psoriasis (see below).

## TREATMENT

### Psoriasis

Treatment of psoriasis depends on the type, location, and extent of disease. All patients should be instructed to avoid excess drying or irritation of their skin and to maintain adequate cutaneous hydration. Most cases of localized, plaque-type psoriasis can be managed

with mid-potency topical glucocorticoids, although their long-term use is often accompanied by loss of effectiveness (tachyphylaxis) and atrophy of the skin. A topical vitamin D analogue (calcipotriene) and a retinoid (azarotene) are also efficacious in the treatment of limited psoriasis and have largely replaced other topical agents such as coal tar, salicylic acid, and anthralin.

Ultraviolet (UV) light, natural or artificial, is an effective therapy for many patients with widespread psoriasis. Ultraviolet B (UVB), narrowband UVB, and ultraviolet A (UVA) light with either oral or topical psoralens (PUVA) are used clinically. UV light's immunosuppressive properties are thought to be responsible for its therapeutic activity in psoriasis. It is also mutagenic, potentially leading to an increased incidence of nonmelanoma and melanoma skin cancer. UV-light therapy is contraindicated in patients receiving cyclosporine and should be used with great care in all immunocompromised patients due to the increased risk of skin cancer.

Various systemic agents can be used for severe, widespread psoriatic disease (Table 57-3). Oral glucocorticoids should not be used for the treatment of psoriasis due to the potential for development of life-threatening pustular psoriasis when therapy is discontinued. Methotrexate is an effective agent, especially in patients with PsA. The synthetic retinoid acitretin is useful, especially when immunosuppression must be avoided; however, teratogenicity limits its use. Apremilast inhibits phosphodiesterase type 4. It is approved for both psoriasis and PsA. It must be used cautiously in the presence of renal failure or depression.

The evidence implicating psoriasis as a T-cell-mediated disorder has directed therapeutic efforts to immunoregulation. Cyclosporine and other immunosuppressive agents can be very effective in the treatment of psoriasis, and much attention is currently directed toward the development of biologic agents with more selective immunosuppressive properties and better safety profiles (Table 57-4). These biologic agents appear to be quite efficacious in treatment of psoriasis and are well tolerated; however, caution with certain patient comorbidities must be exercised. Use of tumor necrosis factor- $\alpha$  (TNF- $\alpha$ ) inhibitors may worsen congestive heart failure (CHF), and they should be used with caution in patients at risk for or known to have CHF. Further, none of the immunosuppressive agents used in the treatment of psoriasis should be initiated if the patient has a severe infection (including tuberculosis, HIV, hepatitis B or C); patients on such therapy should be routinely screened for tuberculosis. There have been reports of progressive multifocal leukoencephalopathy and lupus erythematosus in association with treatment with the TNF- $\alpha$  inhibitors. Malignancies, including a risk or history of certain malignancies, may limit the use of these systemic agents. In general, immunosuppressive agents have also been linked to an increase risk of skin cancer, and patients receiving these agents should be monitored for the development of skin cancer.

### LICHEN PLANUS

Lichen planus (LP) is a papulosquamous disorder that may affect the skin, scalp, nails, and mucous membranes. The primary cutaneous lesions are pruritic, polygonal, flat-topped, violaceous papules. Close

TABLE 57-3 FDA-Approved Systemic Therapy for Psoriasis

AGENT	MEDICATION CLASS	ADMINISTRATION		ADVERSE EVENTS (SELECTED)
		ROUTE	FREQUENCY	
Methotrexate	Antimetabolite	Oral	Weekly <sup>a</sup>	Hepatotoxicity, pulmonary toxicity, pancytopenia, potential for increased malignancies, ulcerative stomatitis, nausea, diarrhea, teratogenicity
Acitretin	Retinoid	Oral	Daily	Teratogenicity, hepatotoxicity, hyperostosis, hyperlipidemia/pancreatitis, depression, ophthalmologic effects, pseudotumor cerebri
Cyclosporine	Calcineurin inhibitor	Oral	Twice daily	Renal dysfunction, hypertension, hyperkalemia, hyperuricemia, hypomagnesemia, hyperlipidemia, increased risk of malignancies
Apremilast	Phosphodiesterase type 4 inhibitor	Oral	Twice daily <sup>b</sup>	Hypersensitivity reaction, depression, nausea, diarrhea, vomiting, dyspepsia, weight loss, headache, fatigue

<sup>a</sup>Initial test dose is required. <sup>b</sup>Initial dose escalation is required.

Abbreviation: FDA, Food and Drug Administration.

TABLE 57-4 FDA-Approved Biologics for Psoriasis or Psoriatic Arthritis

Mechanism of Action	Agents (Indication; Route)	Frequency	Warnings, Selected
Anti-TNF- $\alpha$	Etanercept (Ps, PsA; SC) Adalimumab (Ps, PsA; SC) Certolizumab (Ps, PsA; SC) Infliximab (Ps, PsA; IV) Golimumab (PsA; SC)	Ranges from once or twice weekly <sup>a</sup> to every 8 weeks <sup>a</sup>	Serious infections, hepatotoxicity, CHF, hematologic events, hypersensitivity reactions, neurologic events, potential for increased malignancies
Anti-IL-12 and anti-IL-23	Ustekinumab (Ps, PsA; SC)	Every 12 weeks <sup>a</sup>	Serious infections, neurologic events, potential for increased malignancies
Anti-IL-23	Risankizumab (Ps; SC) Tildrakizumab (Ps; SC) Guselkumab (Ps; SC)	Ranges from every 8–12 weeks <sup>a</sup>	Serious infections, headaches
Anti-IL-17	Secukinumab (Ps, PsA; SC) Ixekizumab (Ps; SC) Brodalumab (Ps; SC)	Ranges from every 2–4 weeks <sup>a</sup>	Serious infections, hypersensitivity reaction, inflammatory bowel disease

<sup>a</sup>Initial dose modifications required.Abbreviations: CHF, congestive heart failure; IL, interleukin; IV, intravenous; Ps, psoriasis; PsA, psoriatic arthritis; SC, subcutaneous; TNF- $\alpha$ , tumor necrosis factor- $\alpha$ .

examination of the surface of these papules often reveals a network of gray lines (*Wickham's striae*). The skin lesions may occur anywhere but have a predilection for the wrists, shins, lower back, and genitalia (Fig. 57-5). Involvement of the scalp (*lichen planopilaris*) may lead to scarring alopecia, and nail involvement may lead to permanent deformity or loss of fingernails and toenails. LP commonly involves mucous membranes, particularly the buccal mucosa, where it can present on a spectrum ranging from a mild, white, reticular eruption of the mucosa to a severe, erosive stomatitis. Erosive stomatitis may persist for years and may be linked to an increased risk of oral squamous cell carcinoma. Cutaneous eruptions clinically resembling LP have been observed after administration of numerous drugs, including thiazide diuretics, gold, antimalarial agents, penicillamine, and phenothiazines, and in patients with skin lesions of chronic graft-versus-host disease. In addition, LP may be associated with hepatitis C infection. The course of LP is variable, but most patients have spontaneous remissions 6 months to 2 years after the onset of disease. Topical glucocorticoids are the mainstay of therapy.

### PITYRIASIS ROSEA

Pityriasis rosea (PR) is a papulosquamous eruption of unknown etiology occurring more commonly in the spring and fall. Its first manifestation is the development of a 2- to 6-cm annular lesion (the herald patch). This is followed in a few days to a few weeks by the appearance of many smaller annular or papular lesions with a predilection to occur on the trunk (Fig. 57-6). The lesions are generally oval, with their long

axis parallel to the skinfold lines. Individual lesions may range in color from red to brown and have a trailing scale. PR shares many clinical features with the eruption of secondary syphilis, but palm and sole lesions are extremely rare in PR and common in secondary syphilis. The eruption tends to be moderately pruritic and lasts 3–8 weeks. Treatment is directed at alleviating pruritus and consists of oral antihistamines; mid-potency topical glucocorticoids; and, in some cases, UVB phototherapy.

## CUTANEOUS INFECTIONS TABLE 57-5

### IMPETIGO, ECTHYMA, AND FURUNCULOSIS

*Impetigo* is a common superficial bacterial infection of skin caused most often by *S. aureus* (Chap. 147) and in some cases by group A  $\beta$ -hemolytic streptococci (Chap. 148). The primary lesion is a superficial pustule that ruptures and forms a characteristic yellow-brown honey-colored crust (see Chap. 148, Fig. 148-3). Lesions may occur on normal skin (primary infection) or in areas already affected by another skin disease (secondary infection). Lesions caused by staphylococci may be tense, clear bullae, and this less common form of the disease is called *bullous impetigo*. Blisters are caused by the production of exfoliative toxin by *S. aureus* phage type II. This is the same toxin responsible for staphylococcal scalded-skin syndrome, often resulting in dramatic loss of the superficial epidermis due to blistering. The latter syndrome is much more common in children than in adults; however, it should be considered along with toxic epidermal necrolysis



FIGURE 57-5 Lichen planus. An example of lichen planus showing multiple flat-topped, violaceous papules and plaques. Nail dystrophy, as seen in this patient's thumbnail, may also be a feature. (Courtesy of Robert Swerlick, MD; with permission.)



FIGURE 57-6 Pityriasis rosea. In this patient with pityriasis rosea, multiple round to oval erythematous patches with fine central scale are distributed along the skin tension lines on the trunk.

TABLE 57-5 Common Skin Infections

	CLINICAL FEATURES	ETIOLOGIC AGENT	TREATMENT
Impetigo	Honey-colored crusted papules, plaques, or bullae	Group A <i>Streptococcus</i> and <i>Staphylococcus aureus</i>	Systemic or topical antistaphylococcal and antistreptococcal antibiotics
Dermatophytosis	Inflammatory or noninflammatory annular scaly plaques; may involve hair loss; groin involvement spares scrotum; hyphae on KOH preparation	<i>Trichophyton</i> , <i>Epidermophyton</i> , or <i>Microsporum</i> spp.	Topical azoles, systemic griseofulvin, terbinafine, or azoles
Candidiasis	Inflammatory papules and plaques with satellite pustules, frequently in intertriginous areas; may involve scrotum; pseudohyphae on KOH preparation	<i>Candida albicans</i> and other <i>Candida</i> spp.	Topical nystatin or azoles; systemic azoles for resistant disease
Tinea versicolor	Hyper- or hypopigmented scaly patches on trunk; characteristic mixture of hyphae and spores ("spaghetti and meatballs") on KOH preparation	<i>Malassezia furfur</i>	Topical selenium sulfide lotion or azoles

Abbreviation: KOH, potassium hydroxide.

and severe drug eruptions in patients with widespread blistering of the skin. *Ecthyma* is a deep nonbullous variant of impetigo that causes punched-out ulcerative lesions. It is more often caused by a primary or secondary infection with *Streptococcus pyogenes*. Ecthyma is a deeper infection than typical impetigo and resolves with scars. Treatment of both ecthyma and impetigo involves gentle debridement of adherent crusts, facilitated by using soaks and topical antibiotics in conjunction with appropriate oral antibiotics.

*Furunculosis* is also caused by *S. aureus*, and this disorder has gained prominence in the past few decades because of CA-MRSA. A furuncle, or boil, is a painful, erythematous nodule that can occur on any cutaneous surface. The lesions may be solitary but are most often multiple. Patients frequently believe they have been bitten by spiders or insects. Family members or close contacts may also be affected. Furuncles can rupture and drain spontaneously or may need incision and drainage, which may be adequate therapy for small solitary furuncles without cellulitis or systemic symptoms. Whenever possible, lesional material should be sent for culture. Current recommendations for methicillin-sensitive infections are β-lactam antibiotics. Therapy for CA-MRSA is discussed previously (see "Atopic Dermatitis"). Warm compresses and nasal mupirocin are helpful therapeutic additions. Severe infections may require IV antibiotics.

## ■ ERYSIPELAS AND CELLULITIS

See Chap. 129.

## ■ DERMATOPHYTOSIS

Dermatophytes are fungi that infect skin, hair, and nails and include members of the genera *Trichophyton*, *Microsporum*, and *Epidermophyton* (Chap. 219). *Tinea corporis*, or infection of the relatively hairless skin of the body (glabrous skin), may have a variable appearance depending on the extent of the associated inflammatory reaction. Typical infections consist of erythematous, scaly plaques, with an annular appearance that accounts for the common name "ringworm." Deep inflammatory nodules or granulomas occur in some infections, most often those inappropriately treated with mid- to high-potency topical glucocorticoids. Involvement of the groin (*tinea cruris*) is more common in males than in females. It presents as a scaling, erythematous eruption sparing the scrotum. Infection of the foot (*tinea pedis*) is the most common dermatophyte infection and is often chronic; it is characterized by variable erythema, edema, scaling, pruritus, and occasionally vesication. The infection may be widespread or localized but generally involves the web space between the fourth and fifth toes. Infection of the nails (*tinea unguium* or *onychomycosis*) occurs in many patients with *tinea pedis* and is characterized by opacified, thickened nails and subungual debris. The distal-lateral variant is most common. Proximal subungual onychomycosis may be a marker for HIV infection or other immunocompromised states. Dermatophyte infection of the scalp (*tinea capitis*) continues to be common, particularly affecting inner-city children but also affecting immunocompromised adults. The predominant organism is *Trichophyton tonsurans*, which can produce a relatively noninflammatory infection with mild scale and hair

loss that is diffuse or localized. *T. tonsurans* and *Microsporum canis* can also cause a markedly inflammatory dermatosis with edema and nodules. This latter presentation is a *kerion*.

The diagnosis of tinea can be made from skin scrapings, nail scrapings, or hair by culture or direct microscopic examination with KOH. Nail clippings may be sent for histologic examination with periodic acid–Schiff (PAS) stain.

## TREATMENT

### Dermatophytosis

Both topical and systemic therapies may be used in dermatophyte infections. Treatment depends on the site involved and the type of infection. Topical therapy is generally effective for uncomplicated *tinea corporis*, *tinea cruris*, and limited *tinea pedis*. Topical agents are not effective as monotherapy for *tinea capitis* or *onychomycosis* (see below), and nystatin is not active against dermatophytes. Topicals are generally applied twice daily, and treatment should continue for 1 week beyond clinical resolution of the infection. *Tinea pedis* often requires longer treatment courses and frequently relapses. Oral antifungal agents may be required for recalcitrant *tinea pedis* or *tinea corporis*.

For dermatophyte infections involving the hair and nails and for other infections unresponsive to topical therapy, oral antifungal agents are often used. Markedly inflammatory *tinea capitis* may result in scarring and hair loss, and a systemic antifungal agent plus systemic or topical glucocorticoids may be helpful in preventing these sequelae. A fungal etiology should be confirmed by direct microscopic examination or by culture before oral antifungal agents are prescribed for any infection. All the oral agents may cause hepatotoxicity. They should not be used in women who are pregnant or breast-feeding.

Griseofulvin is approved in the United States for dermatophyte infections involving the skin, hair, or nails. Common side effects of griseofulvin include gastrointestinal distress, headache, and urticaria.

Two other oral antifungal agents, itraconazole and terbinafine, are sometimes prescribed "off-label" for superficial fungal infections. Oral itraconazole is approved for onychomycosis. Itraconazole has the potential for serious interactions with other drugs requiring the P450 enzyme system for metabolism. Itraconazole should not be administered to patients with evidence of ventricular dysfunction or patients with known CHF.

Terbinafine is also approved for onychomycosis, and the granule version is approved for treatment of *tinea capitis*. Terbinafine has fewer interactions with other drugs than itraconazole; however, caution should be used with patients who are on multiple medications. The risk/benefit ratio should be considered when an asymptomatic toenail infection is treated with systemic agents.

The FDA has limited the use of a third oral agent due to potential hepatotoxicity and published the following: "Nizoral [ketoconazole]

oral tablets should not be a first-line treatment for any fungal infection.” The topical form of ketoconazole is not affected by this action.

## ■ TINEA PITYRIASIS VERSICOLOR

Tinea versicolor is caused by a nondermatophytic, dimorphic fungus, *Malassezia furfur*, a normal inhabitant of the skin. The expression of infection is promoted by heat and humidity. The typical lesions consist of oval scaly macules, papules, and patches concentrated on the chest, shoulders, and back but only rarely on the face or distal extremities. On dark skin, the lesions often appear as hypopigmented areas, whereas on light skin, they are slightly erythematous or hyperpigmented. A KOH preparation from scaling lesions will demonstrate a confluence of short hyphae and round spores (“spaghetti and meatballs”). Lotions or shampoos containing sulfur, salicylic acid, or selenium sulfide are the treatments of choice and will clear the infection if used daily for 1–2 weeks and then weekly thereafter. These preparations are irritating if left on the skin for >10 min; thus, they should be washed off completely. Treatment with some oral antifungal agents is also effective, but they do not provide lasting results and are not FDA approved for this indication.

## ■ CANDIDIASIS

Candidiasis is a fungal infection caused by a related group of yeasts whose manifestations may be localized to the skin and mucous membranes or, rarely, may be systemic and life-threatening (Chap. 216). The causative organism is usually *Candida albicans*. These organisms are normal saprophytic inhabitants of the gastrointestinal tract but may overgrow due to broad-spectrum antibiotic therapy, diabetes mellitus, or immunosuppression and cause disease. Candidiasis is a very common infection in HIV-infected individuals (Chap. 202). The oral cavity is commonly involved. Lesions may occur on the tongue or buccal mucosa (*thrush*) and appear as white plaques. Fissured, macerated lesions at the corners of the mouth (*perleche*) are often seen in individuals with poorly fitting dentures and may also be associated with candidal infection. In addition, candidal infections have an affinity for sites that are chronically wet and macerated, including the skin around nails (onycholysis and paronychia), and in intertriginous areas. Intertriginous lesions are characteristically edematous, erythematous, and scaly, with scattered “satellite pustules.” In males, there is often involvement of the penis and scrotum as well as the inner aspect of the thighs. In contrast to dermatophyte infections, candidal infections are frequently painful and accompanied by a marked inflammatory response. Diagnosis of candidal infection is based on the clinical pattern and demonstration of yeast on KOH preparation or culture.

## TREATMENT

### Candidiasis

Treatment involves removal of any predisposing factors such as antibiotic therapy or chronic moisture and the use of appropriate topical or systemic antifungal agents. Effective topicals include nystatin or azoles (miconazole, clotrimazole, econazole, or ketoconazole). The associated inflammatory response accompanying candidal infection on glabrous skin can be treated with a mild glucocorticoid lotion or cream (2.5% hydrocortisone). Systemic therapy is usually reserved for immunosuppressed patients or individuals with chronic or recurrent disease who fail to respond to appropriate topical therapy. Oral fluconazole is most commonly prescribed for cutaneous candidiasis. Oral nystatin is effective only for candidiasis of the gastrointestinal tract.

## ■ WARTS

Warts are cutaneous neoplasms caused by papillomaviruses. More than 100 different human papillomaviruses (HPVs) have been described. A typical wart, *verruca vulgaris*, is sessile, dome-shaped, and usually about a centimeter in diameter. Its surface is hyperkeratotic, consisting of many small filamentous projections. HPV also causes typical plantar warts, flat warts (*verruca plana*), and filiform warts. Plantar warts

are endophytic and are covered by thick keratin. Paring of the wart will generally reveal a central core of keratinized debris and punctate bleeding points. Filiform warts are commonly seen on the face, neck, and skinfolds and present as papillomatous lesions on a narrow base. Flat warts are only slightly elevated and have a velvety, non verrucous surface. They have a propensity for the face, arms, and legs, and are often spread by shaving.

Genital warts begin as small papillomas that may grow to form large, fungating lesions. In women, they may involve the labia, perineum, or perianal skin. In addition, the mucose of the vagina, urethra, and anus can be involved as well as the cervical epithelium. In men, the lesions often occur initially in the coronal sulcus but may be seen on the shaft of the penis, the scrotum, or the perianal skin or in the urethra.

Appreciable evidence has accumulated indicating that HPV plays a role in the development of neoplasia of the uterine cervix and anogenital skin (Chap. 89). HPV types 16 and 18 have been most intensely studied and are the major risk factors for intraepithelial neoplasia and squamous cell carcinoma of the cervix, anus, vulva, and penis. The risk is higher among patients immunosuppressed after solid organ transplantation and among those infected with HIV. Recent evidence also implicates other HPV types. Histologic examination of biopsied samples from affected sites may reveal changes associated with typical warts and/or features typical of intraepidermal carcinoma (Bowen's disease). Squamous cell carcinomas associated with HPV infections have also been observed in extragenital skin (Chap. 76), most commonly in patients immunosuppressed after organ transplantation. Patients on long-term immunosuppression should be monitored for the development of squamous cell carcinoma and other cutaneous malignancies.

## TREATMENT

### Warts

Treatment of warts, other than anogenital warts, should be tempered by the observation that most warts in normal individuals resolve spontaneously within 1–2 years. There are many modalities available to treat warts, but no single therapy is universally effective. Factors that influence the choice of therapy include the location of the wart, the extent of disease, the age and immunologic status of the patient, and the patient's desire for therapy. Perhaps the most useful and convenient method for treating warts in almost any location is cryotherapy with liquid nitrogen. Equally effective for non-genital warts, but requiring much more patient compliance, is the use of keratolytic agents such as salicylic acid plasters or solutions. For genital warts, in-office application of a podophyllin solution is moderately effective but may be associated with marked local reactions. Prescription preparations of dilute, purified podophyllin are available for home use. Topical imiquimod, a potent inducer of local cytokine release, has been approved for treatment of genital warts. A topical compound composed of green tea extracts (sinecatechins) is also available. Conventional and laser surgical procedures may be required for recalcitrant warts. Recurrence of warts appears to be common with all these modalities. A highly effective vaccine for selected types of HPV has been approved by the FDA, and its use is reported to reduce the incidence of anogenital and cervical carcinoma.

## ■ HERPES SIMPLEX

See Chap. 192.

## ■ HERPES ZOSTER

See Chap. 193.

## ACNE

## ■ ACNE VULGARIS

Acne vulgaris is a self-limited disorder primarily of teenagers and young adults, although perhaps 10–20% of adults may continue to experience some form of the disorder. The permissive factor for the

expression of the disease in adolescence is the increase in sebum production by sebaceous glands with puberty. Small cysts, called *comedones*, form in hair follicles due to blockage of the follicular orifice by retention of keratinous material and sebum. The activity of bacteria (*Cutibacterium acnes*) within the comedones releases free fatty acids from sebum, causes inflammation within the cyst, and results in rupture of the cyst wall. An inflammatory foreign-body reaction develops as result of extrusion of oily and keratinous debris from the cyst.

The clinical hallmark of acne vulgaris is the comedone, which may be closed (*whitehead*) or open (*blackhead*). Closed comedones appear as 1- to 2-mm pebbly white papules, which are accentuated when the skin is stretched. They are the precursors of inflammatory lesions of acne vulgaris. The contents of closed comedones are not easily expressed. Open comedones, which rarely result in inflammatory acne lesions, have a dilated follicular orifice and are filled with easily expressible oxidized, darkened, oily debris. Comedones are usually accompanied by inflammatory lesions: papules, pustules, or nodules.

The earliest lesions seen in adolescence are generally mildly inflamed or noninflammatory comedones on the forehead. Subsequently, more typical inflammatory lesions develop on the cheeks, nose, and chin (Fig. 57-7). The most common location for acne is the face, but involvement of the chest and back is common. Most disease remains mild and does not lead to scarring. A small number of patients develop large inflammatory cysts and nodules, which may drain and result in significant scarring. Regardless of the severity, acne may affect a patient's quality of life. With adequate treatment, this effect may be transient. In the case of severe, scarring acne, the effects can be permanent and profound. Early therapeutic intervention in severe acne is essential.

Exogenous and endogenous factors can alter the expression of acne vulgaris. Friction and trauma (from headbands or chin straps of athletic helmets), application of comedogenic topical agents (cosmetics or hair preparations), or chronic topical exposure to certain industrial compounds may elicit or aggravate acne. Glucocorticoids, topical or systemic, may also elicit acne. Other systemic medications such as progestin-only contraception, lithium, isoniazid, androgenic steroids, halogens, phenytoin, and phenobarbital may produce acneiform eruptions or aggravate preexisting acne. Genetic factors and polycystic ovary disease may also play a role.

## TREATMENT

### Acne Vulgaris

Treatment of acne vulgaris is directed toward elimination of comedones by normalizing follicular keratinization and decreasing sebaceous gland activity, the population of *C. acnes*, and inflammation. Minimal to moderate pauci-inflammatory disease may respond adequately to local therapy alone. Although areas affected with acne should be kept clean, overly vigorous scrubbing may aggravate acne due to mechanical rupture of comedones. Topical agents such as retinoic acid, benzoyl peroxide, or salicylic acid may alter



FIGURE 57-7 Acne vulgaris. An example of acne vulgaris with inflammatory papules, pustules, and comedones. (Courtesy of Kalman Watsky, MD; with permission.)

the pattern of epidermal desquamation, preventing the formation of comedones and aiding in the resolution of preexisting cysts. Topical antibacterial agents (such as benzoyl peroxide, azelaic acid, erythromycin, clindamycin, or dapsone) are also useful adjuncts to therapy. Topical antibiotics (erythromycin and clindamycin) should be used in combination with benzoyl peroxide to prevent development of bacterial resistance.

Patients with moderate to severe acne with a prominent inflammatory component will benefit from the addition of systemic therapy, such as minocycline or doxycycline in doses of 100 mg bid or in lower dose, extended-release preparations. Such antibiotics appear to have anti-inflammatory effects independent of their antibacterial effects. Female patients who do not respond to oral antibiotics may benefit from hormonal therapy. Several oral contraceptives are now approved by the FDA for use in the treatment of acne vulgaris. Spironolactone is emerging as a safe, effective, and durable antiandrogen treatment in women.

Patients with severe nodulocystic acne unresponsive to the therapies discussed above may benefit from treatment with the synthetic retinoid isotretinoin. Dosing is weight-based and cumulative, with duration of therapy dictated by summative dose or acne lesion remission. Results are excellent in appropriately selected patients. Its use is highly regulated due to its potential for severe adverse events, primarily teratogenicity and depression. In addition, patients receiving this medication develop dry skin and cheilitis and must be followed for development of hypertriglyceridemia.

At present, prescribers must enroll in a program designed to prevent pregnancy and adverse events while patients are taking isotretinoin. These measures are imposed to ensure that all prescribers are familiar with the risks of isotretinoin, that all female patients have two negative pregnancy tests prior to initiation of therapy and a negative pregnancy test prior to each refill, and that all patients have been warned about the risks associated with isotretinoin.

### ACNE ROSACEA

Acne rosacea, commonly referred to simply as *rosacea*, is an inflammatory disorder predominantly affecting the central face. Persons most often affected are Caucasians of northern European background, but rosacea also occurs in patients with dark skin. Rosacea is seen almost exclusively in adults, only rarely affecting patients <30 years old. Rosacea is more common in women, but those most severely affected are men. It is characterized by the presence of erythema, telangiectasias, and superficial pustules (Fig. 57-8) but is not associated with the presence of comedones. Rosacea rarely involves the chest or back.

There is a relationship between the tendency for facial flushing and the subsequent development of acne rosacea. Often, individuals with rosacea initially demonstrate a pronounced flushing reaction. This may be in response to heat, emotional stimuli, alcohol, hot drinks, or spicy foods. As the disease progresses, the flush persists longer and longer and may eventually become permanent. Papules, pustules, and



FIGURE 57-8 Acne rosacea. Prominent facial erythema, telangiectasia, scattered papules, and small pustules are seen in this patient with acne rosacea. (Courtesy of Robert Swerlick, MD; with permission.)

telangiectasias can become superimposed on the persistent flush. Rosacea of very long standing may lead to connective tissue overgrowth, particularly of the nose (*rhinophyma*). Rosacea may also be complicated by various inflammatory disorders of the eye, including keratitis, blepharitis, iritis, and recurrent chalazion. These ocular problems are potentially sight-threatening and warrant ophthalmologic evaluation.

## TREATMENT

### Acne Rosacea

Acne rosacea can be treated topically or systemically. Mild disease often responds to topical preparations of metronidazole, sodium sulfacetamide, azelaic acid, ivermectin, brimonidine, or oxymetazoline. More severe disease requires oral tetracyclines in subantimicrobial, modified-release preparations. Residual telangiectasia may respond to laser therapy. Topical glucocorticoids, especially potent agents, should be avoided because chronic use of these preparations may elicit rosacea. Application of topical agents to the skin is not effective treatment for ocular disease.

## SKIN DISEASES AND SMALLPOX VACCINATION

Although smallpox vaccinations were discontinued several decades ago for the general population, they are still required for certain military personnel and first responders. In the absence of a bioterrorism attack and a real or potential exposure to smallpox, such vaccination is contraindicated in persons with a history of skin diseases, such as AD, eczema, and psoriasis, who have a higher incidence of adverse events associated with smallpox vaccination. In the case of such exposure, the risk of smallpox infection outweighs that of adverse events from the vaccine (Chap. S3).

### FURTHER READING

- B JL et al (eds): *Dermatology*, 4th ed. Philadelphia, Elsevier, 2018.
- J WD et al (eds): *Andrew's Diseases of the Skin Clinical Dermatology*, 13th ed. Philadelphia, Elsevier, 2020.
- K S et al (eds): *Fitzpatrick's Dermatology in General Medicine*, 9th ed. New York, McGraw-Hill, 2019.
- W K et al (eds): *Fitzpatrick's Color Atlas and Synopsis of Clinical Dermatology*, 8th ed. New York, McGraw-Hill, 2017.

individual diseases, but by describing the various presenting clinical signs and symptoms that point to specific disorders. Concise differential diagnoses will be generated in which the significant diseases will be distinguished from the more common cutaneous disorders that have minimal or no significance with regard to associated internal disease. The latter disorders are reviewed in table form and always need to be excluded when considering the former. For a detailed description of individual diseases, the reader should consult a dermatologic text.

## PAPULOSQUAMOUS SKIN LESIONS

(Table 58-1) When an eruption is characterized by elevated lesions, either papules (<1 cm) or plaques (>1 cm), in association with scale, it is referred to as *papulosquamous*. The most common papulosquamous diseases—*tinea*, *psoriasis*,  *pityriasis rosea*, and *lichen planus*—are primary cutaneous disorders (Chap. 57). When psoriatic lesions are accompanied by arthritis, the possibility of psoriatic arthritis or reactive arthritis should be considered. A history of oral ulcers, conjunctivitis, uveitis, and/or urethritis points to the latter diagnosis. Lithium, beta blockers, anti-PD-1/PD-L1 antibodies, HIV or streptococcal infections, and a rapid taper of systemic glucocorticoids are known to exacerbate psoriasis; despite being used to treat psoriasis, tumor necrosis factor (TNF) inhibitors can also induce psoriatic lesions. Comorbidities in patients with psoriasis include cardiovascular disease and metabolic syndrome.

Whenever the clinical diagnosis of pityriasis rosea or lichen planus is made, it is important to review the patient's medications because the eruption may resolve by simply discontinuing the offending agent. Pityriasis rosea-like drug eruptions are seen most commonly with beta blockers, angiotensin-converting enzyme (ACE) inhibitors, and metronidazole, whereas the drugs that can produce a lichenoid eruption include thiazides, antimarlars, quinidine, beta blockers, TNF inhibitors, anti-PD-1/PD-L1 antibodies, and ACE inhibitors. In some populations (e.g., Europeans), there is a higher prevalence of hepatitis C viral infection in patients with oral lichen planus. Lichen planus-like lesions are also observed in chronic graft-versus-host disease.

In its early stages, the mycosis fungoidea (MF) form of *cutaneous T-cell lymphoma* (CTCL) may be confused with eczema or psoriasis, but it often eventually fails to respond to appropriate therapy for those inflammatory diseases. MF can develop within lesions of large-plaque parapsoriasis and is suggested by an increase in the thickness of the lesions. The diagnosis of MF is established by skin biopsy in which

TABLE 58-1 Selected Causes of Papulosquamous Skin Lesions

1. Primary cutaneous disorders
  - a. *Tinea*<sup>a</sup>—widespread disease may be sign of immunosuppression
  - b. *Psoriasis*<sup>a</sup>—widespread or resistant disease may be sign of HIV infection
  - c. *Pityriasis rosea*<sup>a</sup>
  - d. *Lichen planus*<sup>a</sup>
  - e. *Parapsoriasis*, small plaque and large plaque
  - f. *Bowen's disease* (squamous cell carcinoma in situ)<sup>b</sup>
2. Drugs
3. Systemic diseases
  - a. *Lupus erythematosus*, primarily subacute or chronic (discoid) lesions<sup>c</sup>
  - b. *Cutaneous T-cell lymphoma*, in particular, *mycosis fungoidea*<sup>d</sup>
  - c. *Secondary syphilis*
  - d. *Reactive arthritis*
  - e. *Sarcoidosis*<sup>e</sup>—with scale less common than without scale
  - f. *Bazex syndrome* (acrokeratosis paraneoplastica)<sup>f</sup>

<sup>a</sup>Discussed in detail in Chap. 57; cardiovascular disease and the metabolic syndrome are comorbidities in psoriasis; primarily in Europe, hepatitis C virus is associated with oral lichen planus. <sup>b</sup>Associated with chronic sun exposure more often than exposure to arsenic; usually one or a few lesions. <sup>c</sup>See also Red Lesions in "Papulonodular Skin Lesions." <sup>d</sup>Also cutaneous lesions of HTLV-1-associated adult T-cell leukemia/lymphoma. <sup>e</sup>See also Red-Brown Lesions in "Papulonodular Skin Lesions." <sup>f</sup>Psoriasisiform lesions of the helices, nose, and acral sites; squamous cell carcinoma of the upper aerodigestive tract most common underlying malignancy.

Abbreviation: HIV, human immunodeficiency virus.

# 58

## Skin Manifestations of Internal Disease

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It is a generally accepted concept in medicine that the skin can develop signs of internal disease. Therefore, in textbooks of medicine, one finds a chapter describing in detail the major systemic disorders that can be identified by cutaneous signs. The underlying assumption of such a chapter is that the clinician has been able to identify the specific disorder in the patient and needs only to read about it in the textbook. In reality, concise differential diagnoses and the identification of these disorders are actually difficult for the nondermatologist because he or she is not well-versed in the recognition of cutaneous lesions or their spectrum of presentations. Therefore, this chapter covers this particular topic of cutaneous medicine not by simply focusing on

TABLE 58-2 Causes of Erythroderma

1. Primary cutaneous disorders
  - a. Psoriasis<sup>a</sup>
  - b. Dermatitis (atopic > contact > stasis [with autosensitization] or seborrheic [primarily infants])<sup>a</sup>
  - c. Pityriasis rubra pilaris
2. Drugs
3. Systemic diseases
  - a. Cutaneous T-cell lymphoma (Sézary syndrome, erythrodermic mycosis fungoides)
  - b. Other lymphomas
  - c. Rarely, late-stage solid tumors
4. Idiopathic (usually older men)

<sup>a</sup>Discussed in detail in *Chap. 57*.

collections of atypical T lymphocytes are found in the epidermis and dermis. As the disease progresses, cutaneous tumors and lymph node involvement may appear.

In *secondary syphilis*, there are scattered pink to red-brown papules with thin scale. The eruption often involves the palms and soles and can resemble pityriasis rosea. Associated findings are helpful in making the diagnosis and include nonscarring alopecia, annular plaques on the face, mucous patches, condyloma lata (broad-based and moist), and lymphadenopathy, as well as malaise, fever, headache, and myalgias. The interval between the primary chancre and the secondary stage is usually 4–8 weeks, and spontaneous resolution without appropriate therapy occurs.

## ERYthroderMA

(Table 58-2) *Erythroderma* is the term used when the majority of the skin surface is erythematous (red in color). There may be associated scale, erosions, or pustules as well as shedding of the hair and nails. Potential systemic manifestations include fever, chills, hypothermia, reactive lymphadenopathy, peripheral edema, hypoalbuminemia, and high-output cardiac failure. The major etiologies of erythroderma are (1) cutaneous diseases such as psoriasis and dermatitis (Table 58-3); (2) drugs; (3) systemic diseases, most commonly CTCL; and (4) idiopathic. In the first three groups, the location and description of the initial lesions, prior to the development of the erythroderma, aid in the diagnosis. For example, a history of red scaly plaques on the elbows and knees would point to psoriasis. It is also important to examine the skin carefully for a migration of the erythema and associated secondary changes such as pustules or erosions. Migratory waves of erythema studded with superficial pustules are seen in *pustular psoriasis*.

Drug-induced erythroderma may begin as an exanthematos (morbilliform) eruption (*Chap. 60*) or may arise as diffuse erythema. A number of drugs can produce an erythroderma, including penicillins, sulfonamides, aromatic anticonvulsants (e.g., carbamazepine, phenytoin), and allopurinol. Fever and peripheral eosinophilia often accompany the eruption, and there may also be facial swelling, hepatitis, myocarditis, thyroiditis, and allergic interstitial nephritis; this constellation is frequently referred to as *drug reaction with eosinophilia and systemic symptoms* (DRESS) or *drug-induced hypersensitivity syndrome* (DIHS). In addition, these reactions, especially to aromatic anticonvulsants, can lead to a pseudolymphoma syndrome with adenopathy and circulating atypical lymphocytes, while reactions to allopurinol may be accompanied by gastrointestinal bleeding.

The most common malignancy that is associated with erythroderma is CTCL; in some series, up to 25% of the cases of erythroderma were due to CTCL. The patient may progress from isolated plaques and tumors, but more commonly, the erythroderma is present throughout the course of the disease (Sézary syndrome). In Sézary syndrome, there are circulating clonal atypical T lymphocytes, pruritus, and lymphadenopathy. In cases of erythroderma where there is no apparent cause (idiopathic), longitudinal evaluation is mandatory to monitor for the possible development of CTCL.

## ALOPECIA

(Table 58-4) The two major forms of alopecia are scarring and non-scarring. *Scarring alopecia* is associated with fibrosis, inflammation, and loss of hair follicles. A smooth scalp with a decreased number of follicular openings is usually observed clinically, but in some patients, the changes are seen only in biopsy specimens from affected areas. In *nonscarring alopecia*, the hair shafts are absent or miniaturized, but the hair follicles are preserved, explaining the reversible nature of nonscarring alopecia.

The most common causes of nonscarring alopecia include *androgenetic alopecia*, *telogen effluvium*, *alopecia areata*, *tinea capitis*, and the early phase of *traumatic alopecia* (Table 58-5). In women with androgenetic alopecia, an elevation in circulating levels of androgens may be seen as a result of ovarian or adrenal gland dysfunction or neoplasm. When there are signs of virilization, such as a deepened voice and/or enlarged clitoris, the possibility of an ovarian or adrenal gland tumor should be considered.

Exposure to various drugs can also cause diffuse hair loss, usually by inducing a telogen effluvium. An exception is the anagen effluvium observed with chemotherapeutic agents such as daunorubicin. Alopecia is a side effect of the following drugs: warfarin, heparin, propylthiouracil, carbimazole, isotretinoin, acitretin, lithium, beta blockers, interferons, colchicine, and amphetamines. Fortunately, spontaneous regrowth usually follows discontinuation of the offending agent.

Less commonly, nonscarring alopecia is associated with *lupus erythematosus* and *secondary syphilis*. In systemic lupus, there are two forms of alopecia—one is scarring secondary to discoid lesions (see below), and the other is nonscarring. The latter form coincides with flares of systemic disease and may involve the entire scalp or just the frontal scalp, with the appearance of multiple short hairs ("lupus hairs") as a sign of initial regrowth. Scattered, poorly circumscribed patches of alopecia with a "moth-eaten" appearance are a manifestation of the secondary stage of syphilis. Diffuse thinning of the hair is also associated with hypothyroidism and hyperthyroidism (Table 58-4).

Scarring alopecia is more frequently the result of a primary cutaneous disorder such as *lichen planus*, *chronic cutaneous (discoid) lupus*, *central centrifugal cicatricial alopecia*, *folliculitis decalvans*, or *linear scleroderma (morphea)* than it is a sign of systemic disease. Although the scarring lesions of *discoid lupus* can be seen in patients with systemic lupus, in the majority of patients, the disease process is limited to the skin. Less common causes of scarring alopecia include *sarcoidosis* (see "Papulonodular Skin Lesions," below), chemotherapeutic agents, and *cutaneous metastases*.

In the early phases of discoid lupus, lichen planus, and folliculitis decalvans, there are circumscribed areas of alopecia. Fibrosis and subsequent loss of hair follicles are observed primarily in the center of these alopecic patches, whereas the inflammatory process is most prominent at the periphery. The areas of active inflammation in discoid lupus are erythematous with scale, whereas the areas of previous inflammation are often hypopigmented with a rim of hyperpigmentation. In lichen planus, perifollicular macules at the periphery are usually violet-colored. A complete examination of the skin and oral mucosa combined with a biopsy and direct immunofluorescence microscopy of inflamed skin will aid in distinguishing these two entities. The peripheral active lesions in folliculitis decalvans are follicular pustules; these patients can develop a reactive arthritis.

## FIGURATE SKIN LESIONS

(Table 58-6) In *figurate eruptions*, the lesions form rings and arcs that are usually erythematous but can be skin-colored to brown. Most commonly, they are due to primary cutaneous diseases such as *tinea*, *urticaria*, *granuloma annulare*, and *erythema annulare centrifugum* (*Chaps. 57 and 59*). An underlying systemic illness is found in a second, less common group of migratory annular erythemas. It includes *erythema migrans*, *erythema gyratum repens*, *erythema marginatum*, and *necrolytic migratory erythema*.

In *erythema gyratum repens*, one sees numerous mobile concentric arcs and wavefronts that resemble the grain in wood. A search for an

TABLE 58-3 Erythroderma (Primary Cutaneous Disorders)

	INITIAL LESIONS	LOCATION OF INITIAL LESIONS	OTHER FINDINGS	DIAGNOSTIC AIDS	TREATMENT
Psoriasis <sup>a</sup>	Pink-red, silvery scale, sharply demarcated	Elbows, knees, scalp, presacral area, intergluteal fold	Nail dystrophy (e.g., pits, oil drop sign), arthritis, pustules, SAPHO syndrome <sup>b</sup>	Skin biopsy	Topical glucocorticoids, vitamin D analogs; UV-B (narrowband) > PUVA; oral retinoids; MTX; anti-TNF agents, anti-IL-12/23 Ab, anti-IL-23 Ab, anti-IL-17A or -IL-17 receptor A Ab; apremilast; cyclosporine
<b>Dermatitis<sup>a</sup></b>					
Atopic	Acute: Erythema, fine scale, crust, indistinct borders, excoriations  Chronic: Lichenification (increased skin markings), excoriations	Antecubital and popliteal fossae, neck, hands, eyelids	Pruritus  Personal and/or family history of atopy, including asthma, allergic rhinitis or conjunctivitis, and atopic dermatitis  Exclude secondary infection with <i>Staphylococcus aureus</i> or HSV  Exclude superimposed irritant or allergic contact dermatitis	Skin biopsy	Topical glucocorticoids, tacrolimus, pimecrolimus, tar, crisaborole, and antipruritics; oral antihistamines for sedation; open wet dressings; UV-B ± UV-A > PUVA; anti-IL-4/13 Ab; oral/IM glucocorticoids (short-term); MTX; mycophenolate mofetil; azathioprine; cyclosporine  Topical or oral antibiotics
Contact	Local: Erythema, crusting, vesicles, and bullae  Systemic: Erythema, fine scale, crust	Depends on offending agent  Generalized vs major intertriginous zones (especially groin)	Irritant—onset often within hours  Allergic—delayed-type hypersensitivity; lag time of 48 h with rechallenge  Patient has history of allergic contact dermatitis to topical agent and then receives systemic medication that is structurally related, e.g., formaldehyde (skin), aspartame (oral)	Patch testing; repeat open application test  Patch testing	Remove irritant or allergen; topical glucocorticoids; oral antihistamines; oral/IM glucocorticoids (short-term)  Same as local
Seborrheic (rare in adults)	Pink-red to pink-orange, greasy scale	Scalp, nasolabial folds, eyebrows, intertriginous zones	Rashes with stress, HIV infection  Associated with Parkinson's disease	Skin biopsy	Topical glucocorticoids and imidazoles
Stasis (with autosensitization)	Erythema, crusting, excoriations	Lower extremities	Pruritus, lower extremity edema, varicosities, hemosiderin deposits, lipodermatosclerosis  History of venous ulcers, thrombophlebitis, and/or cellulitis  Exclude cellulitis  Exclude superimposed contact dermatitis, e.g., topical neomycin	Skin biopsy	Topical glucocorticoids; open wet dressings; leg elevation; pressure stockings; pressure wraps if associated ulcers
Pityriasis rubra pilaris	Orange-red (salmon-colored), perifollicular papules	Generalized, but characteristic "skip" areas of normal skin	Wax-like palmarplantar keratoderma  Exclude cutaneous T-cell lymphoma	Skin biopsy	Isotherapy or acitretin; MTX; anti-IL-12/23 Ab, anti-IL-23 Ab, anti-TNF agents, anti-IL-17A or -IL-17 receptor A Ab

<sup>a</sup>Discussed in detail in Chap. 57. <sup>b</sup>SAPHO syndrome occurs more commonly in patients with palmarplantar pustulosis than in those with erythrodermic psoriasis.

**Abbreviations:** Ab, antibody; HSV, herpes simplex virus; IL, interleukin; IM, intramuscular; MTX, methotrexate; PUVA, psoralens plus ultraviolet A irradiation; SAPHO, synovitis, acne, pustulosis, hyperostosis, and osteitis (a subtype is chronic recurrent multifocal osteomyelitis); TNF, tumor necrosis factor; UV-A, ultraviolet A irradiation; UV-B, ultraviolet B irradiation.

underlying malignancy is mandatory in a patient with this eruption. Erythema migrans is the cutaneous manifestation of Lyme disease, which is caused by the spirochete *Borrelia burgdorferi*. In the initial stage (3–30 days after tick bite), a single annular lesion is usually seen, which can expand to ≥10 cm in diameter. Within several days, up to half of the patients develop multiple smaller erythematous lesions at sites distant from the bite. Associated symptoms include fever, headache, photophobia, myalgias, arthralgias, and malar rash. Erythema marginatum is seen in patients with rheumatic fever, primarily on the trunk. Lesions are pink-red in color, flat to minimally elevated, and transient.

There are additional cutaneous diseases that present as annular eruptions but lack an obvious migratory component. Examples include *CTCL*, *subacute cutaneous lupus*, *secondary syphilis*, and *sarcoidosis* (see “Papulonodular Skin Lesions,” below).

## ACNE

(Table 58-7) In addition to *acne vulgaris* and *acne rosacea*, the two major forms of acne (Chap. 57), there are drugs and systemic diseases that can lead to acneiform eruptions.

Patients with the *carcinoid syndrome* have episodes of flushing of the head, neck, and sometimes the trunk. Resultant skin changes of the

TABLE 58-4 Causes of Alopecia

I. Nonscarring alopecia
A. Primary cutaneous disorders
1. Androgenetic alopecia (female pattern, male pattern)
2. Telogen effluvium
3. Alopecia areata
4. Tinea capitis
5. Traumatic alopecia <sup>a</sup>
6. Psoriasiform alopecia, including TNF inhibitor-induced
B. Drugs
1. Telogen effluvium—see text for most common causes
2. Anagen effluvium—chemotherapeutic agents (e.g., anthracyclines)
C. Systemic diseases
1. Systemic lupus erythematosus
2. Secondary syphilis
3. Hypothyroidism
4. Hyperthyroidism
5. Hypopituitarism
6. Deficiencies of protein, biotin, zinc, and perhaps iron
II. Scarring alopecia
A. Primary cutaneous disorders
1. Cutaneous lupus (chronic discoid lesions) <sup>b</sup>
2. Lichen planus, including frontal fibrosing alopecia
3. Central centrifugal cicatricial alopecia
4. Folliculitis decalvans
5. Dissecting cellulitis
6. Linear morphea (linear scleroderma) <sup>c</sup>
B. Drugs
1. Chemotherapeutic agents (e.g., taxanes, busulfan)
C. Systemic diseases
1. Discoid lesions in the setting of systemic lupus erythematosus <sup>b</sup>
2. Sarcoidosis
3. Cutaneous metastases

<sup>a</sup>Most patients with trichotillomania or early stages of traction alopecia and some patients with pressure-induced alopecia. <sup>b</sup>While the majority of patients with discoid lesions have only cutaneous disease, these lesions do represent one of the criteria in the European League Against Rheumatism (EULAR)/American College of Rheumatology (ACR) [2019] and ACR [1982] classification schemes for systemic lupus erythematosus. <sup>c</sup>Can involve underlying muscles and osseous structures, and rarely in linear morphea of the frontal scalp (*en coup de sabre*), there is involvement of the meninges and brain.

face, in particular telangiectasias, may mimic the clinical appearance of erythematotelangiectatic acne rosacea.

## PUSTULAR LESIONS

*Acneiform eruptions* (see “Acne,” above) and *folliculitis* represent the most common pustular dermatoses. An important consideration in the evaluation of follicular pustules is a determination of the associated pathogen, for example, normal flora (culture-negative), *Staphylococcus aureus*, *Pseudomonas aeruginosa* (“hot tub” folliculitis), *Malassezia*, dermatophytes (Majocchi’s granuloma), and *Demodex* spp. Noninfectious forms of folliculitis include HIV- or immunosuppression-associated eosinophilic folliculitis and folliculitis secondary to drugs such as glucocorticoids, lithium, and epidermal growth factor receptor (EGFR) or MEK inhibitors. Administration of high-dose systemic glucocorticoids can result in a widespread eruption of follicular pustules on the trunk, characterized by lesions in the same stage of development. With regard to underlying systemic diseases, nonfollicular-based pustules are a characteristic component of pustular psoriasis (sterile) and can be seen in septic emboli of bacterial or fungal origin (see “Purpura,” below). In patients with acute generalized exanthematous pustulosis (AGEP) due primarily to medications (e.g., cephalosporins), there are large areas of erythema studded with multiple sterile pustules in addition to neutrophilia.

## TELANGIECTASIAS

(Table 58-8) To distinguish the various types of telangiectasias, it is important to examine the shape and configuration of the dilated blood vessels. *Linear telangiectasias* are seen on the face of patients with *actinically damaged skin* and *acne rosacea*, and they are found on the legs of patients with *venous hypertension* and first appear on the legs in *generalized essential telangiectasia*. Patients with an unusual form of *mastocytosis* (telangiectasia macularis eruptiva perstans) and the *carcinoid syndrome* (see “Acne,” above) also have linear telangiectasias. Lastly, linear telangiectasias are found in areas of cutaneous inflammation. For example, longstanding lesions of discoid lupus frequently have telangiectasias within them.

*Poikiloderma* is a term used to describe a patch of skin with: (1) reticular hypo- and hyperpigmentation, (2) wrinkling secondary to epidermal atrophy, and (3) telangiectasias. Poikiloderma does not imply a single disease entity—although it is becoming less common, it is seen in skin damaged by *ionizing radiation* as well as in patients with autoimmune connective tissue diseases, primarily *dermatomyositis* (DM), and rare genodermatoses (e.g., Kindler syndrome).

In *systemic sclerosis* (*scleroderma*), the dilated blood vessels have a unique configuration and are known as *mat telangiectasias*. The lesions are broad macules that usually measure 2–7 mm in diameter but occasionally are larger. Mats have a polygonal or oval shape, and their erythematous color may appear uniform, but, upon closer inspection, the erythema is the result of delicate telangiectasias. The most common locations for mat telangiectasias are the face, oral mucosa, and hands—peripheral sites that are prone to intermittent ischemia. The limited form of systemic sclerosis, also referred to as the CREST (calcinosis cutis, Raynaud’s phenomenon, esophageal dysmotility, sclerodactyly, and telangiectasia) variant (Chap. 360), is associated with a chronic course and anticentromere antibodies. Mat telangiectasias are an important clue to the diagnosis of this variant as well as the diffuse form of systemic sclerosis because they may be the only cutaneous finding.

*Nailfold telangiectasias* are pathognomonic signs of the three major autoimmune connective tissue diseases: *lupus erythematosus*, *systemic sclerosis*, and *DM*. They are easily visualized by the naked eye and occur in at least two-thirds of these patients. In both DM and lupus, there is associated nailfold erythema, and in DM, the erythema is often accompanied by “ragged” cuticles and fingertip tenderness. Under 10× magnification or by dermoscopy, the blood vessels in the nailfolds of lupus patients are tortuous and resemble “glomeruli,” whereas in systemic sclerosis and DM, there is a loss of capillary loops and those that remain are markedly dilated.

In *hereditary hemorrhagic telangiectasia* (Osler-Rendu-Weber disease), the lesions usually appear during adolescence (mucosal) and adulthood (cutaneous) and are most commonly seen on the mucous membranes (nasal, orolabial), face, and distal extremities, including under the nails. They represent arteriovenous (AV) malformations of the dermal microvasculature, are dark red in color, and are usually slightly elevated. When the skin is stretched over an individual lesion, an eccentric punctum with radiating legs is seen. Although the degree of systemic involvement varies in this autosomal dominant disease (due primarily to mutations in either the endoglin or activin receptor-like kinase gene), the major symptoms are recurrent epistaxis and gastrointestinal bleeding. The fact that these mucosal telangiectasias are actually AV communications helps to explain their tendency to bleed.

## HYPOPIGMENTATION

(Table 58-9) Disorders of hypopigmentation are often classified as either diffuse or localized. The classic example of *diffuse hypopigmentation* is *oculocutaneous albinism* (OCA). The most common forms are due to mutations in the tyrosinase gene (type I) or the *P* gene (type II); patients with type IA OCA have a total lack of enzyme activity. At birth, different forms of OCA can appear similar—white hair, gray-blue eyes, and pink-white skin. However, the patients with no tyrosinase activity maintain this phenotype, whereas those with decreased activity will acquire some pigmentation of the eyes, hair, and skin as they age.

TABLE 58-5 Nonscarring Alopecia (Primary Cutaneous Disorders)

	CLINICAL CHARACTERISTICS	PATHOGENESIS	TREATMENT
Telogen effluvium	Diffuse shedding of normal hairs Follows major stress (high fever, severe infection) or change in hormone levels (postpartum) Reversible without treatment	Stress causes more of the asynchronous growth cycles of individual hairs to become synchronous; therefore, larger numbers of growing (anagen) hairs simultaneously enter the dying (telogen) phase	Observation; discontinue any drugs that have alopecia as a side effect; must exclude underlying metabolic causes, e.g., hypothyroidism, hyperthyroidism
Androgenetic alopecia (male pattern; female pattern)	Miniaturization of hairs along the midline of the scalp Recession of the anterior scalp line in men and some women	Increased sensitivity of affected hairs to the effects of androgens—most common Increased levels of circulating androgens (ovarian or adrenal source in women)—less common	If no evidence of hyperandrogenemia, then topical minoxidil; finasteride <sup>a</sup> ; spironolactone (women); hair transplant; low-dose oral minoxidil
Alopecia areata	Well-circumscribed, circular areas of hair loss, 2–5 cm in diameter In extensive cases, coalescence of lesions and/or involvement of other hair-bearing surfaces of the body Pitting or sandpapered appearance of the nails	The germinative zones of the hair follicles are surrounded by T lymphocytes Occasional associated diseases: hyperthyroidism, hypothyroidism, vitiligo, Down syndrome	Topical anthralin or tazarotene; intralesional glucocorticoids; topical contact sensitizers; JAK inhibitors
Tinea capitis	Varies from scaling with minimal hair loss to discrete patches with “black dots” (sites of broken infected hairs) to boggy plaque with pustules (kerion) <sup>b</sup>	Invasion of hairs by dermatophytes, most commonly <i>Trichophyton tonsurans</i>	Oral griseofulvin or terbinafine plus 2.5% selenium sulfide or ketoconazole shampoo; examine family members
Traumatic alopecia <sup>c</sup>	Broken hairs, often of varying lengths Irregular outline in trichotillomania and traction alopecia Fringe sign in traction alopecia	Traction with curlers, rubber bands, tight braiding Exposure to heat or chemicals (e.g., hair straighteners) Mechanical pulling (trichotillomania)	Discontinuation of offending hair style or chemical treatments; diagnosis of trichotillomania may require observation of shaved hairs (for growth) or biopsy, possibly followed by psychotherapy

<sup>a</sup>To date, Food and Drug Administration-approved for men. <sup>b</sup>Scarring alopecia can occur at sites of kerions. <sup>c</sup>May also be scarring, especially late-stage traction alopecia.

The degree of pigment formation is also a function of racial background, and the pigmentary dilution is more readily apparent when patients are compared to their first-degree relatives. The ocular findings in OCA correlate with the degree of hypopigmentation and include decreased visual acuity, nystagmus, photophobia, strabismus, and a lack of normal binocular vision.

TABLE 58-6 Causes of Figurate Skin Lesions

I. Primary cutaneous disorders
A. Tinea
B. Urticaria (primary in ≥90% of patients)
C. Granuloma annulare
D. Erythema annulare centrifugum
E. Psoriasis, annular pustular psoriasis
F. Interstitial granulomatous drug reaction
II. Systemic diseases
A. Migratory
1. Erythema migrans (CDC case definition is ≥5 cm in diameter)
2. Urticaria (≤10% of patients)
3. Erythema gyratum repens
4. Erythema marginatum
5. Pustular psoriasis (generalized and annular forms)
6. Necrolytic migratory erythema (glucagonoma syndrome) <sup>a</sup>
B. Nonmigratory (may slowly expand)
1. Subacute cutaneous LE, LE tumidus
2. Sarcoidosis
3. Leprosy (borderline, tuberculoid)
4. Secondary syphilis (especially the face)
5. Cutaneous T-cell lymphoma (especially mycosis fungoïdes)
6. Interstitial granulomatous dermatitis <sup>b</sup>
7. Annular erythema of Sjögren's syndrome

<sup>a</sup>Migratory erythema with erosions; favors lower extremities and girdle area.

<sup>b</sup>Underlying diseases include rheumatoid arthritis, LE, and granulomatosis with polyangiitis.

Abbreviations: CDC, Centers for Disease Control and Prevention; LE, lupus erythematosus.

The differential diagnosis of *localized hypomelanosis* includes the following primary cutaneous disorders: *postinflammatory hypopigmentation*, *idiopathic guttate hypomelanosis*, *pityriasis (tinea) versicolor*, *vitiligo*, *chemical- or drug-induced leukoderma*, *nevus depigmentosus* (see below), *progressive macular hypomelanosis*, and *piebaldism* (Table 58-10). In this group of diseases, the areas of involvement are macules or patches with a decrease or absence of pigmentation. Patients with vitiligo also have an increased incidence of several autoimmune disorders, including Hashimoto's thyroiditis, Graves' disease, pernicious anemia, Addison's disease, uveitis, alopecia areata, chronic mucocutaneous candidiasis, and the autoimmune polyendocrine syndromes (types I and II). Diseases of the thyroid gland are the most frequently associated disorders, occurring in up to 30% of patients with vitiligo. Circulating autoantibodies are often found, and the most common ones are antithyroglobulin, antimicrosomal, and antithyroid-stimulating hormone receptor antibodies.

There are four systemic diseases that should be considered in a patient with skin findings suggestive of vitiligo—*systemic sclerosis*, *melanoma-associated leukoderma*, *onchocerciasis*, and *Vogt-Koyanagi-Harada syndrome*. The vitiligo-like leukoderma seen in patients with

TABLE 58-7 Causes of Acneiform Eruptions

I. Primary cutaneous disorders
A. Acne vulgaris
B. Acne rosacea
II. Drugs, e.g., anabolic steroids, glucocorticoids, lithium, EGFR inhibitors, HER2 inhibitors, MEK inhibitors, iodides
III. Systemic diseases
A. Increased androgen production
1. Adrenal origin, e.g., Cushing's disease, 21-hydroxylase deficiency
2. Ovarian origin, e.g., polycystic ovary syndrome, ovarian hyperthecosis
B. Cryptococcosis, disseminated
C. Dimorphic fungal infections
D. Behçet's disease

Abbreviations: EGFR, epidermal growth factor receptor; HER2, human epidermal growth factor receptor 2; MEK, MAP (mitogen activated protein) kinase.

TABLE 58-8 Causes of Telangiectasias

I. Primary cutaneous disorders
A. Linear/branching
1. Acne rosacea (face)
2. Actinically damaged skin (face, neck, V of chest)
3. Venous hypertension (legs)
4. Generalized essential telangiectasia
5. Cutaneous collagenous vasculopathy
6. Within basal cell carcinomas or cutaneous lymphoma
B. Poikiloderma
1. Ionizing radiation <sup>a</sup>
C. Spider angioma
1. Idiopathic
2. Pregnancy
II. Systemic diseases
A. Linear/branching
1. Carcinoid (head, neck, upper trunk)
2. Ataxia-telangiectasia (bulbar conjunctivae, head and neck)
3. Mastocytosis (within lesions)
B. Poikiloderma
1. Dermatomyositis, lupus erythematosus
2. Mycosis fungoides, patch stage
3. Genodermatoses, e.g., xeroderma pigmentosum, Kindler syndrome
C. Mat
1. Systemic sclerosis (scleroderma)
D. Nailfold
1. Lupus erythematosus
2. Systemic sclerosis (scleroderma)
3. Dermatomyositis
4. Hereditary hemorrhagic telangiectasia
E. Papular
1. Hereditary hemorrhagic telangiectasia
F. Spider angioma
1. Cirrhosis <sup>b</sup>

<sup>a</sup>Becoming less common. <sup>b</sup>Due to hyperestrogenic state.

systemic sclerosis has a clinical resemblance to idiopathic vitiligo that has begun to repigment as a result of treatment; that is, perifollicular macules of normal pigmentation are seen within areas of depigmentation. The basis of this leukoderma is unknown; there is no evidence of inflammation in areas of involvement, but it can resolve if the underlying connective tissue disease becomes inactive. In contrast to idiopathic vitiligo, melanoma-associated vitiligo-like leukoderma often begins on the trunk, and its appearance, if spontaneous, should prompt a search for metastatic disease. It is also seen in patients undergoing immunotherapy for melanoma, including immune checkpoint-blocking antibodies, with cytotoxic T lymphocytes presumably recognizing cell surface antigens common to melanoma cells and melanocytes, and is associated with a greater likelihood of a clinical response. A history of aseptic meningitis, nontraumatic uveitis, tinnitus, hearing loss, and/or dysacusis points to the diagnosis of the Vogt-Koyanagi-Harada syndrome. In these patients, the face and scalp are the most common locations of pigment loss.

There are two systemic disorders (neurocristopathies) that may have the cutaneous findings of piebaldism (Table 58-9). They are *Shah-Waardenburg syndrome* and *Waardenburg syndrome*. A possible explanation for both disorders is an abnormal embryonic migration or survival of two neural crest-derived elements, one of them being melanocytes and the other myenteric ganglion cells (leading to Hirschsprung disease in Shah-Waardenburg syndrome) or auditory nerve cells (Waardenburg syndrome). The latter syndrome is characterized by congenital sensorineural hearing loss, dystopia canthorum (lateral displacement of the inner canthi but normal interpupillary distance), heterochromic irises, and a broad nasal root, in addition to the piebaldism. The facial

TABLE 58-9 Causes of Hypopigmentation

I. Primary cutaneous disorders
A. Diffuse
1. Generalized vitiligo <sup>a</sup>
B. Localized
1. Postinflammatory
2. Idiopathic guttate hypomelanosis
3. Pityriasis (tinea) versicolor
4. Vitiligo <sup>a</sup>
5. Chemical- or drug-induced leukoderma, e.g., topical imiquimod, oral imatinib
6. Nevus depigmentosus and pigmentary mosaicism
7. Progressive macular hypomelanosis
8. Piebaldism <sup>a</sup>
II. Systemic diseases
A. Diffuse
1. Oculocutaneous albinism <sup>b</sup>
2. Hermansky-Pudlak syndrome <sup>b,c</sup>
3. Chédiak-Higashi syndrome <sup>b,d</sup>
4. Phenylketonuria
B. Localized
1. Systemic sclerosis (scleroderma) <sup>e</sup>
2. Melanoma-associated vitiligo-like leukoderma, immunotherapy-induced or spontaneous <sup>e</sup>
3. Sarcoidosis
4. Cutaneous T-cell lymphoma (especially mycosis fungoides)
5. Tuberculoid and indeterminate leprosy
6. Onchocerciasis <sup>e</sup>
7. Linear nevoid hypopigmentation (pigmentary mosaicism) <sup>b,f</sup>
8. Incontinentia pigmenti (stage IV)
9. Tuberous sclerosis
10. Waardenburg syndrome and Shah-Waardenburg syndrome
11. Vogt-Koyanagi-Harada syndrome <sup>e</sup>

<sup>a</sup>Absence of melanocytes in areas of leukoderma; congenital in piebaldism.

<sup>b</sup>Normal number of melanocytes. <sup>c</sup>Platelet storage defect and restrictive lung disease secondary to deposits of ceroid-like material or immunodeficiency; due to mutations in  $\beta$  or  $\delta$  subunit of adaptors-related protein complex 3 as well as subunits of biogenesis of lysosome-related organelles complex (BLOC)-1, -2, and -3. <sup>d</sup>Giant lysosomal granules and recurrent infections. <sup>e</sup>Can resemble vitiligo due to acquired complete loss of pigment. <sup>f</sup>Minority of patients in a nonreferral setting have systemic abnormalities (musculoskeletal, central nervous system, ocular), previously referred to as hypomelanosis of Ito.

dysmorphism can be explained by the neural crest origin of the connective tissues of the head and neck. Patients with Waardenburg syndrome have been shown to have mutations in four genes, including *PAX-3* and *MITF*, all of which encode transcription factors, whereas patients with Hirschsprung disease plus white spotting have mutations in one of three genes—endothelin 3, endothelin B receptor, and *SOX-10*.

In *tuberous sclerosis*, the earliest cutaneous sign is macular hypomelanosis, referred to as an ash leaf spot. These lesions are often present at birth and are usually multiple; however, detection may require Wood's lamp examination, especially in lightly pigmented individuals. The pigment within them is reduced, but not absent. The average size is 1–3 cm, and the common shapes are polygonal and lance-ovate. Examination of the patient for additional cutaneous signs such as multiple angiofibromas of the face (adenoma sebaceum), ungual and intraoral fibromas, fibrous cephalic plaques, and connective tissue nevi (shagreen patches) is recommended. It is important to remember that an ash leaf spot on the scalp will result in a circumscribed patch of lightly pigmented hair. Internal manifestations include seizures, intellectual disability, central nervous system (CNS) and retinal hamartomas, pulmonary lymphangioleiomyomatosis (women), renal angiomyolipomas, and cardiac rhabdomyomas. The latter can be detected in up to 60% of children (<18 years) with tuberous sclerosis by echocardiography.

*Nevus depigmentosus* is a stable, well-circumscribed hypomelanosis that is present at birth. There is usually a single oval or rectangular

TABLE 58-10 Hypopigmentation (Primary Cutaneous Disorders, Localized)

	CLINICAL CHARACTERISTICS	WOOD'S LAMP EXAMINATION (UV-A; PEAK = 365 NM)	SKIN BIOPSY SPECIMEN	PATHOGENESIS	TREATMENT
Postinflammatory hypopigmentation	Can develop within active lesions, as in subacute cutaneous lupus, or after the lesion fades, as in atopic dermatitis	Depends on particular disease Usually less enhancement than in vitiligo	Type of inflammatory infiltrate depends on specific disease	Block in transfer of melanin from melanocytes to keratinocytes could be secondary to edema or decrease in contact time Destruction of melanocytes if inflammatory cells attack basal layer of epidermis	Treat underlying inflammatory disease
Idiopathic guttate hypomelanosis	Common; acquired; usually 2–4 mm in diameter Shins and extensor forearms	Less enhancement than vitiligo	Abrupt decrease in epidermal melanin content	Possible somatic mutations as a reflection of aging or UV exposure	None
Pityriasis (tinea) versicolor <sup>a</sup>	Common disorder Upper trunk and neck (shawl-like distribution), groin Young adults Macules have fine white scale when scratched	Golden fluorescence	Hyphal forms and budding yeast in stratum corneum	Invasion of stratum corneum by the yeast <i>Malassezia</i> Yeast is lipophilic and produces C <sub>9</sub> and C <sub>11</sub> , dicarboxylic acids, which in vitro inhibit tyrosinase	Selenium sulfide 2.5% shampoo; topical imidazoles; oral triazoles
Vitiligo	Acquired; progressive Symmetric areas of complete pigment loss Periorificial—around mouth, nose, eyes, nipples, umbilicus, anus Other areas—flexor wrists, extensor distal extremities Segmental form is less common—unilateral, dermatomal-like	More apparent Chalk-white	Absence of melanocytes in well-developed lesions Mild inflammation	Autoimmune phenomenon that results in destruction of melanocytes—primarily cellular (circulating skin-homing autoreactive T cells)	Topical glucocorticoids; topical calcineurin inhibitors; UV-B (narrowband); PUVA; JAK inhibitors; transplants, if stable; depigmentation (topical MBEH), if widespread and treatment-resistant
Chemical- or drug-induced leukoderma	Similar appearance to vitiligo Often begins on hands when associated with chemical exposure Satellite lesions in areas not exposed to chemicals	More apparent Chalk-white	Decreased number or absence of melanocytes	Exposure to chemicals that selectively destroy melanocytes, in particular phenols and catechols (germicides; rubber products) or ingestion of drugs such as imatinib Release of cellular antigens and activation of circulating lymphocytes may explain satellite phenomenon Possible inhibition of KIT receptor	Avoid exposure to offending agent, then treat as vitiligo Drug-induced variant may undergo repigmentation when medication is discontinued
Piebaldism	Autosomal dominant Congenital, stable White forelock Areas of amelanosis contain normally pigmented and hyperpigmented macules of various sizes Symmetric involvement of central forehead, ventral trunk, and mid regions of upper and lower extremities	Enhancement of leukoderma and hyperpigmented macules	Amelanotic areas—few to no melanocytes	Defect in migration of melanoblasts from neural crest to involved skin or failure of melanoblasts to survive or differentiate in these areas Mutations within the <i>KIT</i> protooncogene that encodes the tyrosine kinase receptor for stem cell growth factor (kit ligand)	None; occasionally transplants

<sup>a</sup>If potassium hydroxide (KOH) examination of scale is negative, consider the possibility of progressive macular hypomelanosis.

Abbreviations: MBEH, monobenzylether of hydroquinone; PUVA, psoralens plus ultraviolet A irradiation; UV-B, ultraviolet B irradiation.

lesion, but when there are multiple lesions, the possibility of tuberous sclerosis needs to be considered. In *linear nevoid hypopigmentation*, a term that is replacing hypomelanosis of Ito and segmental or systematized nevus depigmentosus, streaks and swirls of hypopigmentation are observed. Up to one-third of patients in a tertiary care setting had associated abnormalities involving the musculoskeletal system (asymmetry), the CNS (seizures and intellectual disability), and the eyes (strabismus and hypertelorism). Chromosomal mosaicism has

been detected in these patients, lending support to the hypothesis that the cutaneous pattern is the result of the migration of two clones of primordial melanocytes, each with a different pigment potential.

Localized areas of decreased pigmentation are commonly seen as a result of cutaneous inflammation (Table 58-10) and have been observed in the skin overlying active lesions of sarcoidosis (see “Papulonodular Skin Lesions,” below) as well as in CTCL. Cutaneous infections also present as disorders of hypopigmentation, and in *tuberculoid*

*leprosy*, there are a few asymmetric patches of hypomelanosis that have associated anesthesia, anhidrosis, and alopecia. Biopsy specimens of the palpable border show dermal granulomas that contain rare, if any, *Mycobacterium leprae* organisms.

## HYPERPIGMENTATION

(Table 58-11) Disorders of hyperpigmentation are also divided into two major groups—localized and diffuse. The localized forms are due to an epidermal alteration, a proliferation of melanocytes, or an increase in pigment production. Both acanthosis nigricans and seborrheic keratoses belong to the first group. *Acanthosis nigricans* can be a reflection of an internal malignancy, most commonly of the gastrointestinal tract, and it appears as velvety hyperpigmentation, primarily in flexural areas. However, in the majority of patients, acanthosis nigricans is associated with obesity and insulin resistance, although it may be a reflection of an endocrinopathy such as acromegaly, Cushing's syndrome, polycystic ovary syndrome, or insulin-resistant diabetes mellitus (type A, type B, and lipodystrophic forms). *Seborrheic keratoses* are common lesions, but in one rare clinical setting, they are a sign of systemic disease, and that setting is the sudden appearance of multiple lesions, often with an inflammatory base and in association with acrochordons (skin tags) and acanthosis nigricans. This is termed the *sign of Leser-Trélat* and alerts the clinician to search for an internal malignancy.

A proliferation of melanocytes results in the following pigmented lesions: *lentigo*, *melanocytic nevus*, and *melanoma* (Chap. 76). In an adult, the majority of lentigines are related to sun exposure, which explains their distribution. However, in the Peutz-Jeghers and LEOPARD (lentigines; ECG abnormalities, primarily conduction defects; ocular hypertelorism; pulmonary stenosis and subaortic valvular stenosis; abnormal genitalia [cryptorchidism, hypospadias]; retardation of growth; and deafness [sensorineural]) syndromes, lentigines do serve as a clue to systemic disease. In *LEOPARD/Noonan with multiple lentigines syndrome*, hundreds of lentigines develop during childhood and are scattered over the entire surface of the body. The lentigines in patients with *Peutz-Jeghers syndrome* are located primarily around the nose and mouth, on the hands and feet, and within the oral cavity. While the pigmented macules on the face may fade with age, the oral lesions persist. However, similar intraoral lesions are also seen in Addison's disease, in Laugier-Hunziker syndrome (no internal manifestations), and as a normal finding in darkly pigmented individuals. Patients with this autosomal dominant syndrome (due to mutations in a novel serine threonine kinase gene) have multiple benign polyps of the gastrointestinal tract, testicular or ovarian tumors, and an increased risk of developing gastrointestinal (primarily colon) and pancreatic cancers.

In the *Carney complex*, numerous lentigines are also seen, but they are in association with cardiac myxomas. This autosomal dominant disorder is also known as the *LAMB* (lentigines, atrial myxomas, mucocutaneous myxomas, and blue nevi) syndrome or *NAME* (nevi, atrial myxoma, myxoid neurofibroma, and ephelides [freckles]) syndrome. These patients can also have evidence of endocrine overactivity in the form of Cushing's syndrome (pigmented nodular adrenocortical disease) and acromegaly.

The third type of localized hyperpigmentation is due to a local increase in pigment production, and it includes *ephelides* and *café au lait macules* (CALMs). While a single CALM can be seen in up to 10% of the normal population, the presence of multiple or large-sized CALMs raises the possibility of an associated genodermatosis, for example, neurofibromatosis (NF) or McCune-Albright syndrome. CALMs are flat, uniformly brown in color (usually two shades darker than uninvolved skin), and can vary in size from 0.5 to 12+ cm. More than 90% of adult patients with *type I NF* will have six or more CALMs measuring  $\geq 1.5$  cm in diameter. Additional findings are discussed in the section on neurofibromas (see "Papulonodular Skin Lesions," below). In comparison with NF, the CALMs in patients with *McCune-Albright syndrome* (polyostotic fibrous dysplasia with precocious puberty in females due to mosaicism for an activating mutation

TABLE 58-11 Causes of Hyperpigmentation

- I. Primary cutaneous disorders
  - A. Localized
    - 1. Epidermal alteration
      - a. Seborrheic keratosis
      - b. Pigmented actinic keratosis
    - 2. Proliferation of melanocytes
      - a. Lentigo
      - b. Melanocytic nevus (mole)
      - c. Melanoma
    - 3. Increased pigment production
      - a. Ephelide (freckle)
      - b. Café au lait macule
      - c. Postinflammatory hyperpigmentation (also dermal)
      - d. Melasma (also dermal)
    - 4. Dermal pigmentation
      - a. Fixed drug eruption
  - B. Localized and diffuse
    - 1. Drugs (e.g., minocycline, hydroxychloroquine, bleomycin)
- II. Systemic diseases
  - A. Localized
    - 1. Epidermal alteration
      - a. Acanthosis nigricans (insulin resistance > other endocrine disorders, paraneoplastic)
      - b. Seborrheic keratoses (sign of Leser-Trélat)
    - 2. Proliferation of melanocytes
      - a. Lentigines (Peutz-Jeghers and LEOPARD/Noonan with multiple lentigines syndromes; xeroderma pigmentosum)
      - b. Melanocytic nevi (Carney complex [LAMB and NAME syndromes])<sup>a</sup>
    - 3. Increased pigment production
      - a. Café au lait macules (neurofibromatosis, Legius syndrome, McCune-Albright syndrome<sup>b</sup>)
      - b. Urticaria pigmentosa<sup>c</sup>
    - 4. Dermal pigmentation
      - a. Incontinentia pigmenti (stage III)
      - b. Dyskeratosis congenita
    - 5. Dermal deposits
      - a. Exogenous ochronosis
      - b. Localized argyria
  - B. Diffuse
    - 1. Endocrinopathies
      - a. Addison's disease
      - b. Nelson syndrome
      - c. Ectopic ACTH syndrome
      - d. Hyperthyroidism
    - 2. Metabolic
      - a. Porphyria cutanea tarda
      - b. Hemochromatosis
      - c. Vitamin B<sub>12</sub>/folate deficiency
      - d. Pellagra
      - e. Malabsorption, including Whipple's disease
    - 3. Melanism secondary to metastatic melanoma
    - 4. Autoimmune
      - a. Primary biliary cholangitis
      - b. Systemic sclerosis (scleroderma)
      - c. POEMS syndrome
      - d. Eosinophilia-myalgia syndrome<sup>d</sup>
    - 5. Drugs (e.g., cyclophosphamide) and metals (e.g., silver)

<sup>a</sup>Also lentigines. <sup>b</sup>Polyostotic fibrous dysplasia. <sup>c</sup>See also "Papulonodular Skin Lesions." <sup>d</sup>Late 1980s.

Abbreviations: LAMB, lentigines, atrial myxomas, mucocutaneous myxomas, and blue nevi; LEOPARD, lentigines, ECG abnormalities, ocular hypertelorism, pulmonary stenosis and subaortic valvular stenosis, abnormal genitalia, retardation of growth, and deafness (sensorineural); NAME, nevi, atrial myxoma, myxoid neurofibroma, and ephelides (freckles); POEMS, polyneuropathy, organomegaly, endocrinopathies, M-protein, and skin changes.

in a G protein [G $\alpha$ ] gene) are usually larger, are more irregular in outline, and tend to respect the midline.

In *incontinentia pigmenti*, dyskeratosis congenita, and bleomycin pigmentation, the areas of localized hyperpigmentation form a pattern—swirls and streaks in the first, reticulated in the second, and flagellate in the third. In *dyskeratosis congenita*, atrophic reticulated hyperpigmentation is seen on the neck, trunk, and thighs and is accompanied by nail dystrophy, pancytopenia, and leukoplakia of the oral and anal mucosae. The latter often develops into squamous cell carcinoma. In addition to the flagellate pigmentation (linear streaks) on the trunk, patients receiving bleomycin often have hyperpigmentation overlying the elbows, knees, and small joints of the hand.

Localized hyperpigmentation is seen as a side effect of several other *systemic medications*, including those that produce fixed drug reactions (nonsteroidal anti-inflammatory drugs [NSAIDs], sulfonamides, barbiturates, and tetracyclines) and those that can complex with melanin or iron (antimalarials and minocycline). Fixed drug eruptions recur in the exact same location as circular areas of erythema that can become bullous and then resolve as brown macules. The eruption usually appears within hours of readministration of the offending agent, and common locations include the genitalia, distal extremities, and perioral region. Chloroquine and hydroxychloroquine produce gray-brown to blue-black discoloration of the shins, hard palate, and face, while blue macules (often misdiagnosed as bruises) can be seen on the lower extremities and in sites of inflammation with prolonged minocycline administration. Estrogen in oral contraceptives can induce melasma—symmetric brown patches on the face, especially the cheeks, upper lip, and forehead. Similar changes are seen in pregnancy and in patients receiving phenytoin.

In the diffuse forms of hyperpigmentation, the darkening of the skin may be of equal intensity over the entire body or may be accentuated in sun-exposed areas. The causes of diffuse hyperpigmentation can be divided into four major groups—endocrine, metabolic, autoimmune, and drugs. The endocrinopathies that frequently have associated hyperpigmentation include *Addison's disease*, *Nelson's syndrome*, and *ectopic adrenocorticotrophic hormone (ACTH) syndrome*. In these diseases, the increased pigmentation is diffuse but is accentuated in sun-exposed areas, as well as in the palmar creases, sites of friction, and scars. An overproduction of the pituitary hormones  $\alpha$ -MSH (melanocyte-stimulating hormone) and ACTH can lead to an increase in melanocyte activity. These peptides are products of the proopiomelanocortin gene and exhibit homology; for example,  $\alpha$ -MSH and ACTH share 13 amino acids. A minority of patients with Cushing's disease or hyperthyroidism have generalized hyperpigmentation.

The metabolic causes of hyperpigmentation include *porphyria cutanea tarda* (PCT), *hemochromatosis*, vitamin B<sub>12</sub> deficiency, folic acid deficiency, *pellagra*, and *malabsorption*, including *Whipple's disease*. In patients with PCT (see "Vesicles/Bullae," below), the skin darkening is seen in sun-exposed areas and is a reflection of the photoreactive properties of porphyrins. The increased level of iron in the skin of patients with type 1 hemochromatosis stimulates melanin pigment production and leads to the classic bronze color. Patients with pellagra have a brown discoloration of the skin, especially in sun-exposed areas, as a result of nicotinic acid (niacin) deficiency. In the areas of increased pigmentation, there is a thin, varnish-like scale. These changes are also seen in patients who are vitamin B<sub>6</sub> deficient, have functioning carcinoid tumors (increased consumption of niacin), or take isoniazid. Approximately 50% of the patients with Whipple's disease have an associated generalized hyperpigmentation in association with diarrhea, weight loss, arthritis, and lymphadenopathy. A diffuse, slate-blue to gray-brown color is seen in patients with *melanosis secondary to metastatic melanoma*. The color reflects widespread deposition of melanin within the dermis as a result of the high concentration of circulating melanin precursors.

Of the autoimmune diseases associated with diffuse hyperpigmentation, *primary biliary cholangitis* and *systemic sclerosis* are the most common, and occasionally, both disorders are seen in the same patient. The skin is dark brown in color, especially in sun-exposed areas. In primary biliary cholangitis, the hyperpigmentation is accompanied by

pruritus, jaundice, and xanthomas, whereas in systemic sclerosis, it is accompanied by sclerosis of the extremities, face, and, less commonly, the trunk. Additional clues to the diagnosis of systemic sclerosis are mat and cuticular telangiectasias, calcinosis cutis, Raynaud's phenomenon, and distal ulcerations (see "Telangiectasias," above). The differential diagnosis of cutaneous sclerosis with hyperpigmentation includes POEMS (polyneuropathy; organomegaly [liver, spleen, lymph nodes]; endocrinopathies [impotence, gynecomastia]; M-protein; and skin changes) syndrome. The skin changes include hyperpigmentation, induration, hypertrichosis, angiomas, clubbing, and facial lipoatrophy.

Diffuse hyperpigmentation that is due to drugs or metals can result from one of several mechanisms—induction of melanin pigment formation, complexing of the drug or its metabolites to melanin, and deposits of the drug in the dermis. Busulfan, cyclophosphamide, 5-fluorouracil, and inorganic arsenic induce pigment production. Complexes containing melanin or iron plus the drug or its metabolites are seen in patients receiving minocycline, and a diffuse, brown-gray, muddy appearance within sun-exposed areas may develop, in addition to pigmentation of the mucous membranes, teeth, nails, bones, and thyroid. Administration of amiodarone can result in both a phototoxic eruption (exaggerated sunburn) and/or a slate-gray to violaceous discoloration of sun-exposed skin. Biopsy specimens of the latter show yellow-brown granules in dermal macrophages, which represent intralysosomal accumulations of lipids, amiodarone, and its metabolites. Actual deposits of a particular drug or metal in the skin are seen with silver (argyria), where the skin appears blue-gray in color; gold (chrysiasis), where the skin has a brown to blue-gray color; and clofazimine, where the skin appears reddish brown. The associated pigmentation is accentuated in sun-exposed areas, and discoloration of the eye is seen with gold (sclerae) and clofazimine (conjunctivae).

## VESICLES/ BULLAE

(Table 58-12) Depending on their size, cutaneous blisters are referred to as *vesicles* (<1 cm) or *bullae* (>1 cm). The primary autoimmune blistering disorders include *pemphigus vulgaris*, *pemphigus foliaceus*, *paraneoplastic pemphigus*, *bullous pemphigoid*, *gestational pemphigoid*, *cicatricial pemphigoid*, *epidermolysis bullosa acquisita*, *linear IgA bullous dermatosis (LABD)*, and *dermatitis herpetiformis (Chap. 59)*.

Vesicles and bullae are also seen in *contact dermatitis*, both allergic and irritant forms (Chap. 57). When there is a linear arrangement of vesicular lesions, an exogenous cause or herpes zoster should be suspected. Bullous disease secondary to the ingestion of drugs can take one of several forms, including phototoxic eruptions, isolated bullae, Stevens-Johnson syndrome (SJS), and toxic epidermal necrolysis (TEN) (Chap. 60). Clinically, phototoxic eruptions resemble an exaggerated sunburn with diffuse erythema and bullae in sun-exposed areas. The most commonly associated drugs are doxycycline, quinolones, voriconazole, thiiazides, NSAIDs, vemurafenib, and psoralens. The development of a phototoxic eruption is dependent on the doses of both the drug and ultraviolet (UV)-A irradiation.

*Toxic epidermal necrolysis* is characterized by bullae that arise on widespread areas of tender erythema and then slough. This results in large areas of denuded skin. The associated morbidity, such as sepsis, and mortality rates are relatively high and are a function of the extent of epidermal necrosis. In addition, these patients may also have involvement of the mucous membranes and respiratory and intestinal tracts. Drugs are the primary cause of TEN, and the most common offenders are aromatic anticonvulsants (phenytoin, barbiturates, carbamazepine), sulfonamides, aminopenicillins, allopurinol, and NSAIDs. Generalized bullous fixed drug eruption, severe acute graft-versus-host disease (grade 4), vancomycin-induced LABD, and flares of cutaneous lupus can also resemble TEN.

In *erythema multiforme (EM)*, the primary lesions are pink-red macules and edematous papules, the centers of which may become vesicular. In contrast to a morbilliform exanthem, the clue to the diagnosis of EM, and especially SJS, is the development of a "dusky" violet color in the center of the lesions. Target lesions are also characteristic of EM and arise as a result of active centers and borders in combination

TABLE 58-12 Causes of Vesicles/ Bullae

I. Primary mucocutaneous diseases
A. Primary blistering diseases (autoimmune)
1. Pemphigus, foliaceus and vulgaris <sup>a</sup>
2. Bullous pemphigoid <sup>b</sup>
3. Gestational pemphigoid <sup>b</sup>
4. Cicatricial pemphigoid <sup>b</sup>
5. Dermatitis herpetiformis <sup>b,c</sup>
6. Linear IgA bullous dermatosis <sup>b</sup>
7. Epidermolysis bullosa acquisita <sup>b,d</sup>
B. Secondary blistering diseases
1. Contact dermatitis <sup>a,b</sup>
2. Erythema multiforme <sup>e</sup>
3. Stevens-Johnson syndrome <sup>e</sup>
4. Toxic epidermal necrolysis <sup>e</sup>
5. Bullous fixed drug eruption, including generalized variant <sup>e</sup>
6. Pseudoporphyria, drug- or tanning booth-induced
C. Infections
1. Varicella-zoster virus <sup>a,f</sup>
2. Herpes simplex virus <sup>a,f</sup>
3. Enteroviruses, e.g., hand-foot-and-mouth disease <sup>f</sup>
4. SARS-CoV-2
5. Staphylococcal scalded-skin syndrome <sup>a,g</sup>
6. Bullous impetigo <sup>a</sup>
7. Bullous tinea
II. Systemic diseases
A. Autoimmune
1. Paraneoplastic pemphigus <sup>a</sup> (bronchiolitis obliterans)
B. Infections
1. Cutaneous emboli <sup>b</sup>
C. Metabolic
1. Diabetic bullae <sup>a,b</sup>
2. Porphyria cutanea tarda <sup>b</sup>
3. Porphyria variegata <sup>b</sup>
4. Bullous dermatosis of hemodialysis <sup>b</sup> (less often associated with peritoneal dialysis and also referred to as pseudoporphyria)
D. Ischemia
1. Coma bullae
E. Secondary blistering diseases
1. Toxic epidermal necrolysis <sup>e</sup> (respiratory and gastrointestinal tracts can be involved)

<sup>a</sup>Intraepidermal. <sup>b</sup>Subepidermal. <sup>c</sup>Associated with gluten enteropathy. <sup>d</sup>Associated with inflammatory bowel disease. <sup>e</sup>Degeneration of cells within the basal layer of the epidermis can give impression split is subepidermal. <sup>f</sup>Also systemic. <sup>g</sup>In adults, associated with renal failure and immunocompromised state.

with centrifugal spread. However, target lesions need not be present to make the diagnosis of EM.

EM has been subdivided into two major groups: (1) EM minor due to herpes simplex virus (HSV); and (2) EM major due to HSV, *Mycoplasma pneumonia*, or, occasionally, other viruses, *Chlamydia*, or drugs. Involvement of the mucous membranes (ocular, nasal, oral, and genital) is seen more commonly in the latter form, and in patients with *Mycoplasma pneumoniae*-induced rash and mucositis (MIRM), there may be minimal cutaneous involvement. Hemorrhagic crusts of the lips are characteristic of EM major and SJS as well as herpes simplex, pemphigus vulgaris, and paraneoplastic pemphigus. Fever, malaise, myalgias, sore throat, and cough may precede or accompany the eruption. The lesions of EM usually resolve over 2–4 weeks but may be recurrent, especially when due to HSV. In addition to HSV (in which lesions usually appear 7–12 days after the viral eruption), EM can also follow vaccinations, radiation therapy, and exposure to environmental toxins, including the oleoresin in poison ivy.

Induction of SJS is most often due to drugs, especially sulfonamides, aromatic anticonvulsants, lamotrigine, aminopenicillins,

and nonnucleoside reverse transcriptase inhibitors (e.g., nevirapine). Widespread dusky macules and significant mucosal involvement are characteristic of SJS, and the cutaneous lesions may or may not develop epidermal detachment. If the latter occurs, by definition, it is limited to <10% of the body surface area (BSA). Greater involvement leads to the diagnosis of SJS/TEN overlap (10–30% BSA) or TEN (>30% BSA).

In addition to primary blistering disorders and hypersensitivity reactions, bacterial and viral infections can lead to vesicles and bullae. The most common infectious agents are HSV (Chap. 192), varicella-zoster virus (Chap. 193), and *S. aureus* (Chap. 147).

*Staphylococcal scalded-skin syndrome* (SSSS) and *bullous impetigo* are two blistering disorders associated with staphylococcal (phage group II) infection. In SSSS, the initial findings are redness and tenderness of the central face, neck, trunk, and intertriginous zones. This is followed by short-lived flaccid bullae and a slough or exfoliation of the superficial epidermis. Crusted areas then develop, characteristically around the mouth in a radial pattern. SSSS is distinguished from TEN by the following features: younger age group (primarily infants and toddlers), more superficial site of blister formation, no oral lesions, shorter course, lower morbidity and mortality rates, and an association with staphylococcal exfoliative toxin (“exfoliatin”), not drugs. A rapid diagnosis of SSSS versus TEN can be made by a frozen section of the blister roof or exfoliative cytology of the blister contents. In SSSS, the site of staphylococcal infection is usually extracutaneous (conjunctivitis, rhinorrhea, otitis media, pharyngitis, tonsillitis), and the cutaneous lesions are sterile, whereas in bullous impetigo, the skin lesions are the site of infection. Impetigo is more localized than SSSS and usually presents with honey-colored crusts. Occasionally, superficial purulent blisters also form. *Cutaneous emboli* from gram-negative infections may present as isolated bullae, but the base of the lesion is purpuric or necrotic, and it may develop into an ulcer (see “Purpura,” below).

Several metabolic disorders are associated with blister formation, including diabetes mellitus, renal failure, and porphyria. Local hypoxemia secondary to decreased cutaneous blood flow can also produce blisters, which explains the presence of bullae over pressure points in comatose patients (coma bullae). In *diabetes mellitus*, tense bullae with clear sterile viscous fluid arise on normal skin. The lesions can be as large as 6 cm in diameter and are located on the distal extremities. There are several types of porphyria, but the most common form with cutaneous findings is *porphyria cutanea tarda* (PCT). In sun-exposed areas (primarily the hands), the skin is very fragile, with trauma leading to erosions mixed with tense vesicles. These lesions then heal with scarring and formation of milia; the latter are firm, 1- to 2-mm white or yellow papules that represent epidermoid cysts. Associated findings can include hypertrichosis of the lateral malar region (men) or face (women) and, in sun-exposed areas, hyperpigmentation and firm sclerotic plaques. An elevated level of urinary uroporphyrins confirms the diagnosis and is due to a decrease in uroporphyrinogen decarboxylase activity. PCT can be exacerbated by alcohol, hemochromatosis and other forms of iron overload, chlorinated hydrocarbons, hepatitis C virus and HIV infections, and hepatomas.

The differential diagnosis of PCT includes (1) *porphyria variegata*—the skin signs of PCT plus the systemic findings of acute intermittent porphyria; it has a diagnostic plasma porphyrin fluorescence emission at 626 nm; (2) *drug-induced pseudoporphyria*—the clinical and histologic findings are similar to PCT, but porphyrins are normal; etiologic agents include naproxen and other NSAIDs, furosemide, tetracycline, and voriconazole; (3) *bullous dermatosis of hemodialysis*—the same appearance as PCT, but porphyrins are usually normal or occasionally borderline elevated; patients have chronic renal failure and are on hemodialysis; (4) *PCT associated with hepatomas and hemodialysis*; and (5) *epidermolysis bullosa acquisita* (Chap. 59).

## EXANTHEMS

(Table 58-13) Exanthems are characterized by an acute generalized eruption. The most common presentation is erythematous macules and papules (morbilliform) and less often confluent blanching erythema (scarlatiniform). *Morbilliform* eruptions are usually due to either drugs or viral infections. For example, up to 5% of patients receiving penicillins,

TABLE 58-13 Causes of Exanthems

I. Morbilliform
A. Drugs
B. Viral
1. Rubeola (measles)
2. Rubella
3. Erythema infectiosum (erythema of cheeks; reticulated on extremities)
4. Epstein-Barr virus, echovirus, coxsackievirus, CMV, adenovirus, HHV-6/HHV-7 <sup>a</sup> , dengue, Zika, chikungunya, SARS-CoV-2, and West Nile virus infections
5. HIV seroconversion exanthem (plus mucosal ulcerations)
C. Bacterial
1. Typhoid fever
2. Early secondary syphilis
3. Early <i>Rickettsia</i> infections
4. Early meningococcemia
5. Ehrlichiosis
D. Acute graft-versus-host disease
E. Kawasaki disease
II. Scarlatiniform
A. Scarlet fever
B. Toxic shock syndrome
C. Kawasaki disease
D. Early staphylococcal scalded-skin syndrome

<sup>a</sup>Primary infection in infants and reactivation in the setting of immunosuppression.

Abbreviations: CMV, cytomegalovirus; HHV, human herpesvirus; HIV, human immunodeficiency virus.

sulfonamides, phenytoin, or nevirapine will develop a maculopapular eruption. Accompanying signs may include pruritus, fever, eosinophilia, transaminitis, and transient lymphadenopathy (Chap. 60). Similar maculopapular eruptions are seen in the classic childhood viral exanthems, including (1) *rubeola* (measles)—a prodrome of coryza, cough, and conjunctivitis followed by Koplik's spots on the buccal mucosa; the eruption begins behind the ears, at the hairline, and on the forehead and then spreads down the body, often becoming confluent; (2) *rubella*—the eruption begins on the forehead and face and then spreads down the body; it resolves in the same order and is associated with retroauricular and suboccipital lymphadenopathy; and (3) *erythema infectiosum* (fifth disease)—erythema of the cheeks is followed by a reticulated pattern on the extremities; it is secondary to a parvovirus B19 infection, and an associated arthritis is seen in adults.

Both measles and rubella can occur in unvaccinated adults, and an atypical form of measles is seen in adults immunized with either killed measles vaccine or killed vaccine followed in time by live vaccine. In contrast to classic measles, the eruption of atypical measles begins on the palms, soles, wrists, and ankles, and the lesions may become purpuric. The patient with atypical measles can have pulmonary involvement and be quite ill. Rubelliform and roseoliform eruptions are also associated with *Epstein-Barr virus* (5–15% of patients), *echovirus*, *coxsackievirus*, *cytomegalovirus*, *adenovirus*, SARS-CoV-2, and *dengue*, *chikungunya*, and *West Nile virus* infections. Detection of specific IgM antibodies or fourfold elevations in IgG antibodies often allows the proper diagnosis, but polymerase chain reaction (PCR) is gradually replacing serologic assays. Occasionally, a maculopapular drug eruption is a reflection of an underlying viral infection. For example, ~95% of the patients with infectious mononucleosis who are given ampicillin will develop a rash.

Of note, early in the course of infections with *Rickettsia* and meningococcus, prior to the development of petechiae and purpura, the lesions may be erythematous macules and papules. This is also the case in chickenpox prior to the development of vesicles. Maculopapular eruptions are associated with early *HIV* infection, early secondary *syphilis*, *typhoid fever*, and *acute graft-versus-host disease*. In the last, lesions frequently begin on the dorsal hands and forearms; the macular rose spots of typhoid fever involve primarily the anterior trunk.

The prototypic *scarlatiniform* eruption is seen in *scarlet fever* and is due to an erythrogenic toxin produced by bacteriophage-containing group A β-hemolytic streptococci, most commonly in the setting of pharyngitis. This eruption is characterized by diffuse erythema, which begins on the neck and upper trunk, and red follicular puncta. Additional findings include a white strawberry tongue (white coating with red papillae) followed by a red strawberry tongue (red tongue with red papillae); petechiae of the palate; a facial flush with circumoral pallor; linear petechiae in the antecubital fossae; and desquamation of the involved skin, palms, and soles 5–20 days after onset of the eruption. A similar desquamation of the palms and soles is seen in toxic shock syndrome (TSS), in Kawasaki disease, and after severe febrile illnesses. Certain strains of staphylococci also produce an erythrogenic toxin that leads to the same clinical findings as in streptococcal scarlet fever, except that the anti-streptolysin O or DNase B titers are not elevated.

In *toxic shock syndrome*, staphylococcal (phage group I) infections produce an exotoxin (TSST-1) that causes the fever and rash as well as enterotoxins. Initially, the majority of cases were reported in menstruating women who were using tampons. However, other sites of infection, including wounds and nasal packing, can lead to TSS. The diagnosis of TSS is based on clinical criteria (Chap. 147), and three of these involve mucocutaneous sites (diffuse erythema of the skin, desquamation of the palms and soles 1–2 weeks after onset of illness, and involvement of the mucous membranes). The latter is characterized as hyperemia of the vagina, oropharynx, or conjunctivae. Similar systemic findings have been described in *streptococcal toxic shock syndrome* (Chap. 148), and although an exanthem is seen less often than in TSS due to a staphylococcal infection, the underlying infection is often in the soft tissue (e.g., cellulitis).

The cutaneous eruption in *Kawasaki disease* (Chap. 363) is polymorphous, but the two most common forms are morbilliform and scarlatiniform. Additional mucocutaneous findings include bilateral conjunctival injection; erythema and edema of the hands and feet followed by desquamation; and diffuse erythema of the oropharynx, red strawberry tongue, and dry fissured lips. This clinical picture can resemble TSS and scarlet fever, but clues to the diagnosis of Kawasaki disease are cervical lymphadenopathy, cheilitis, and thrombocytosis. The most serious associated systemic finding in this disease is coronary aneurysms secondary to arteritis. Seen primarily in children, SARS-CoV-2-associated multisystem inflammatory syndrome must be distinguished from Kawasaki disease. Scarlatiniform eruptions are also seen in the early phase of SSSS (see “Vesicles/Bullae,” above), in young adults with *Arcanobacterium haemolyticum* infection, and as reactions to drugs.

## URTICARIA

(Table 58-14) *Urticaria* (hives) are transient lesions that are composed of a central wheal surrounded by an erythematous halo or flare. Individual lesions are round, oval, or figurate and are often pruritic. Acute and chronic urticarias have a wide variety of allergic etiologies

TABLE 58-14 Causes of Urticaria and Angioedema

I. Primary cutaneous disorders
A. Acute and chronic urticaria <sup>a</sup>
B. Physical urticaria
1. Dermographism
2. Solar urticaria <sup>b</sup>
3. Cold urticaria <sup>b</sup>
4. Cholinergic urticaria <sup>b</sup>
C. Angioedema (hereditary and acquired) <sup>b,c</sup>
II. Systemic diseases
A. Urticarial vasculitis
B. Hepatitis B or C viral infection, SARS-CoV-2 infection
C. Serum sickness
D. Angioedema (hereditary and acquired)

<sup>a</sup>A small minority develop anaphylaxis. <sup>b</sup>Also systemic. <sup>c</sup>Acquired angioedema can be idiopathic, associated with a lymphoproliferative disorder, or due to a drug, e.g., angiotensin-converting enzyme (ACE) inhibitors.

and reflect edema in the dermis. Urticular lesions can also be seen in patients with mastocytosis (*urticaria pigmentosa*), hypo- or hyperthyroidism, Schnitzler's syndrome, and systemic-onset juvenile idiopathic arthritis (Still's disease). In both juvenile- and adult-onset Still's disease, the lesions coincide with the fever spike, are transient, and are due to dermal infiltrates of neutrophils; the latter is also referred to as neutrophilic urticarial dermatosis.

The common *physical urticarias* include dermographism, solar urticaria, cold urticaria, and cholinergic urticaria. Patients with *dermographism* exhibit linear wheals following minor pressure or scratching of the skin and may be a contributing factor to pruritic dermatoses. It is a common disorder, affecting ~5% of the population. *Solar urticaria* characteristically occurs within minutes of sun exposure and is a skin sign of one systemic disease—erythropoietic protoporphyrina. In addition to the urticaria, these patients have subtle pitted scarring of the nose and hands. *Cold urticaria* is precipitated by exposure to the cold, and therefore, exposed areas are usually affected. In occasional patients, the disease is associated with abnormal circulating proteins—more commonly cryoglobulins and less commonly cryofibrinogens. Additional systemic symptoms include wheezing and syncope, thus explaining the need for these patients to avoid swimming in cold water. Autosomal dominantly inherited cold urticaria is associated with dysfunction of cryopyrin. *Cholinergic urticaria* is precipitated by heat, exercise, or emotion and is characterized by small wheals with relatively large flares. It is occasionally associated with wheezing.

Whereas urticarias are the result of dermal edema, subcutaneous edema leads to the clinical picture of *angioedema*. Sites of involvement include the eyelids, lips, tongue, larynx, and gastrointestinal tract as well as the subcutaneous tissue. Angioedema occurs alone or in combination with urticaria, including urticarial vasculitis and the physical urticarias. Both acquired and hereditary (autosomal dominant) forms of angioedema occur (Chap. 354), and in the latter, urticaria is rarely, if ever, seen.

*Urticular vasculitis* is an immune complex disease that may be confused with simple urticaria. In contrast to simple urticaria, individual lesions tend to last longer than 24 h and usually develop central petechiae that can be observed even after the urticarial phase has resolved. The patient may also complain of burning rather than pruritus. On biopsy, there is a leukocytoclastic vasculitis of the small dermal blood vessels. Although urticarial vasculitis may be idiopathic in origin, it can be a reflection of an underlying systemic illness such as lupus erythematosus, Sjögren's syndrome, or hereditary complement deficiency. There is a spectrum of urticarial vasculitis that ranges from purely cutaneous to multisystem involvement. The most common systemic signs and symptoms are arthralgias and/or arthritis, nephritis, and crampy abdominal pain, with asthma and chronic obstructive lung disease seen less often. Hypocomplementemia occurs in one- to two-thirds of patients, even in the idiopathic cases. Urticarial vasculitis can also be seen in patients with *hepatitis B* and *hepatitis C* infections and *serum sickness*, but is usually not seen in *serum sickness-like illnesses* (e.g., due to cefaclor, minocycline).

## PAPULONODULAR SKIN LESIONS

(Table 58-15) In the *papulonodular diseases*, the lesions are elevated above the surface of the skin and may coalesce to form larger plaques. The location, consistency, and color of the lesions are the keys to their diagnosis; this section is organized on the basis of color.

### WHITE LESIONS

In *calcinosis cutis*, there are firm white to white-yellow papules with an irregular surface. When the contents are expressed, a chalky white material is seen. *Dystrophic calcification* is seen at sites of previous inflammation or damage to the skin. It develops in acne scars as well as on the distal extremities of patients with systemic sclerosis and in the subcutaneous tissue and intermuscular fascial planes in DM. The latter is more extensive and is more commonly seen in children. An elevated calcium phosphate product, most commonly due to secondary hyperparathyroidism in the setting of renal failure, can lead to nodules of *metastatic calcinosis cutis*, which tend to be subcutaneous and

TABLE 58-15 Papulonodular Skin Lesions According to Color Groups

- I. White
  - A. Calcinosis cutis
  - B. Osteoma cutis (also skin-colored or blue)
- II. Skin-colored
  - A. Rheumatoid nodules
  - B. Neurofibromas (von Recklinghausen's disease [NF1])
  - C. Angiofibromas (tuberous sclerosis, MEN syndrome, type 1; also pink-red)
  - D. Neviomas (MEN syndrome, type 2b)
  - E. Adnexal tumors
    - 1. Basal cell carcinomas (basal cell nevus syndrome)
    - 2. Tricholemmomas (Cowden disease)
    - 3. Fibrofolliculomas (Birt-Hogg-Dubé syndrome)
    - F. Osteomas (arise in skull and jaw in Gardner syndrome)
  - G. Primary cutaneous disorders
    - 1. Epidermal inclusion cysts<sup>a</sup>
    - 2. Lipomas
- III. Pink/translucent<sup>b</sup>
  - A. Amyloidosis, primary systemic
  - B. Papular mucinosis/scleromyxedema
  - C. Multicentric reticulohistiocytosis
- IV. Yellow
  - A. Xanthomas
  - B. Tophi
  - C. Necrobiosis lipoidica
  - D. Pseudoxanthoma elasticum
  - E. Sebaceous adenomas (Muir-Torre syndrome)
- V. Red<sup>b</sup>
  - A. Papules
    - 1. Angiokeratomas (Fabry disease and related lysosomal storage diseases)<sup>c</sup>
    - 2. Bacillary angiomatosis (primarily in AIDS)
  - B. Papules/plaques
    - 1. Cutaneous lupus erythematosus
    - 2. Lymphoma cutis
    - 3. Leukemia cutis
    - 4. Sweet syndrome
  - C. Nodules
    - 1. Panniculitis
    - 2. Medium-sized vessel vasculitis (e.g., cutaneous polyarteritis nodosa)
  - D. Primary cutaneous disorders
    - 1. Arthropod bites
    - 2. Cherry hemangiomas
    - 3. Infections, e.g., streptococcal cellulitis, sporotrichosis
    - 4. Polymorphous light eruption
    - 5. Cutaneous lymphoid hyperplasia (lymphocytoma cutis, pseudolymphoma)
- VI. Red-brown<sup>b</sup>
  - A. Sarcoidosis
  - B. Urticaria pigmentosa
  - C. Erythema elevatum diutinum (chronic leukocytoclastic vasculitis)
  - D. Lupus vulgaris
- VII. Blue<sup>b</sup>
  - A. Venous malformations (e.g., blue rubber bleb syndrome)
  - B. Primary cutaneous disorders
    - 1. Venous lake
    - 2. Blue nevus
- VIII. Violaceous
  - A. Lupus pernio (sarcoidosis)
  - B. Lymphoma cutis
  - C. Cutaneous lupus erythematosus
- IX. Purple
  - A. Kaposi's sarcoma, acral angiokeratoma (pseudo-Kaposi's sarcoma)
  - B. Angiosarcoma
  - C. Palpable purpura (see Table 58-16)
  - D. Primary cutaneous disorders
    - 1. Angiokeratomas of the scrotum and vulva
- X. Brown-black<sup>d</sup>
- XI. Any color
  - A. Metastases

<sup>a</sup>If multiple with childhood onset, consider Gardner syndrome. <sup>b</sup>May have darker hue in more darkly pigmented individuals. <sup>c</sup>More widespread, especially lower trunk and girdle region, and often red-purple in color. <sup>d</sup>See also "Hyperpigmentation."

Abbreviations: MEN, multiple endocrine neoplasia; NF1, neurofibromatosis type 1.

periarticular. These patients can also develop calcification of muscular arteries and subsequent ischemic necrosis (calciphylaxis). *Osteoma cutis*, in the form of small papules, most commonly occurs on the face of individuals with a history of acne vulgaris, whereas plate-like lesions occur in rare genetic syndromes.

### ■ SKIN COLORED LESIONS

There are several types of skin-colored lesions, including epidermoid cysts, lipomas, rheumatoid nodules, neurofibromas, angiomyomas, neuromas, and adnexal tumors such as tricholemmomas. Both *epidermoid cysts* and *lipomas* are very common mobile subcutaneous nodules—the former are rubbery and drain cheeselike material (sebum and keratin) if incised. Lipomas are firm and somewhat lobulated on palpation. When extensive facial epidermoid cysts develop during childhood or there is a family history of such lesions, the patient should be examined for other signs of Gardner syndrome, including osteomas and desmoid tumors. *Rheumatoid nodules* are firm 0.5- to 4-cm nodules that favor the extensor aspect of joints, especially the elbows. They are seen in ~20% of patients with rheumatoid arthritis and 6% of patients with Still's disease. Biopsies of the nodules show palisading granulomas. Similar lesions that are smaller and shorter-lived are seen in rheumatic fever.

*Neurofibromas* (benign Schwann cell tumors) are soft papules or nodules that exhibit the “button-hole” sign; that is, they invaginate into the skin with pressure in a manner similar to a hernia. Single lesions are seen in normal individuals, but multiple neurofibromas, usually in combination with six or more CALMs measuring >1.5 cm (see “Hyperpigmentation,” above), axillary freckling, and multiple Lisch nodules, are seen in von Recklinghausen’s disease (NF type I) (Chap. 90). In some patients, the neurofibromas are localized and unilateral due to somatic mosaicism.

*Angiomyomas* are firm pink-red to skin-colored papules that measure from 3 mm to 1.5 cm in diameter. When multiple lesions are located on the central cheeks (adenoma sebaceum), the patient has tuberous sclerosis or multiple endocrine neoplasia (MEN) syndrome, type 1. The former is an autosomal disorder due to mutations in two different genes, and the associated findings are discussed in the section on ash leaf spots as well as in Chap. 90.

*Neuromas* (benign proliferations of nerve fibers) are also firm, skin-colored papules. They are more commonly found at sites of amputations and in rudimentary polydactyly. However, when there are multiple neuromas on the eyelids, lips, distal tongue, and/or oral mucosa, the patient should be investigated for other signs of MEN syndrome, type 2b. Associated findings include marfanoid habitus, protuberant lips, intestinal ganglioneuromas, and medullary thyroid carcinoma (>75% of patients; Chap. 388).

*Adnexal tumors* are derived from pluripotent cells of the epidermis that can differentiate toward hair, sebaceous, or apocrine or eccrine glands, or remain undifferentiated. *Basal cell carcinomas* (BCCs) are examples of adnexal tumors that have little or no evidence of differentiation. Clinically, they are translucent papules with rolled borders, telangiectasias, and central erosion. BCCs commonly arise in sun-damaged skin of the head and neck as well as the upper trunk. When a patient has multiple BCCs, especially prior to age 30, the possibility of the basal cell nevus syndrome should be raised. It is inherited as an autosomal dominant trait and is associated with jaw cysts, palmar and plantar pits, frontal bossing, medulloblastomas, and calcification of the falx cerebri and diaphragma sellae. *Tricholemmomas* are also skin-colored adnexal tumors but differentiate toward hair follicles and can have a wartlike appearance. The presence of multiple tricholemmomas on the face and cobblestoning of the oral mucosa points to the diagnosis of Cowden disease (multiple hamartoma syndrome) due to mutations in the phosphatase and tensin homolog (*PTEN*) gene. Internal organ involvement (in decreasing order of frequency) includes fibrocystic disease and carcinoma of the breast, adenomas and carcinomas of the thyroid, and gastrointestinal polyposis. Keratoses of the palms, soles, and dorsal aspect of the hands are also seen. *Fibrofolliculomas* are skin-colored to white, smooth papules that favor the face, ears, and neck and, when multiple, are associated

with Birt-Hogg-Dubé syndrome, which is associated with renal lesions including cancer (Chap. 85).

### ■ PINK LESIONS

The cutaneous lesions associated with primary systemic *amyloidosis* are often pink to pink-orange in color and translucent. Common locations are the face, especially the periorbital and perioral regions, and flexural areas. On biopsy, homogeneous deposits of amyloid are seen in the dermis and in the walls of blood vessels; the latter lead to an increase in vessel wall fragility. As a result, petechiae and purpura develop in clinically normal skin as well as in lesional skin following minor trauma, hence the term *pinch purpura*. Amyloid deposits are also seen in the striated muscle of the tongue and result in macroglossia.

Even though specific mucocutaneous lesions are present in only ~30% of the patients with primary systemic (AL) amyloidosis, the diagnosis can be made via histologic examination of abdominal subcutaneous fat, in conjunction with a serum free light chain assay. By special staining, amyloid deposits are seen around blood vessels or individual fat cells in 40–50% of patients. There are also three forms of amyloidosis that are limited to the skin and that should not be construed as cutaneous lesions of systemic amyloidosis. They are macular amyloidosis (upper back), lichen amyloidosis (usually lower extremities), and nodular amyloidosis. In macular and lichen amyloidosis, the deposits are composed of altered epidermal keratin. Early-onset macular and lichen amyloidosis have been associated with MEN syndrome, type 2a.

Patients with *multicentric reticulohistiocytosis* also have pink-colored papules and nodules on the face and mucous membranes as well as on the extensor surface of the hands and forearms. They have a polyarthritides that can mimic rheumatoid arthritis clinically. On histologic examination, the papules have characteristic giant cells that are not seen in biopsies of rheumatoid nodules. Pink to skin-colored papules that are firm, 2–5 mm in diameter, and often in a linear arrangement are seen in patients with *papular mucinosis*. This disease is also referred to as *scleromyxedema*. The latter name comes from the induration of the face and extremities that may accompany the papular eruption. Biopsy specimens of the papules show localized mucin deposition, and serum protein electrophoresis plus immunofixation electrophoresis demonstrates a monoclonal spike of IgG, usually with a λ light chain.

### ■ YELLOW LESIONS

Several systemic disorders are characterized by yellow-colored cutaneous papules or plaques—hyperlipidemia (xanthomas), gout (tophi), diabetes (necrobiosis lipoidica), pseudoxanthoma elasticum, and Muir-Torre syndrome (sebaceous tumors). Eruptive xanthomas are the most common form of *xanthomas* and are associated with hypertriglyceridemia (primarily hyperlipoproteinemia types I, IV, and V). Crops of yellow papules with erythematous halos occur primarily on the extensor surfaces of the extremities and the buttocks, and they spontaneously involute with a fall in serum triglycerides. Types II and III result in one or more of the following types of xanthoma: xanthelasma, tendon xanthomas, and plane xanthomas. Xanthelasma are found on the eyelids, whereas tendon xanthomas are frequently associated with the Achilles and extensor finger tendons; plane xanthomas are flat and favor the palmar creases and flexural folds. Tuberous xanthomas are frequently associated with hypercholesterolemia; however, they are also seen in patients with hypertriglyceridemia and are found most frequently over the large joints or hand. Biopsy specimens of xanthomas show collections of lipid-containing macrophages (foam cells).

Patients with several disorders, including biliary cirrhosis, can have a secondary form of hyperlipidemia with associated tuberous and plane xanthomas. However, patients with plasma cell dyscrasias have *normolipemic plane xanthomas*. This latter form of xanthoma may be ≥12 cm in diameter and is most frequently seen on the neck, upper trunk, and flexural folds. It is important to note that the most common setting for eruptive xanthomas is uncontrolled diabetes mellitus. The least specific sign for hyperlipidemia is xanthelasma, because at least 50% of the patients with this finding have normal lipid profiles.

In *tophaceous gout*, there are deposits of monosodium urate in the skin around the joints, particularly those of the hands and feet. Additional

sites of *tophi* formation include the helix of the ear and the olecranon and prepatellar bursae. The lesions are firm, yellow to yellow-white in color, and occasionally discharge a chalky material. Their size varies from 1 mm to 7 cm, and the diagnosis can be established by polarized light microscopy of the aspirated contents of a tophus. Lesions of *necrobiosis lipoidica* are found primarily on the shins (90%), and patients can have diabetes mellitus or develop it subsequently. Characteristic findings include a central yellow color, atrophy (transparency), telangiectasias, and a red to red-brown border. Ulcerations can also develop within the plaques. Biopsy specimens show necrobiosis of collagen and granulomatous inflammation.

In *pseudoxanthoma elasticum* (PXE), due to mutations in the gene *ABCC6*, there is an abnormal deposition of calcium on the elastic fibers of the skin, eye, and blood vessels. In the skin, the flexural areas such as the neck, axillae, antecubital fossae, and inguinal area are the primary sites of involvement. Yellow papules coalesce to form reticulated plaques that have an appearance similar to that of plucked chicken skin. In severely affected skin, hanging, redundant folds develop. Biopsy specimens of involved skin show swollen and irregularly clumped elastic fibers with deposits of calcium. In the eye, the calcium deposits in Bruch's membrane lead to angiod streaks and choroiditis; in the arteries of the heart, kidney, gastrointestinal tract, and extremities, the deposits lead to angina, hypertension, gastrointestinal bleeding, and claudication, respectively.

Adnexal tumors that have differentiated toward sebaceous glands include sebaceous adenoma, sebaceous carcinoma, and sebaceous hyperplasia. Except for sebaceous hyperplasia, which is commonly seen on the face, these tumors are fairly rare. Patients with Muir-Torre syndrome have one or more *sebaceous adenoma(s)*, and they can also have sebaceous carcinomas and sebaceous hyperplasia as well as keratoacanthomas. The internal manifestations of Muir-Torre syndrome include *multiple* carcinomas of the gastrointestinal tract (primarily colon) as well as cancers of the genitourinary tract.

## ■ RED LESIONS

Cutaneous lesions that are red in color have a wide variety of etiologies; in an attempt to simplify their identification, they will be subdivided into papules, papules/plaques, and subcutaneous nodules. Common red papules include *arthropod bites* and *cherry hemangiomas*; the latter are small, bright-red, dome-shaped papules that represent a benign proliferation of capillaries. In patients with AIDS (Chap. 202), the development of multiple red hemangioma-like lesions points to bacillary angiomatosis, and biopsy specimens show clusters of bacilli that stain positively with the Warthin-Starry stain; the pathogens have been identified as *Bartonella henselae* and *Bartonella quintana*. Disseminated visceral disease is seen primarily in immunocompromised hosts but can occur in immunocompetent individuals.

Multiple *angiokeratomas* are seen in Fabry disease, an X-linked recessive lysosomal storage disease that is due to a deficiency of  $\alpha$ -galactosidase A. The lesions are red to red-purple in color and can be quite small in size (1–3 mm), with the most common location being the lower trunk. Associated findings include chronic renal disease, peripheral neuropathy, and corneal opacities (*cornea verticillata*). While electron photomicrographs demonstrate lamellar lipid deposits in dermal fibroblasts, pericytes, and endothelial cells, nowadays, genetic analysis is more frequently performed for diagnosis. Widespread acute eruptions of erythematous papules are discussed in the section on exanthems.

There are several infectious diseases that present as erythematous papules or nodules in a lymphocutaneous or sporotrichoid pattern, that is, in a linear arrangement along the lymphatic channels. The two most common etiologies are *Sporothrix schenckii* (sporotrichosis) and the atypical mycobacterium *Mycobacterium marinum*. The organisms are introduced as a result of trauma, and a primary inoculation site is often seen in addition to the lymphatic nodules. Additional causes include *Nocardia*, *Leishmania*, and other atypical mycobacteria and dimorphic fungi; culture or PCR of lesional tissue will aid in the diagnosis.

The diseases that are characterized by erythematous plaques with scale are reviewed in the papulosquamous section, and the various

forms of dermatitis are discussed in the section on erythroderma. Additional disorders in the differential diagnosis of red papules/plaques include *cellulitis*, *polymorphous light eruption* (PMLE), *cutaneous lymphoid hyperplasia* (*lymphocytoma cutis*), *cutaneous lupus*, *lymphoma cutis*, and *leukemia cutis*. The first three diseases represent primary cutaneous disorders, although cellulitis may be accompanied by a bacteremia. PMLE is characterized by erythematous papules and plaques in a primarily sun-exposed distribution—dorsum of the hand, extensor forearm, and upper trunk. Lesions follow exposure to UV-B and/or UV-A, and in higher latitudes, PMLE is most severe in the late spring and early summer. A process referred to as “hardening” occurs with continued UV exposure, and the eruption fades, but in temperate climates, it recurs the next spring. PMLE must be differentiated from cutaneous lupus, and this is accomplished by observation of the natural history, histologic examination, and sometimes direct immunofluorescence of the lesions. Cutaneous lymphoid hyperplasia (pseudolymphoma) is a *benign* polyclonal proliferation of lymphocytes within the skin that presents as infiltrated pink-red to red-purple papules and plaques; it must be distinguished from lymphoma cutis.

Several types of red plaques are seen in patients with systemic *lupus*, including (1) erythematous urticarial plaques across the cheeks and nose in the classic butterfly rash; (2) erythematous discoid lesions with fine or “carpet-tack” scale, telangiectasias, central hypopigmentation, peripheral hyperpigmentation, follicular plugging, and atrophy located on the scalp, face, external ears, arms, and upper trunk; and (3) psoriasiform or annular lesions of subacute cutaneous lupus with hypopigmented centers located primarily on the extensor arms and upper trunk. Additional mucocutaneous findings include (1) a violaceous flush on the face and V of the neck; (2) photosensitivity; (3) urticarial vasculitis (see “Urticaria,” above); (4) lupus panniculitis (see below); (5) diffuse alopecia; (6) alopecia secondary to discoid lesions; (7) nailfold telangiectasias and erythema; (8) EM- or TEN-like lesions that may become bullous; (9) oral or nasal ulcers; (10) livedo reticularis; and (11) distal ulcerations secondary to Raynaud’s phenomenon, vasculitis, or livedoid vasculopathy. Patients with only discoid lesions usually have the form of lupus that is limited to the skin. However, up to 10–15% of these patients eventually develop systemic lupus. Direct immunofluorescence of involved skin, in particular discoid lesions, shows deposits of IgG or IgM and C3 in a granular distribution along the dermal-epidermal junction.

In *lymphoma cutis*, there is a clonal proliferation of malignant lymphocytes within the skin, and the clinical appearance resembles that of cutaneous lymphoid hyperplasia—infiltrated pink-red to red-purple papules and plaques. Lymphoma cutis can occur anywhere on the surface of the skin, whereas the sites of predilection for lymphocytomas include the malar ridge, tip of the nose, and earlobes. Patients with non-Hodgkin’s lymphomas have specific cutaneous lesions more often than those with Hodgkin’s lymphoma, and, occasionally, the skin nodules precede the development of extracutaneous non-Hodgkin’s lymphoma or represent the only site of involvement (e.g., primary cutaneous B-cell lymphoma). Arcuate lesions are sometimes seen in lymphoma and lymphocytoma cutis as well as in CTCL. *Adult T-cell leukemia/lymphoma* that develops in association with HTLV-1 infection is characterized by cutaneous plaques, hypercalcemia, and circulating CD25+ lymphocytes. *Leukemia cutis* has the same appearance as lymphoma cutis, and specific lesions are seen more commonly in monocytic leukemias than in lymphocytic or granulocytic leukemias. Cutaneous chloromas (granulocytic sarcomas) may precede the appearance of circulating blasts in acute myelogenous leukemia and, as such, represent a form of aleukemic leukemia cutis.

*Sweet syndrome* is characterized by pink-red to red-brown edematous plaques that are frequently painful and occur primarily on the head, neck, and upper extremities. The patients also have fever, neutrophilia, and a dense dermal infiltrate of neutrophils in the lesions. In ~10% of the patients, there is an associated malignancy, most commonly acute myelogenous leukemia. Sweet syndrome has also been reported with inflammatory bowel disease, systemic lupus erythematosus, and solid tumors (primarily of the genitourinary tract) as well as drugs (e.g., granulocyte colony-stimulating factor [G-CSF], hypomethylating

agents, all-*trans*-retinoic acid). The differential diagnosis includes neutrophilic eccrine hidradenitis; bullous forms of pyoderma gangrenosum; and, occasionally, cellulitis. Extracutaneous sites of involvement include joints, muscles, eyes, kidneys (proteinuria, occasionally glomerulonephritis), and lungs (neutrophilic infiltrates). The idiopathic form of Sweet syndrome is seen more often in women, following a respiratory tract infection.

Common causes of erythematous subcutaneous nodules include inflamed epidermoid cysts, acne cysts, and furuncles. *Panniculitis*, an inflammation of the fat, also presents as subcutaneous nodules and is frequently a sign of systemic disease. There are several forms of panniculitis, including erythema nodosum, erythema induratum/nodular vasculitis, lupus panniculitis, lipodermatosclerosis,  $\alpha_1$ -antitrypsin deficiency, factitial, and fat necrosis secondary to pancreatic disease. Except for erythema nodosum, these lesions may break down and ulcerate or heal with a scar. The shin is the most common location for the nodules of erythema nodosum, whereas the calf is the most common location for lesions of erythema induratum. In erythema nodosum, the nodules are initially red but then develop a blue bruise-like color as they resolve. Patients with erythema nodosum but no underlying systemic illness can still have fever, malaise, leukocytosis, arthralgias, and/or arthritis. However, the possibility of an underlying illness should be excluded, and the most common associations are streptococcal infections, upper respiratory viral infections, sarcoidosis, and inflammatory bowel disease, in addition to drugs (oral contraceptives, sulfonamides, penicillins, bro-mides, iodides, BRAF inhibitors). Less common associations include bacterial gastroenteritis (*Yersinia*, *Salmonella*) and coccidioidomycosis followed by tuberculosis, histoplasmosis, brucellosis, and infections with *Chlamydia pneumoniae*, *Chlamydia trachomatis*, *Mycoplasma pneumoniae*, or hepatitis B virus.

Erythema induratum and nodular vasculitis have overlapping features clinically and histologically, and whether they represent two separate entities or the ends of a single disease spectrum is a point of debate; in general, the latter is usually idiopathic and the former is associated with the presence of *Mycobacterium tuberculosis* DNA by PCR within skin lesions. The lesions of lupus panniculitis are found primarily on the cheeks, upper arms, and buttocks (sites of abundant fat) and are seen in both the cutaneous and systemic forms of lupus. The overlying skin may be normal, erythematous, or have the changes of discoid lupus. The subcutaneous fat necrosis that is associated with pancreatic disease is presumably secondary to circulating lipases and is seen in patients with pancreatic carcinoma as well as in patients with acute and chronic pancreatitis. In this disorder, there may be an associated arthritis, fever, and inflammation of visceral fat. Histologic examination of deep incisional biopsy specimens will aid in the diagnosis of the particular type of panniculitis.

Subcutaneous erythematous nodules are also seen in cutaneous polyarteritis nodosa and as a manifestation of *systemic vasculitis* when there is involvement of medium-sized vessels, for example, systemic polyarteritis nodosa, eosinophilic granulomatosis with polyangiitis, or granulomatosis with polyangiitis (Chap. 363). Cutaneous polyarteritis nodosa presents with painful subcutaneous nodules and ulcers within a red-purple, netlike pattern of livedo reticularis. The latter is due to slowed blood flow through the superficial horizontal venous plexus. The majority of lesions are found on the lower extremities, and while arthralgias and myalgias may accompany cutaneous polyarteritis nodosa, there is no evidence of systemic involvement. In both the cutaneous and systemic forms of vasculitis, skin biopsy specimens of the associated nodules will show the changes characteristic of a necrotizing vasculitis and/or granulomatous inflammation.

### ■ RED BROWN LESIONS

The cutaneous lesions in *sarcoidosis* (Chap. 367) are classically red to red-brown in color, and with diascopy (pressure with a glass slide), a yellow-brown residual color is observed that is secondary to the granulomatous infiltrate. The waxy papules and plaques may be found anywhere on the skin, but the face is the most common location. Usually there are no surface changes, but occasionally, the lesions will have scale. Biopsy specimens of the papules show “naked” granulomas in

the dermis, that is, granulomas surrounded by a minimal number of lymphocytes. Other cutaneous findings in sarcoidosis include annular lesions with an atrophic or scaly center, papules within scars, hypopigmented papules and patches, subcutaneous plaques, alopecia, acquired ichthyosis, erythema nodosum, and lupus pernio (see below).

The differential diagnosis of sarcoidosis includes foreign-body granulomas produced by chemicals such as beryllium and zirconium, late secondary syphilis, and *lupus vulgaris*. Lupus vulgaris is a form of cutaneous tuberculosis that is seen in previously infected and sensitized individuals. There is often underlying active tuberculosis elsewhere, usually in the lungs or lymph nodes. Lesions occur primarily in the head and neck region and are red-brown plaques with a yellow-brown color on diascopy. Secondary scarring can develop within the central portion of the plaques. Cultures or PCR analysis of the lesions should be performed, along with an interferon  $\gamma$  release assay of peripheral blood, because it is rare for the acid-fast stain to show bacilli within the dermal granulomas.

A generalized distribution of red-brown macules and papules is seen in the form of mastocytosis known as *urticaria pigmentosa* (Chap. 354). Each lesion represents a collection of mast cells in the dermis, with hyperpigmentation of the overlying epidermis. Stimuli such as rubbing cause these mast cells to degranulate, and this leads to the formation of localized urticaria (Darier's sign). Additional symptoms can result from mast cell degranulation and include headache, flushing, diarrhea, and pruritus. Mast cells also infiltrate various organs such as the liver, spleen, and gastrointestinal tract, and accumulations of mast cells in the bones may produce either osteosclerotic or osteolytic lesions on radiographs. In the majority of these patients, however, the internal involvement remains indolent. A subtype of chronic cutaneous small-vessel vasculitis, *erythema elevatum diutinum* (EED), also presents with papules that are red-brown in color. The papules coalesce into plaques on the extensor surfaces of knees, elbows, and the small joints of the hand. Flares of EED have been associated with streptococcal infections.

### ■ BLUE LESIONS

Lesions that are blue in color are the result of vascular ectasias, hyperplasias, and tumors or melanin pigment within the dermis. *Venous lakes* (ectasias) are compressible dark-blue lesions that are found commonly in the head and neck region. *Venous malformations* are also compressible blue papulonodules and plaques that can occur anywhere on the body, including the oral mucosa. When there are multiple papulonodules rather than a single congenital lesion, the patient may have the blue rubber bleb syndrome or Maffucci's syndrome. Patients with the blue rubber bleb syndrome also have vascular anomalies of the gastrointestinal tract that may bleed, whereas patients with Maffucci's syndrome have associated osteochondromas. *Blue nevi* (moles) are seen when there are collections of pigment-producing nevus cells in the dermis. These benign papular lesions are dome-shaped and occur most commonly on the dorsum of the hand or foot or in the head and neck region.

### ■ VIOLACEOUS LESIONS

Violaceous papules and plaques are seen in *lupus pernio*, *lymphoma cutis*, and *cutaneous lupus*. Lupus pernio is a particular type of sarcoidosis that involves the tip and alar rim of the nose as well as the earlobes, with lesions that are violaceous in color rather than red-brown. This form of sarcoidosis is associated with involvement of the upper respiratory tract. The plaques of lymphoma cutis and cutaneous lupus may be red or violaceous in color and were discussed above.

### ■ PURPLE LESIONS

Purple-colored papules and plaques are seen in vascular tumors, such as *Kaposi's sarcoma* (Chap. 202) and *angiosarcoma*, and when there is extravasation of red blood cells into the skin in association with inflammation, as in *palpable purpura* (see “Purpura” below). Patients with congenital or acquired AV fistulas and venous hypertension can develop purple papules on the lower extremities that can resemble Kaposi's sarcoma clinically and histologically; this condition is referred

to as pseudo-Kaposi's sarcoma (acral angiodermatitis). Angiosarcoma is found most commonly on the scalp and face of elderly patients or within areas of chronic lymphedema and presents as purple papules and plaques. In the head and neck region, the tumor often extends beyond the clinically defined borders and may be accompanied by facial edema.

### BROWN AND BLACK LESIONS

Brown- and black-colored papules are reviewed in "Hyperpigmentation," above.

### CUTANEOUS METASTASES

These are discussed last because they can have a wide range of colors. Most commonly, they present as either firm, skin-colored subcutaneous nodules or firm, red to red-brown papulonodules, whereas metastatic melanoma can be pink, blue, or black in color. Cutaneous metastases develop from hematogenous or lymphatic spread and are most often due to the following primary carcinomas: in men, melanoma, oropharynx, lung, and colon; and in women, breast, melanoma, and ovary. These metastatic lesions may be the initial presentation of the carcinoma, especially when the primary site is the lung.

## PURPURA

(Table 58-16) *Purpura* are seen when there is an extravasation of red blood cells into the dermis and, as a result, the lesions do not blanch with pressure. This is in contrast to those erythematous or violet-colored lesions that are due to localized vasodilation—they do blanch with pressure. Purpura ( $\geq 3$  mm) and petechiae ( $\leq 2$  mm) are divided into two major groups: palpable and nonpalpable. The most frequent causes of *nonpalpable* purpura and petechiae are primary cutaneous disorders such as *trauma*, *solar (actinic) purpura*, *stasis purpura*, and *capillaritis*. Less common causes are *steroid purpura* and *livedoid vasculopathy* (see "Ulcers," below). Solar purpura are seen primarily on the extensor forearms, whereas steroid purpura secondary to potent topical glucocorticoids or endogenous or exogenous Cushing's syndrome can be more widespread. In both cases, there is alteration of the supporting connective tissue that surrounds the dermal blood vessels. In contrast, the petechiae that result from capillaritis are found primarily on the lower extremities. In capillaritis, there is an extravasation of erythrocytes as a result of perivascular lymphocytic inflammation. The petechiae are bright red, 1–2 mm in size, and scattered within yellow-brown patches. The yellow-brown color is caused by hemosiderin deposits within the dermis.

Systemic causes of nonpalpable purpura fall into several categories, and those secondary to clotting disturbances and vascular fragility will be discussed first. The former group includes *thrombocytopenia* (Chap. 115), *abnormal platelet function* as is seen in uremia, and *clotting factor defects*. The initial site of presentation for thrombocytopenia-induced petechiae is the distal lower extremity. Capillary fragility leads to nonpalpable purpura in patients with systemic *amyloidosis* (see "Papulonodular Skin Lesions," above), disorders of collagen production such as *Ehlers-Danlos syndrome*, and *scurvy*. In scurvy, there are flattened corkscrew hairs with surrounding hemorrhage on the lower extremities, in addition to gingivitis. Vitamin C is a cofactor for lysyl hydroxylase, an enzyme involved in the posttranslational modification of procollagen that is necessary for cross-link formation.

In contrast to the previous group of disorders, the noninflammatory purpura seen in the following group of diseases are associated with thrombi formation within vessels and have a retiform configuration. It is important to note that these thrombi are demonstrable in skin biopsy specimens. This group of disorders includes disseminated intravascular coagulation (DIC), monoclonal cryoglobulinemia, thrombocytosis, thrombotic thrombocytopenic purpura, antiphospholipid antibody syndrome, and reactions to warfarin and heparin (heparin-induced thrombocytopenia and thrombosis). DIC is triggered by several types of infection (gram-negative, gram-positive, viral, and rickettsial) as well as by tissue injury and neoplasms. Widespread purpura and hemorrhagic infarcts of the distal extremities are seen. Similar lesions are found in *purpura fulminans*, which is a form of DIC associated with

TABLE 58-16 Causes of Purpura

- I. Primary cutaneous disorders
  - A. Nonpalpable
    - 1. Trauma
    - 2. Solar (actinic, senile) purpura
    - 3. Steroid purpura
    - 4. Stasis purpura due to venous hypertension
    - 5. Capillaritis
    - 6. Livedoid vasculopathy in the setting of venous hypertension<sup>a</sup>
  - B. Drugs (e.g., antiplatelet agents, anticoagulants)
  - C. Systemic diseases
- A. Nonpalpable
  - 1. Clotting disturbances
    - a. Thrombocytopenia (including ITP)
    - b. Abnormal platelet function
    - c. Clotting factor defects
  - 2. Vascular fragility
    - a. Amyloidosis (within normal-appearing skin)
    - b. Ehlers-Danlos syndrome
    - c. Scurvy
  - 3. Thrombi
    - a. Disseminated intravascular coagulation, purpura fulminans
    - b. Warfarin (Coumadin)-induced necrosis
    - c. Heparin-induced thrombocytopenia and thrombosis
    - d. Antiphospholipid antibody syndrome
    - e. Monoclonal cryoglobulinemia
    - f. Vasculopathy induced by levamisole-adulterated cocaine<sup>b</sup>
    - g. SARS-CoV-2 infection
    - h. Thrombotic thrombocytopenic purpura
    - i. Thrombocytosis
    - j. Homozygous protein C or protein S deficiency
  - 4. Emboli
    - a. Cholesterol
    - b. Fat
  - 5. Possible immune complex
    - a. Gardner-Diamond syndrome (autoerythrocyte sensitivity)
    - b. Waldenström's hypergammaglobulinemic purpura
- B. Palpable
  - 1. Vasculitis
    - a. Cutaneous small-vessel vasculitis, including in the setting of systemic vasculitides
  - 2. Emboli<sup>c</sup>
    - a. Acute meningococcemia
    - b. Disseminated gonococcal infection
    - c. Rocky Mountain spotted fever
    - d. Ecthyma gangrenosum

<sup>a</sup>Also associated with underlying disorders that lead to hypercoagulability/thrombophilia, e.g., factor V Leiden, protein C dysfunction/deficiency. <sup>b</sup>Combined vasculopathy/vasculitis can be seen. <sup>c</sup>Bacterial (including rickettsial), fungal, or parasitic.

Abbreviation: ITP, idiopathic thrombocytopenic purpura.

fever and hypotension that occurs more commonly in children following an infectious illness such as varicella, scarlet fever, or an upper respiratory tract infection. In both disorders, hemorrhagic bullae can develop in involved skin.

*Monoclonal cryoglobulinemia* is associated with plasma cell dyscrasias, chronic lymphocytic leukemia, and lymphoma. Purpura, primarily of the lower extremities, and hemorrhagic infarcts of the fingers, toes, nose and ears are seen in these patients. Exacerbations of disease activity can follow cold exposure or an increase in serum viscosity. Biopsy specimens show precipitates of the cryoglobulin within dermal vessels. Similar deposits have been found in the lung, brain, and renal glomeruli. Patients with *thrombotic thrombocytopenic purpura* can also have hemorrhagic infarcts as a result of intravascular thromboses.

Additional signs include microangiopathic hemolytic anemia and fluctuating neurologic abnormalities, especially headaches and confusion.

Administration of warfarin can result in painful areas of erythema that become purpuric and then necrotic with an adherent black eschar; the condition is also referred to as Coumadin-induced necrosis. This reaction is seen more often in women and in areas with abundant subcutaneous fat—breasts, abdomen, buttocks, thighs, and calves. The erythema and purpura develop between the third and tenth day of therapy, most likely as a result of a transient imbalance in the levels of anticoagulant and procoagulant vitamin K-dependent factors. Continued therapy does not exacerbate preexisting lesions, and patients with an inherited or acquired deficiency of protein C are at increased risk for this particular reaction as well as for purpura fulminans and calciphylaxis.

Purpura secondary to *cholesterol emboli* are usually seen on the lower extremities of patients with atherosclerotic vascular disease. They often follow anticoagulant therapy or an invasive vascular procedure such as an arteriogram but also occur spontaneously from disintegration of atheromatous plaques. Associated findings include livedo reticularis, gangrene, cyanosis, and ischemic ulcerations. Multiple step sections of the biopsy specimen may be necessary to demonstrate the cholesterol clefts within the vessels. Petechiae are also an important sign of *fat embolism* and occur primarily on the upper body 2–3 days after a major injury. By using special fixatives, the emboli can be demonstrated in biopsy specimens of the petechiae. Rarely, emboli of tumor or thrombus are seen in patients with atrial myxomas and marantic endocarditis.

In the *Gardner-Diamond syndrome* (autoerythrocyte sensitivity), female patients develop large ecchymoses within areas of painful, warm erythema. Intradermal injections of autologous erythrocytes or phosphatidyl serine derived from the red cell membrane can reproduce the lesions in some patients; however, there are instances where a reaction is seen at an injection site of the forearm but not in the midback region. The latter has led some observers to view Gardner-Diamond syndrome as a cutaneous manifestation of severe emotional stress. More recently, the possibility of platelet dysfunction (as assessed via aggregation studies) has been raised. *Waldenström's hypergammaglobulinemic purpura* is a chronic disorder characterized by recurrent crops of petechiae and larger purpuric macules on the lower extremities. There are circulating complexes of IgG-anti-IgG molecules, and exacerbations are associated with prolonged standing or walking. Patients may have an underlying autoimmune connective tissue disease, e.g., Sjögren's syndrome.

*Palpable purpura* are further subdivided into vasculitic and embolic. In the group of vasculitic disorders, cutaneous small-vessel vasculitis, also known as *leukocytoclastic vasculitis* (LCV), is the one most commonly associated with palpable purpura (Chap. 363). Underlying etiologies include drugs (e.g., antibiotics), infections (e.g., hepatitis C virus), and autoimmune connective tissue diseases (e.g., rheumatoid arthritis, Sjögren's syndrome, lupus). *Henoch-Schönlein purpura* (HSP) is a subtype of acute LCV that is seen more commonly in children and adolescents following an upper respiratory infection. The majority of lesions are found on the lower extremities and buttocks. Systemic manifestations include fever, arthralgias (primarily of the knees and ankles), abdominal pain, gastrointestinal bleeding, and nephritis. Direct immunofluorescence examination shows deposits of IgA within dermal blood vessel walls. Renal disease is of particular concern in adults with IgA vasculitis.

Several types of infectious emboli can give rise to palpable purpura. These embolic lesions are usually *irregular* in outline as opposed to the lesions of LCV, which are *circular* in outline. The irregular outline is indicative of a cutaneous infarct, and the size corresponds to the area of skin that received its blood supply from that particular arteriole or artery. The palpable purpura in LCV are circular because the erythrocytes simply diffuse out evenly from the postcapillary venules as a result of inflammation. Infectious emboli are most commonly due to gram-negative cocci (meningococcus, gonococcus), gram-negative rods (Enterobacteriaceae), and gram-positive cocci (*Staphylococcus*). Additional causes include *Rickettsia* and, in immunocompromised patients, *Aspergillus* and other opportunistic fungi.

The embolic lesions in *acute meningococcemia* are found primarily on the trunk, lower extremities, and sites of pressure, and a gunmetal-gray color often develops within them. Their size varies from a few millimeters to several centimeters, and the organisms can be cultured from the lesions. Associated findings include a preceding upper respiratory tract infection; fever; meningitis; DIC; and, in some patients, a deficiency of the terminal components of complement. In *disseminated gonococcal infection* (arthritis-dermatitis syndrome), a small number of inflammatory papules and vesicopustules, often with central purpura or hemorrhagic necrosis, are found on the distal extremities. Additional symptoms include arthralgias, tenosynovitis, and fever. To establish the diagnosis, a Gram stain of these lesions should be performed. *Rocky Mountain spotted fever* is a tick-borne disease that is caused by *Rickettsia rickettsii*. A several-day history of fever, chills, severe headache, and photophobia precedes the onset of the cutaneous eruption. The initial lesions are erythematous macules and papules on the wrists, ankles, palms, and soles. With time, the lesions spread centripetally and become purpuric.

Lesions of *ecthyma gangrenosum* begin as edematous, erythematous papules or plaques and then develop central purpura and necrosis. Bullae formation also occurs in these lesions, and they are frequently found in the girdle region. The organism that is classically associated with ecthyma gangrenosum is *Pseudomonas aeruginosa*, but other gram-negative rods such as *Klebsiella*, *Escherichia coli*, and *Serratia* can produce similar lesions. In immunocompromised hosts, the list of potential pathogens is expanded to include *Candida* and other opportunistic fungi (e.g., *Aspergillus*, *Fusarium*).

## ULCERS

The approach to the patient with a cutaneous ulcer is outlined in Table 58-17. Peripheral vascular diseases of the extremities are reviewed in Chap. 281, as is Raynaud's phenomenon.

*Livedoid vasculopathy* (livedoid vasculitis; atrophie blanche) represents a combination of a vasculopathy plus intravascular thrombosis. Purpuric lesions and livedo reticularis are found in association with *painful ulcerations* of the lower extremities. These ulcers are often slow to heal, but when they do, irregularly shaped white scars form. The majority of cases are secondary to venous hypertension, but possible underlying illnesses include disorders of hypercoagulability, for example, antiphospholipid syndrome and factor V Leiden (Chaps. 117 and 357).

In *pyoderma gangrenosum*, the border of untreated active ulcers has a characteristic appearance consisting of an undermined necrotic violaceous edge and a peripheral erythematous halo. The ulcers often begin as pustules that then expand rather rapidly to a size as large as 20 cm. Although these lesions are most commonly found on the lower extremities, they can arise anywhere on the surface of the body, including at sites of trauma (pathergy). An estimated 30–50% of cases are idiopathic, and the most common associated disorders are ulcerative colitis and Crohn's disease. Less commonly, pyoderma gangrenosum is associated with seropositive rheumatoid arthritis, acute and chronic myelogenous leukemia, myelodysplasia, a monoclonal gammopathy (usually IgA), or an autoinflammatory disorder. Because the histology of pyoderma gangrenosum may be nonspecific (dermal infiltrate of neutrophils when in untreated state), the diagnosis requires clinicopathologic correlation, in particular, the exclusion of similar-appearing ulcers such as necrotizing vasculitis, Meleney's ulcer (synergistic infection at a site of trauma or surgery), dimorphic fungi, cutaneous amebiasis, spider bites, and factitial. In the myeloproliferative disorders, the ulcers may be more superficial with a pustulobullous border, and these lesions provide a connection between classic pyoderma gangrenosum and acute febrile neutrophilic dermatosis (Sweet syndrome).

## FEVER AND RASH

The major considerations in a patient with a fever and a rash are inflammatory diseases versus infectious diseases. In the hospital setting, the most common scenario is a patient who has a drug rash plus a fever secondary to an underlying infection. However, it should be emphasized that a drug reaction can lead to both a cutaneous eruption and a fever ("drug fever"), especially in the setting of DRESS, AGEP, or serum

**TABLE 58-17 Causes of Mucocutaneous Ulcers**

- I. Primary cutaneous disorders
  - A. Peripheral vascular disease ([Chap. 281](#))
    - 1. Venous
    - 2. Arterial<sup>a</sup>
  - B. Livedoid vasculopathy in the setting of venous hypertension<sup>b</sup>
  - C. Squamous cell carcinoma (e.g., within scars), basal cell carcinomas
  - D. Infections, e.g., ecthyma caused by *Streptococcus* ([Chap. 148](#))
  - E. Physical, e.g., trauma, pressure
  - F. Drugs, e.g., hydroxyurea
- II. Systemic diseases
  - A. Lower legs
    - 1. Small-vessel and medium-vessel vasculitis<sup>c</sup>
    - 2. Hemoglobinopathies ([Chap. 98](#))
    - 3. Cryoglobulinemia;<sup>d</sup> cryofibrinogenemia
    - 4. Cholesterol emboli<sup>a,c</sup>
    - 5. Necrobiosis lipoidica<sup>d</sup>
    - 6. Antiphospholipid syndrome ([Chap. 116](#))
    - 7. Neuropathic<sup>e</sup> ([Chap. 403](#))
    - 8. Panniculitis
    - 9. Kaposi's sarcoma, acral angiodermatitis (pseudo-Kaposi's sarcoma)
    - 10. Diffuse dermal angiogenesis
  - B. Hands and feet
    - 1. Raynaud's phenomenon ([Chap. 281](#))
    - 2. Buerger disease
  - C. Generalized
    - 1. Pyoderma gangrenosum, but most commonly legs
    - 2. Calciphylaxis ([Chap. 410](#))
    - 3. Infections, e.g., dimorphic fungi, leishmaniasis
    - 4. Lymphoma
  - D. Face, especially perioral, and anogenital
    - 1. Chronic herpes simplex<sup>f</sup>
  - E. Mucosal
    - A. Aphthae
    - B. Drug-induced mucositis
    - C. Behcet's disease ([Chap. 364](#))
    - D. Erythema multiforme major, Stevens-Johnson syndrome, TEN
    - E. Primary blistering disorders ([Chap. 59](#))
    - F. Lupus erythematosus, lichen planus, lichenoid GVHD
    - G. Inflammatory bowel disease
    - H. Acute HIV infection
    - I. Reactive arthritis

<sup>a</sup>Underlying atherosclerosis. <sup>b</sup>Also associated with underlying disorders that lead to hypercoagulability/thrombophilia, e.g., factor V Leiden, protein C dysfunction/deficiency, antiphospholipid antibodies. <sup>c</sup>Reviewed in section on purpura. <sup>d</sup>Reviewed in section on papulonodular skin lesions. <sup>e</sup>Favors plantar surface of the foot. <sup>f</sup>Sign of immunosuppression.

Abbreviations: GVHD, graft versus host disease; HIV, human immunodeficiency virus; TEN, toxic epidermal necrolysis.

sickness-like reaction. Additional inflammatory diseases that are often associated with a fever include pustular psoriasis, erythroderma, and Sweet syndrome. Lyme disease, secondary syphilis, and viral and bacterial exanthems (see “Exanthems,” above) are examples of infectious diseases that produce a rash and a fever. Lastly, it is important to determine whether or not the cutaneous lesions represent septic emboli (see “Purpura,” above). Such lesions usually have evidence of ischemia in the form of purpura, necrosis, or impending necrosis (gunmetal-gray color). In the patient with thrombocytopenia, however, purpura can be seen in inflammatory reactions such as morbilliform drug eruptions and infectious lesions.

**FURTHER READING**

B, JL, S, JV, C  
Philadelphia, Elsevier, 2018.

C JP et al (eds): *Dermatological Signs of Systemic Disease*, 5th ed. Edinburgh, Elsevier, 2017.

F N (ed): *Oral Signs of Systemic Disease*. Switzerland, Springer, 2019.

K D: Rheumatologic dermatology. *Clin Dermatol* 36:439, 2018.

T SC et al (eds): *Taylor and Kelly's Dermatology for Skin of Color*, 2nd ed. New York, McGraw-Hill, 2016.

**59****Immunologically Mediated Skin Diseases**

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A number of immunologically mediated skin diseases and immunologically mediated systemic disorders with cutaneous manifestations are now recognized as distinct entities with consistent clinical, histologic, and immunopathologic findings. Clinically, these disorders are characterized by morbidity (pain, pruritus, disfigurement) and, in some instances, result in death (largely due to loss of epidermal barrier function and/or secondary infection). The major features of the more common immunologically mediated skin diseases are summarized in this chapter ([Table 59-1](#)), as are autoimmune systemic disorders with cutaneous manifestations.

**AUTOIMMUNE CUTANEOUS DISEASES****■ PEMPHIGUS VULGARIS**

*Pemphigus* refers to a group of autoantibody-mediated intraepidermal blistering diseases characterized by loss of cohesion between epidermal cells (a process termed *acantholysis*). Manual pressure to the skin of these patients may elicit the separation of the epidermis (*Nikolsky's sign*). This finding, while characteristic of pemphigus, is not specific to this group of disorders and is also seen in toxic epidermal necrolysis, Stevens-Johnson syndrome, and a few other skin diseases.

*Pemphigus vulgaris* (PV) is a mucocutaneous blistering disease that predominantly occurs in patients >40 years of age. PV typically begins on mucosal surfaces and often progresses to involve the skin. This disease is characterized by fragile, flaccid blisters that rupture to produce extensive denudation of mucous membranes and skin ([Fig. 59-1](#)). The mouth, scalp, face, neck, axilla, groin, and trunk are typically involved. PV may be associated with severe skin pain; some patients experience pruritus as well. Lesions usually heal without scarring except at sites complicated by secondary infection or mechanically induced dermal wounds. Postinflammatory hyperpigmentation is usually present for some time at sites of healed lesions.

Biopsies of early lesions demonstrate intraepidermal vesicle formation secondary to loss of cohesion between epidermal cells (i.e., acantholytic blisters). Blister cavities contain acantholytic epidermal cells, which appear as round homogeneous cells containing hyperchromatic nuclei. Basal keratinocytes remain attached to the epidermal basement membrane; hence, blister formation takes place within the suprabasal portion of the epidermis. Lesional skin may contain focal collections of intraepidermal eosinophils within blister cavities; dermal alterations are slight, often limited to an eosinophil-predominant leukocytic infiltrate. Direct immunofluorescence microscopy of lesional or intact patient skin shows deposits of IgG on the surface of keratinocytes; deposits of complement components are typically found in lesional but not in uninvolved skin. Deposits of IgG on keratinocytes are derived from circulating autoantibodies to cell-surface autoantigens.

TABLE 59-1 Immunologically Mediated Blistering Diseases

DISEASE	CLINICAL MANIFESTATIONS	HISTOLOGY	IMMUNOPATHOLOGY	AUTOANTIGENS <sup>a</sup>
Pemphigus vulgaris	Flaccid blisters, denuded skin, oromucosal lesions	Acantholytic blister formed in suprabasal layer of epidermis	Cell surface deposits of IgG on keratinocytes	Dsg3 (plus Dsg1 in patients with skin involvement)
Pemphigus foliaceus	Crusts and shallow erosions on scalp, central face, upper chest, and back	Acantholytic blister formed in superficial layer of epidermis	Cell surface deposits of IgG on keratinocytes	Dsg1
Paraneoplastic pemphigus	Painful stomatitis with papulosquamous or lichenoid eruptions that may progress to blisters	Acantholysis, keratinocyte necrosis, and vacuolar interface dermatitis	Cell surface deposits of IgG and C3 on keratinocytes and (variably) similar immunoreactants in epidermal BMZ	Plakin protein family members and desmosomal cadherins (see text for details)
Bullous pemphigoid	Large tense blisters on flexor surfaces and trunk	Subepidermal blister with eosinophil-rich infiltrate	Linear band of IgG and/or C3 in epidermal BMZ	BPAG1, BPAG2
Pemphigoid gestationis	Pruritic, urticarial plaques rimmed by vesicles and bullae on the trunk and extremities	Teardrop-shaped, subepidermal blisters in dermal papillae; eosinophil-rich infiltrate	Linear band of C3 in epidermal BMZ	BPAG2 (plus BPAG1 in some patients)
Dermatitis herpetiformis	Extremely pruritic small papules and vesicles on elbows, knees, buttocks, and posterior neck	Subepidermal blister with neutrophils in dermal papillae	Granular deposits of IgA in dermal papillae	Epidermal transglutaminase
Linear IgA disease	Pruritic small papules on extensor surfaces; occasionally larger, arciform blisters	Subepidermal blister with neutrophil-rich infiltrate	Linear band of IgA in epidermal BMZ	BPAG2 (see text for specific details)
Epidermolysis bullosa acquisita	Blisters, erosions, scars, and milia on sites exposed to trauma; widespread, inflammatory, tense blisters may be seen initially	Subepidermal blister that may or may not include a leukocytic infiltrate	Linear band of IgG and/or C3 in epidermal BMZ	Type VII collagen
Mucous membrane pemphigoid	Erosive and/or blistering lesions of mucous membranes and possibly the skin; scarring of some sites	Subepidermal blister that may or may not include a leukocytic infiltrate	Linear band of IgG, IgA, and/or C3 in epidermal BMZ	BPAG2, laminin-332, or others

<sup>a</sup>Autoantigens bound by these patients' autoantibodies are defined as follows: Dsg1, desmoglein 1; Dsg3, desmoglein 3; BPAG1, bullous pemphigoid antigen 1; BPAG2, bullous pemphigoid antigen 2.

Abbreviation: BMZ, basement membrane zone.

Such circulating autoantibodies can be demonstrated in 80–90% of PV patients by indirect immunofluorescence microscopy; monkey esophagus is the optimal substrate for these studies. Patients with PV have IgG autoantibodies to *desmogleins* (Dsgs), transmembrane desmosomal glycoproteins that belong to the cadherin family of calcium-dependent adhesion molecules. Such autoantibodies can be precisely quantitated by enzyme-linked immunosorbent assay (ELISA). Patients with early PV (i.e., mucosal disease) have IgG autoantibodies to Dsg3; patients with advanced PV (i.e., mucocutaneous disease) have

IgG autoantibodies to both Dsg3 and Dsg1. Experimental studies have shown that autoantibodies from patients with PV are pathogenic (i.e., responsible for blister formation) and that their titer correlates with disease activity. Recent studies have shown that the anti-Dsg antibody profile in these patients' sera as well as the tissue distribution of Dsg3 and Dsg1 determine the site of blister formation in patients with PV. Coexpression of Dsg3 and Dsg1 by epidermal cells protects against pathogenic IgG antibodies to either of these cadherins but not against pathogenic autoantibodies to both.



A

B

FIGURE 59-1 Pemphigus vulgaris. A. Flaccid bullae are easily ruptured, resulting in multiple erosions and crusted plaques. B. Involvement of the oral mucosa, which is almost invariable, may present with erosions on the gingiva, buccal mucosa, palate, posterior pharynx, or tongue. (Figure B: Courtesy of Robert Swerlick, MD.)

PV can be life-threatening. Prior to the availability of glucocorticoids, mortality rates ranged from 60% to 90%; the current figure is ~5%. Common causes of morbidity and death are infection and complications of treatment. Bad prognostic factors include advanced age, widespread involvement, and the requirement for high doses of glucocorticoids (with or without other immunosuppressive agents) for control of disease. The course of PV in individual patients is variable and difficult to predict. Some patients experience remission, while others may require long-term treatment or succumb to complications of their disease or its treatment. The mainstay of treatment is systemic glucocorticoids alone or in combination with other immunosuppressive agents. Patients with moderate to severe PV are usually started on prednisone at doses  $\leq$  mg/kg per day (single morning dose). If new lesions continue to appear after 1–2 weeks of treatment, the dose of prednisone may need to be increased and/or combined with another immunosuppressive agent. Among these, rituximab in combination with prednisone often achieves remission (though maintenance therapy may be required to prevent relapse). Other immunosuppressive agents sometimes combined with prednisone to treat PV include azathioprine, mycophenolate mofetil, or cyclophosphamide. Patients with severe, treatment-resistant disease may derive benefit from plasmapheresis (six high-volume exchanges [i.e., 2–3 L per exchange] over ~2 weeks) and/or IV immunoglobulin (IVIg). It is important to bring severe or progressive disease under control quickly in order to lessen the severity and/or duration of this disorder. Increasingly, rituximab and daily glucocorticoids are used early in PV patients to avert the development of advanced and/or treatment-resistant disease.

### ■ PEMPHIGUS FOLIACEUS

Pemphigus foliaceus (PF) is distinguished from PV by several features. In PF, acantholytic blisters are located high within the epidermis, usually just beneath the stratum corneum. Hence, PF is a more superficial blistering disease than PV. The distribution of lesions in the two disorders is much the same, except that in PF mucous membranes are almost always spared. Patients with PF rarely have intact blisters but rather exhibit shallow erosions associated with erythema, scale, and crust formation. Mild cases of PF can resemble severe seborrheic dermatitis; severe PF may cause extensive exfoliation. Sun exposure (ultraviolet irradiation) may be an aggravating factor.

PF has immunopathologic features in common with PV. Specifically, direct immunofluorescence microscopy of perilesional skin demonstrates IgG on the surface of keratinocytes. Similarly, patients with PF have circulating IgG autoantibodies directed against the surface of keratinocytes. In PF, autoantibodies are directed against Dsg1, a 160-kDa desmosomal cadherin. These autoantibodies can be quantitated by ELISA. As noted for PV, the autoantibody profile in patients with PF (i.e., anti-Dsg1 IgG) and the tissue distribution of this autoantigen (i.e., expression in oral mucosa that is compensated by coexpression of Dsg3) are thought to account for the distribution of lesions in this disease.

Endemic forms of PF are found in south-central rural Brazil, where the disease is known as *fogo salvagem* (FS), as well as in selected sites in Latin America and Tunisia. Endemic PF, like other forms of this disease, is mediated by IgG autoantibodies to Dsg1. Clusters of FS overlap with those of leishmaniasis, a disease transmitted by bites of the sand fly *Lutzomyia longipalpis*. Studies have shown that sand fly salivary antigens (specifically, the LJM11 salivary protein) are recognized by IgG autoantibodies from FS patients (as well as by monoclonal antibodies to Dsg1 derived from these patients). The demonstration that mice immunized with LJM11 produce antibodies to Dsg1 suggests that insect bites may deliver salivary antigens, initiate a cross-reactive humoral immune response, and lead to FS in genetically susceptible individuals.

Although pemphigus has been associated with several autoimmune diseases, its association with thymoma and/or myasthenia gravis is particularly notable. To date, >30 cases of thymoma and/or myasthenia gravis have been reported in association with pemphigus, usually with PF. Patients may also develop pemphigus as a consequence of drug exposure; drug-induced pemphigus usually resembles PF rather than PV. Drugs containing a thiol group in their chemical structure (e.g., penicillamine, captopril, enalapril) are most commonly associated with

drug-induced pemphigus. Nonthiol drugs linked to pemphigus include penicillins, cephalosporins, and piroxicam. Some cases of drug-induced pemphigus are durable and require treatment with systemic glucocorticoids and/or immunosuppressive agents.

PF is generally a less severe disease than PV and usually carries a better prognosis. Localized disease can sometimes be treated with topical or intralesional glucocorticoids; more active cases can usually be controlled with systemic glucocorticoids either alone or in combination with other immunosuppressive agents. Patients with severe, treatment-resistant disease may require more aggressive interventions, as described above for patients with PV.

### ■ PARANEOPLASTIC PEMPHIGUS

Paraneoplastic pemphigus (PNP) is an autoimmune acantholytic mucocutaneous disease associated with an occult or confirmed neoplasm. Patients with PNP typically have painful stomatitis in association with papulosquamous and/or lichenoid eruptions that often progress to blisters. Palm and sole involvement are common in these patients and raise the possibility that prior reports of neoplasia-associated erythema multiforme may have represented unrecognized cases of PNP. Biopsies of lesional skin from these patients show varying combinations of acantholysis, keratinocyte necrosis, and vacuolar-interface dermatitis. Direct immunofluorescence microscopy of a patient's skin shows deposits of IgG and complement on the surface of keratinocytes and (variably) similar immunoreactants in the epidermal basement membrane zone. Patients with PNP have IgG autoantibodies to cytoplasmic proteins that are members of the plakin family (e.g., desmoplakins I and II, bullous pemphigoid antigen [BPAG] 1, envoplakin, periplakin, and plectin) and to cell-surface proteins that are members of the cadherin family (e.g., Dsg1 and Dsg3). Passive transfer studies have shown that autoantibodies from patients with PNP are pathogenic in animal models.

The predominant neoplasms associated with PNP are non-Hodgkin's lymphoma, chronic lymphocytic leukemia, thymoma, spindle cell tumors, Waldenström's macroglobulinemia, and Castleman's disease; the last-mentioned neoplasm is particularly common among children with PNP. Rare cases of seronegative PNP have been reported in patients with B-cell malignancies previously treated with rituximab. In addition to severe skin lesions, many patients with PNP develop life-threatening bronchiolitis obliterans. PNP is generally resistant to conventional therapies (i.e., those used to treat PV); rarely, a patient's disease may ameliorate or even remit following ablation or removal of underlying neoplasms.

### ■ BULLOUS PEMPHIGOID

Bullous pemphigoid (BP) is a polymorphic autoimmune subepidermal blistering disease usually seen in the elderly. Initial lesions may consist of urticarial plaques; most patients eventually display tense blisters on either normal-appearing or erythematous skin (Fig. 59-2). The lesions are usually distributed over the lower abdomen, groin, and flexor surface of the extremities; oral mucosal lesions are found in some patients. Pruritus may be nonexistent or severe. As lesions evolve, tense blisters tend to rupture and be replaced by erosions with or without surmounting crust. Nontraumatized blisters heal without scarring. The major histocompatibility complex class II allele HLA-DQ $\beta$ 1 0301 is prevalent in patients with BP. Though most cases occur sporadically, BP can be triggered by medications (e.g., furosemide, dipeptidyl peptidase-4 inhibitors, immune checkpoint inhibitors), ultraviolet light, or ionizing radiation. Several studies have shown that BP is associated with neurologic diseases (e.g., stroke, dementia, Parkinson's disease, and multiple sclerosis).

Biopsies of early lesional skin demonstrate subepidermal blisters and histologic features that roughly correlate with the clinical character of the lesion under study. Lesions on normal-appearing skin generally contain a sparse perivascular leukocytic infiltrate with some eosinophils; conversely, biopsies of inflammatory lesions typically show an eosinophil-rich infiltrate at sites of vesicle formation and in perivascular areas. In addition to eosinophils, cell-rich lesions also contain mononuclear cells and neutrophils. It is not possible to distinguish



**FIGURE 59-2** Bullous pemphigoid with tense vesicles and bullae on erythematous, urticarial bases. (Courtesy of the Yale Resident's Slide Collection; with permission.)

BP from other subepidermal blistering diseases by routine histologic studies alone.

Direct immunofluorescence microscopy of normal-appearing perilesional skin from patients with BP shows linear deposits of IgG and/or C3 in the epidermal basement membrane. The sera of ~70% of these patients contain circulating IgG autoantibodies that bind the epidermal basement membrane of normal human skin in indirect immunofluorescence microscopy. IgG from an even higher percentage of patients reacts with the epidermal side of 1 M NaCl split skin (an alternative immunofluorescence microscopy test substrate used to distinguish circulating IgG autoantibodies to the basement membrane in patients with BP from those in patients with similar, yet different, subepidermal blistering diseases; see below). In BP, circulating autoantibodies recognize 230- and 180-kDa hemidesmosome-associated proteins in basal keratinocytes (i.e., BPAG1 and BPAG2, respectively). Autoantibodies to BPAG2 are thought to deposit *in situ*, activate complement, produce dermal mast-cell degranulation, and generate granulocyte-rich infiltrates that cause tissue damage and blister formation.

BP may persist for months to years, with exacerbations or remissions. Extensive involvement may result in widespread erosions and compromise cutaneous integrity; elderly and/or debilitated patients may die. Local or minimal disease can sometimes be controlled with potent topical glucocorticoids alone; more extensive lesions generally respond to systemic glucocorticoids either alone or in combination with other agents. Adjuncts to systemic glucocorticoids include doxycycline, azathioprine, mycophenolate mofetil, and rituximab.

### ■ PEMPHIGOID GESTATIONIS

Pemphigoid gestationis (PG), also known as *herpes gestationis*, is a rare, nonviral, subepidermal blistering disease of pregnancy and the puerperium. PG may begin during any trimester of pregnancy or present shortly after delivery. Lesions are usually distributed over the abdomen, trunk, and extremities; mucous membrane lesions are rare. Skin lesions in these patients may be quite polymorphic and consist of erythematous urticarial papules and plaques, vesiculopapules, and/or frank bullae. Lesions are almost always extremely pruritic. Severe exacerbations of PG frequently follow delivery, typically within 24–48 h. PG tends to recur in subsequent pregnancies, often beginning earlier during such gestations. Brief flare-ups of disease may occur with resumption of menses and may develop in patients later exposed to oral contraceptives. Occasionally, infants of affected mothers have transient skin lesions.

Biopsies of early lesional skin show teardrop-shaped subepidermal vesicles forming in dermal papillae in association with an eosinophil-rich leukocytic infiltrate. Differentiation of PG from other subepidermal

bullous diseases by light microscopy is difficult. However, direct immunofluorescence microscopy of perilesional skin from PG patients reveals the immunopathologic hallmark of this disorder: linear deposits of C3 in the epidermal basement membrane. These deposits develop as a consequence of complement activation produced by low-titer IgG anti–basement membrane autoantibodies directed against BPAG2, the same hemidesmosome-associated protein that is targeted by autoantibodies in patients with BP—a subepidermal bullous disease that resembles PG clinically, histologically, and immunopathologically.

The goals of therapy in patients with PG are to prevent the development of new lesions, relieve intense pruritus, and care for erosions at sites of blister formation. Many patients require treatment with moderate doses of daily glucocorticoids (i.e., 20–40 mg of prednisone) at some point in their course. Mild cases (or brief flare-ups) may be controlled by vigorous use of potent topical glucocorticoids. Infants born of mothers with PG appear to be at increased risk of being born slightly premature or “small for dates.” Current evidence suggests that there is no difference in the incidence of uncomplicated live births between PG patients treated with systemic glucocorticoids and those managed more conservatively. If systemic glucocorticoids are administered, newborns are at risk for development of reversible adrenal insufficiency.

### ■ DERMATITIS HERPETIFORMIS

Dermatitis herpetiformis (DH) is an intensely pruritic, papulovesicular skin disease characterized by lesions symmetrically distributed over extensor surfaces (i.e., elbows, knees, buttocks, back, scalp, and posterior neck) (see Fig. 56-8). Primary lesions in this disorder consist of papules, papulovesicles, or urticarial plaques. Because pruritus is prominent, patients may present with excoriations and crusted papules but no observable primary lesions. Patients sometimes report that their pruritus has a distinctive burning or stinging component; the onset of such local symptoms reliably heralds the development of distinct clinical lesions 12–24 h later. Almost all DH patients have associated, usually subclinical, gluten-sensitive enteropathy (Chap. 325), and >90% express the HLA-B8/DRw3 and HLA-DQw2 haplotypes. DH may present at any age, including in childhood; onset in the second to fourth decades is most common. The disease is typically chronic.

Biopsy of early lesional skin reveals neutrophil-rich infiltrates within dermal papillae. Neutrophils, fibrin, edema, and microvesicle formation at these sites are characteristic of early disease. Older lesions may demonstrate nonspecific features of a subepidermal bulla or an excoriated papule. Because the clinical and histologic features of this disease can be variable and resemble those of other subepidermal blistering disorders, the diagnosis is confirmed by direct immunofluorescence microscopy of normal-appearing perilesional skin. Such studies demonstrate granular deposits of IgA (with or without complement components) in the papillary dermis and along the epidermal basement membrane zone. IgA deposits in the skin are unaffected by control of disease with medication; however, these immunoreactants diminish in intensity or disappear in patients maintained for long periods on a strict gluten-free diet (see below). Patients with DH have granular deposits of IgA in their epidermal basement membrane zone and should be distinguished from individuals with linear IgA deposits at this site (see below).

Although most DH patients do not report overt gastrointestinal symptoms or have laboratory evidence of malabsorption, biopsies of the small bowel usually reveal blunting of intestinal villi and a lymphocytic infiltrate in the lamina propria. As is true for patients with celiac disease, this gastrointestinal abnormality can be reversed by a gluten-free diet. Moreover, if maintained, this diet alone may control the skin disease and eventually in clearance of IgA deposits from these patients’ epidermal basement membrane zones. Subsequent gluten exposure in such patients alters the morphology of their small bowel, elicits a flare-up of their skin disease, and is associated with the reappearance of IgA in their epidermal basement membrane zones. As in patients with celiac disease, dietary gluten sensitivity in patients with DH is associated with IgA anti-endomysial autoantibodies that target tissue transglutaminase. Studies indicate that patients with DH also

have high-avidity IgA autoantibodies to epidermal transglutaminase and that the latter is co-localized with granular deposits of IgA in the papillary dermis of DH patients. Patients with DH also have an increased incidence of thyroid abnormalities, achlorhydria, atrophic gastritis, and autoantibodies to gastric parietal cells. These associations likely relate to the high frequency of the HLA-B8/DRw3 haplotype in these patients, since this marker is commonly linked to autoimmune disorders. The mainstay of treatment of DH is dapsone, a sulfone. Patients respond rapidly (24–48 h) to dapsone, but require careful pre-treatment evaluation (e.g., screening for glucose-6-phosphate dehydrogenase deficiency) and close follow-up to ensure that complications are avoided or controlled. All patients taking dapsone at >100 mg/d will have some hemolysis and methemoglobinemia, which are expected pharmacologic side effects of this agent. Gluten restriction can control DH and lessen dapsone requirements; this diet must rigidly exclude gluten to be of maximal benefit. Many months of dietary restriction may be necessary before a beneficial result is achieved. Good dietary counseling by a trained dietitian is essential.

### ■ LINEAR IgA DISEASE

Linear IgA disease, once considered a variant form of DH, is actually a separate and distinct entity. Clinically, patients with linear IgA disease may resemble individuals with DH, BP, or other subepidermal blistering diseases. Lesions typically consist of papulovesicles, bullae, and/or urticarial plaques that develop predominantly on central or flexural sites. Oral mucosal involvement occurs in some patients. Severe pruritus resembles that seen in patients with DH. Patients with linear IgA disease do not have an increased frequency of the HLA-B8/DRw3 haplotype or an associated enteropathy and therefore are not candidates for treatment with a gluten-free diet.

Histologic alterations in early lesions may be virtually indistinguishable from those in DH. However, direct immunofluorescence microscopy of normal-appearing perilesional skin reveals a linear band of IgA (and often C3) in the epidermal basement membrane zone. Most patients with linear IgA disease have circulating IgA anti-basement membrane autoantibodies directed against neoepitopes in the proteolytically processed extracellular domain of BPAG2. These patients generally respond to treatment with dapsone (50–200 mg/d) alone or in combination with low daily doses of prednisone.

### ■ EPIDERMOLYSIS BULLOSA ACQUISITA

Epidermolysis bullosa acquisita (EBA) is a rare, noninherited, polymorphic, chronic, subepidermal blistering disease. (The inherited form is discussed in Chap. 413.) Patients with classic or noninflammatory EBA have blisters on noninflamed skin, atrophic scars, milia, nail dystrophy, hair loss, and oral lesions. Because lesions generally occur at sites exposed to minor trauma, classic EBA is considered a mechanobullous disease. Other patients with EBA have widespread inflammatory scarring and bullous lesions that resemble severe BP. Inflammatory EBA may evolve into the classic, noninflammatory form of this disease. Rarely, patients present with lesions that predominate on mucous membranes. The HLA-DR2 haplotype is found with increased frequency in EBA patients. Studies suggest that EBA is sometimes associated with inflammatory bowel disease (especially Crohn's disease).

The histology of lesional skin varies with the character of the lesion being studied. Noninflammatory bullae are subepidermal, feature a sparse leukocytic infiltrate, and resemble the lesions in patients with porphyria cutanea tarda. Inflammatory lesions consist of neutrophil-rich subepidermal blisters. EBA patients have continuous deposits of IgG (and frequently C3) in a linear pattern within the epidermal basement membrane zone. Ultrastructurally, these immunoreactants are found in the sublamina densa region in association with anchoring fibrils. Approximately 50% of EBA patients have demonstrable circulating IgG anti-basement membrane autoantibodies directed against type VII collagen—the collagen species that makes up anchoring fibrils. Such IgG autoantibodies bind the dermal side of 1 M NaCl split skin (in contrast to IgG autoantibodies in patients with BP). Studies have shown that passive transfer of experimental or patient IgG against type

VII collagen can produce lesions in mice that clinically, histologically, and immunopathologically resemble those in patients with EBA.

Treatment of EBA is generally unsatisfactory. Some patients with inflammatory EBA may respond to systemic glucocorticoids, either alone or in combination with immunosuppressive agents. Other patients (especially those with neutrophil-rich inflammatory lesions) may respond to dapsone. The chronic, noninflammatory form of EBA is largely resistant to treatment, although some patients may respond to prednisone in combination with rituximab, cyclosporine, mycophenolate mofetil, azathioprine, or IVIg.

### ■ MUCOUS MEMBRANE PEMPHIGOID

Mucous membrane pemphigoid (MMP) is a rare, acquired, subepithelial immunobullous disease characterized by erosive lesions of mucous membranes and skin that result in scarring of at least some sites of involvement. Common sites include the oral mucosa (especially the gingiva) and conjunctiva; other sites that may be affected include the nasopharyngeal, laryngeal, esophageal, and anogenital mucosa. Skin lesions (present in about one-third of patients) tend to predominate on the scalp, face, and upper trunk and generally consist of a few scattered erosions or tense blisters on an erythematous or urticarial base. MMP is typically a chronic and progressive disorder. Serious complications may arise as a consequence of ocular, laryngeal, esophageal, or anogenital lesions. Erosive conjunctivitis may result in shortened fornices, symblepharon, ankyloblepharon, entropion, corneal opacities, and (in severe cases) blindness. Similarly, erosive lesions of the larynx may cause hoarseness, pain, and tissue loss that, if unrecognized and untreated, may eventuate in complete destruction of the airway. Esophageal lesions may result in stenosis and/or strictures that could place patients at risk for aspiration. Strictures may also complicate anogenital involvement.

Biopsies of lesional tissue generally show subepithelial vesiculobullae and a mononuclear leukocytic infiltrate. Neutrophils and eosinophils may be seen in biopsies of early lesions; older lesions may demonstrate a scant leukocytic infiltrate and fibrosis. Direct immunofluorescence microscopy of perilesional tissue typically reveals deposits of IgG, IgA, and/or C3 in the epidermal basement membrane. Because many patients with MMP exhibit no evidence of circulating anti-basement membrane autoantibodies, testing of perilesional skin is important diagnostically. Although MMP was once thought to be a single nosologic entity, it is now largely regarded as a disease phenotype that may develop as a consequence of an autoimmune reaction to a variety of molecules in the epidermal basement membrane (e.g., BPAG2, laminin-332, type VII collagen,  $\alpha_6\beta_4$  integrin) and other antigens yet to be completely defined. Studies suggest that MMP patients with autoantibodies to laminin-332 have an increased relative risk for cancer. Treatment of MMP is largely dependent upon the sites of involvement. Due to potentially severe complications, patients with ocular, laryngeal, esophageal, and/or anogenital involvement require aggressive systemic treatment with dapsone, prednisone, or the latter in combination with another immunosuppressive agent (e.g., rituximab, azathioprine, mycophenolate mofetil, or cyclophosphamide), or IVIg. Less threatening forms of the disease may be managed with topical or intralesional glucocorticoids.

## AUTOIMMUNE SYSTEMIC DISEASES WITH PROMINENT CUTANEOUS FEATURES

### ■ DERMATOMYOSITIS

The cutaneous manifestations of dermatomyositis (Chap. 365) are often distinctive but at times may resemble those of systemic lupus erythematosus (SLE) (Chap. 356), scleroderma (Chap. 360), or other overlapping connective tissue diseases (Chap. 360). The extent and severity of cutaneous disease may or may not correlate with the extent and severity of the myositis. The cutaneous manifestations of dermatomyositis are similar, whether the disease appears in children or in the elderly, except that calcification of subcutaneous tissue is a common late sequela in childhood dermatomyositis. Dermatomyositis may be associated with interstitial lung disease or cancer.



**FIGURE 59-3** Dermatomyositis. Periorbital violaceous erythema characterizes the classic heliotrope rash. (Courtesy of James Krell, MD; with permission.)

The cutaneous signs of dermatomyositis may precede or follow the development of myositis by weeks to years. Cases lacking muscle involvement (i.e., *dermatomyositis sine myositis* or *amyopathic dermatomyositis*) have also been reported. The most common manifestation is a purple-red discoloration of the upper eyelids, sometimes associated with scaling ("heliotrope" erythema; Fig. 59-3) and periorbital edema. Erythema on the cheeks and nose in a "butterfly" distribution may resemble the malar eruption of SLE. Erythematous or violaceous thin, scaly plaques are common on the upper trunk and neck (shawl sign), the scalp, lateral aspects of the thighs (holster sign), and the extensor surfaces of the forearms and hands (tendon streaking). Approximately one-third of patients have violaceous, flat-topped papules over the dorsal interphalangeal joints that are pathognomonic of dermatomyositis (Gottron's papules) (Fig. 59-4). Thin violaceous papules and plaques on the elbows and knees of patients with dermatomyositis are referred to as *Gottron's sign*. These lesions can be contrasted with the erythema and scaling on the dorsum of the fingers that spares the skin over the interphalangeal joints of some SLE patients. Periungual telangiectasias and edema may be prominent in patients with dermatomyositis. Other patients, particularly those with long-standing disease, develop areas of hypopigmentation, hyperpigmentation, mild atrophy, and telangiectasia known as *poikiloderma*. Poikiloderma is rare in both SLE and scleroderma and thus can serve as a clinical sign that distinguishes dermatomyositis from these two diseases. Cutaneous changes may be similar in dermatomyositis and various overlap syndromes where thickening and binding down of the skin of the hands (*sclerodactyly*)



**FIGURE 59-4** Gottron's papules. Dermatomyositis often involves the hands as erythematous flat-topped papules over the knuckles. Periungual telangiectasias are also evident.

as well as Raynaud's phenomenon can be seen. However, the presence of severe muscle disease, Gottron's papules, heliotrope erythema, and poikiloderma serves to distinguish patients with dermatomyositis. Skin biopsy of the erythematous, scaling lesions of dermatomyositis may reveal only mild nonspecific inflammation, but sometimes may show changes indistinguishable from those found in cutaneous lupus erythematosus (LE), including epidermal atrophy, hydropic degeneration of basal keratinocytes, and dermal changes consisting of interstitial mucin deposition and a mild mononuclear cell perivascular infiltrate. Direct immunofluorescence microscopy of lesional skin is usually negative, although granular deposits of immunoglobulin(s) and complement in the epidermal basement membrane zone have been described in some patients. Treatment should be stratified based on the relative severity of disease. Topical treatments include glucocorticoids, sunscreens, and aggressive photoprotective measures. Treatment of systemic disease includes antimicrobials (though some patients may develop a drug eruption upon initiation of therapy) or systemic glucocorticoids in conjunction with methotrexate, mycophenolate mofetil, azathioprine, rituximab, or IVIg.

### LUPUS ERYTHEMATOSUS

The cutaneous manifestations of LE (Chap. 356) can be divided into acute, subacute, and chronic types. *Acute cutaneous LE* is characterized by erythema of the nose and malar eminences in a "butterfly" distribution (Fig. 59-5A). The erythema is often sudden in onset, accompanied



**FIGURE 59-5** Acute cutaneous lupus erythematosus (LE). **A.** Acute cutaneous LE on the face, showing prominent, scaly, malar erythema. Involvement of other sun-exposed sites is also common. **B.** Acute cutaneous LE on the upper chest, demonstrating brightly erythematous and slightly edematous papules and plaques. (Source: B, Courtesy of Robert Swerlick, MD; with permission.)

by edema and fine scale, and correlated with systemic involvement. Patients may have widespread involvement of the face as well as erythema and scaling of the extensor surfaces of the extremities and upper chest (Fig. 59-5B). These acute lesions, while sometimes evanescent, usually last for days and are often associated with exacerbations of systemic disease. Skin biopsy of acute lesions typically shows hydropic degeneration of basal keratinocytes, dermal edema, and (in some cases) a sparse perivascular infiltrate of mononuclear cells in the upper dermis as well as dermal mucin. Direct immunofluorescence microscopy of lesional skin frequently reveals deposits of immunoglobulin(s) and complement in the epidermal basement membrane zone. Treatment of cutaneous disease includes topical glucocorticoids, aggressive photoprotection, antimalarials, and control of systemic disease. Treatment of systemic disease associated with acute cutaneous LE includes systemic glucocorticoids in conjunction with other immunosuppressive agents.

*Subacute cutaneous lupus erythematosus* (SCLE) is characterized by a widespread photosensitive, nonscarring eruption. In most patients, renal and central nervous system involvement is mild or absent. SCLE may present as a papulosquamous eruption that resembles psoriasis or as annular polycyclic lesions. In the papulosquamous form, discrete erythematous papules arise on the back, chest, shoulders, extensor surfaces of the arms, and dorsum of the hands; lesions are uncommon on the central face and the flexor surfaces of the arms as well as below the waist. These slightly scaling papules tend to merge into plaques. The annular form involves the same areas and presents with erythematous papules that evolve into oval, circular, or polycyclic lesions. The lesions of SCLE are more widespread but have less tendency for scarring than lesions of discoid LE. In many patients with SCLE, drugs (e.g., hydrochlorothiazide, calcium channel blockers, antifungals, proton pump inhibitors) may induce or exacerbate disease. Skin biopsy typically reveals epidermal changes that include atrophy, hydropic degeneration of basal keratinocytes, and apoptosis accompanied by an infiltrate of mononuclear cells in the upper dermis. Direct immunofluorescence microscopy of lesional skin reveals deposits of immunoglobulin(s) in the epidermal basement membrane zone in about one-half of these cases. A particulate pattern of IgG deposition throughout the epidermis has been associated with SCLE. Most SCLE patients have anti-Ro autoantibodies. Local therapy alone is usually unsuccessful. Most patients require treatment with aminoquinoline antimalarial drugs. Low-dose therapy with oral glucocorticoids is sometimes necessary. Photoprotective measures against both ultraviolet B and ultraviolet A wavelengths are very important.

*Chronic cutaneous LE* has multiple subtypes; *discoid LE* (DLE) is the most common. DLE is characterized by discrete lesions, most often found on the face, scalp, and/or external ears. The lesions are erythematous papules or plaques with a thick, adherent scale that occludes hair follicles (follicular plugging). When the scale is removed, its underside shows small excrescences that correlate with the openings of hair follicles (so-called "carpet tacking"), a finding relatively specific for DLE. Long-standing lesions develop central atrophy, scarring, and hypopigmentation but frequently have erythematous, sometimes raised borders (Fig. 59-6). These lesions persist for years and tend to expand slowly. Up to 20% of patients with DLE eventually meet the American College of Rheumatology criteria for SLE. Typical discoid lesions are frequently seen in patients with SLE. Biopsy of DLE lesions shows hyperkeratosis, follicular plugging, atrophy of the epidermis, hydropic degeneration of basal keratinocytes, thickening of the epidermal basement membrane zone, and a mononuclear cell infiltrate adjacent to epidermal, adnexal, and microvascular basement membranes. Direct immunofluorescence microscopy demonstrates immunoglobulin(s) and complement deposits at the basement membrane zone in ~90% of cases. Treatment is focused on control of local cutaneous disease and consists mainly of photoprotection and topical or intralesional glucocorticoids. If local therapy is ineffective, use of aminoquinoline antimalarial agents may be indicated.

### SCLERODERMA AND MORPHEA

The skin changes of scleroderma (Chap. 360) may be limited or diffuse. In both instances, disease usually begin on the fingers, hands, toes, feet, and face, with episodes of recurrent nonpitting edema.



FIGURE 59-6 Discoid lupus erythematosus (DLE). Violaceous, hyperpigmented, atrophic plaques, follicular plugging, and scarring are typical features of DLE.

Sclerosis of the skin commences distally on the fingers (sclerodactyly) and spreads proximally, usually accompanied by resorption of bone of the fingertips, which may have punched out ulcers, stellate scars, or areas of hemorrhage (Fig. 59-7). The fingers may shrink and become sausage-shaped, and, because the fingernails are usually unaffected, they may curve over the end of the fingertips. Periungual telangiectasias are usually present, but periungual erythema is rare. In diffuse disease, the extremities show contractures and calcinosis cutis; facial involvement includes a smooth, unwrinkled brow, taut skin over the nose, shrinkage of tissue around the mouth, and perioral radial furrowing (Fig. 59-8). Matlike telangiectasias are often present, particularly on the face and hands. Involved skin feels indurated, smooth, and bound to underlying structures; hyper- and hypopigmentation are common as well. *Raynaud's phenomenon* (i.e., cold-induced blanching, cyanosis, and reactive hyperemia) is documented in almost all patients and can precede development of scleroderma by many years. The combination of calcinosis cutis, Raynaud's phenomenon, esophageal dysmotility, sclerodactyly, and telangiectasias has been termed as the *CREST syndrome*. Anti-centromere autoantibodies have been reported in a very high percentage of patients with CREST syndrome but in only a small minority of patients with scleroderma. Skin biopsy reveals thickening of the dermis, homogenization of collagen bundles, atrophic pilosebaceous and eccrine glands, and a sparse mononuclear cell infiltrate in the dermis and subcutaneous fat. Direct immunofluorescence microscopy of lesional skin is usually negative. Treatments for



FIGURE 59-7 Scleroderma showing acral sclerosis and focal digital ulcers.



**FIGURE 59-8** Scleroderma often eventuates in development of an expressionless, masklike facies.

cutaneous disease include emollients, antipruritics, and phototherapy (UVA1 [ultraviolet A1 irradiation] or PUVA [psoralens + ultraviolet A irradiation]). Treatment of systemic disease includes vascular modifying agents, immunosuppressives, and antifibrotics.

Morphea is characterized by localized thickening and sclerosis of skin; it dominates on the trunk. This disorder may affect children or adults. Morphea begins as erythematous or flesh-colored plaques that become sclerotic, develop central hypopigmentation, and have an erythematous border. In most cases, patients have one or a few lesions, and the disease is termed *circumscribed morphea*. In some patients, widespread cutaneous lesions may occur without systemic involvement (*generalized morphea*). Many adults with generalized morphea have concomitant rheumatic or other autoimmune disorders. Skin biopsy of morphea is generally indistinguishable from that of scleroderma. Scleroderma and morphea are usually quite resistant to therapy. For this reason, physical therapy to prevent joint contractures and to maintain function is employed and is often helpful. Treatment options for early, rapidly progressive disease include phototherapy (UVA1 or PUVA) or methotrexate alone or in combination with daily glucocorticoids.

*Diffuse fasciitis with eosinophilia* is a clinical entity that can sometimes be confused with scleroderma. There is usually a sudden onset of swelling, induration, and erythema of the extremities, frequently following significant physical exertion, initiation of hemodialysis, exposure to certain medications, or other triggers. The proximal portions of the extremities (upper arms, forearms, thighs, calves) are more often involved than are the hands and feet. While the skin is indurated, it usually displays a woody, dimpled, or “pseudocellulite” appearance rather than being bound down as in scleroderma; contractures may occur early secondary to fascial involvement. The latter may also cause muscle groups to be separated and veins to appear depressed (i.e., the “groove sign”). These skin findings are accompanied by peripheral-blood eosinophilia, increased erythrocyte sedimentation rate, and sometimes hypergammaglobulinemia. Deep biopsy of affected areas of skin reveals inflammation and thickening of the deep fascia overlying muscle. An inflammatory infiltrate composed of eosinophils and mononuclear cells is usually found. Patients with eosinophilic fasciitis appear to be at increased risk for developing bone marrow failure or other hematologic abnormalities. While the ultimate course of eosinophilic fasciitis is variable, most patients respond favorably to treatment with prednisone. Relapses may occur and require treatment with prednisone in combination with other immunosuppressive or immunomodulatory agents.

The *eosinophilia-myalgia syndrome*, a disorder with epidemic numbers of cases reported in 1989 and linked to ingestion of -tryptophan manufactured by a single company in Japan, is a multisystem disorder characterized by debilitating myalgias and absolute eosinophilia in association with varying combinations of arthralgias, pulmonary

symptoms, and peripheral edema. In a later phase (3–6 months after initial symptoms), these patients often develop localized scleroderma-like skin changes, weight loss, and/or neuropathy (Chap. 360).

## FURTHER READING

- B JL et al (eds): *Dermatology*, 4th ed. Philadelphia, Elsevier, 2018.
- H CM, S JR: Mechanisms of disease: Pemphigus and bullous pemphigoid. *Annu Rev Pathol* 11:175, 2016.
- K S et al (eds): *Fitzpatrick's Dermatology in General Medicine*, 9th ed. New York, McGraw-Hill, 2019.
- S E, Z D: Pemphigoid diseases. *Lancet* 381:320, 2013.

# 60

## Cutaneous Drug Reactions

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Cutaneous reactions are the most frequent adverse reactions to medications, representing 10–15% of reported adverse drug reactions. Most are benign, but a few can be life threatening. Prompt recognition of severe reactions, drug withdrawal, and appropriate therapeutic interventions can minimize toxicity. This chapter focuses on adverse cutaneous reactions to systemic medications; it covers their incidence, patterns, and pathogenesis, and provides some practical guidelines on treatment, assessment of causality, and future use of drugs.

### USE OF PRESCRIPTION DRUGS IN THE UNITED STATES

In the United States, more than 4 billion prescriptions for >60,000 drug products are dispensed annually. Hospital inpatients alone annually receive about 120 million courses of drug therapy, and half of adult Americans receive prescription drugs on a regular outpatient basis. Adverse effects of a prescription medication may result in 4.5 million urgent or emergency care visits and over 7000 deaths each year in the United States. Many patients use over-the-counter medicines that may cause adverse cutaneous reactions.

### INCIDENCE OF CUTANEOUS REACTIONS

Several recent prospective studies reported that acute cutaneous reactions to drugs affect between 2.2 and 10 per 1000 hospitalized patients. Reactions usually occur a few days to 4 weeks after initiation of therapy.

In a series of 48,005 inpatients over a 20-year period, morbilliform rash (91%) and urticaria (6%) were the most frequent skin reactions, and antimicrobials, radiocontrast, and nonsteroidal anti-inflammatory drugs (NSAIDs) were the most common drug associations. Severe hypersensitivity reactions to medications have been reported to occur in between 1 in 1000 to 2 per million users, depending on the reaction type. Although rare, severe cutaneous reactions to drugs have an important impact on health because of significant sequelae; in addition, they may require hospitalization, increase the duration of hospital stay, or be life threatening. Some populations are at increased risk of drug reactions, including elderly patients, patients with autoimmune disease, hematopoietic stem cell transplant recipients, and those with acute Epstein-Barr virus (EBV) or human immunodeficiency virus (HIV) infection. The pathophysiology underlying this association is unknown but may be related to immune dysregulation. Individuals with advanced HIV disease (e.g., CD4 T lymphocyte count <200 cells/ $\mu$ L) have a 40- to 50-fold increased risk of adverse reactions to sulfamethoxazole (Chap. 202) and increased risk of severe hypersensitivity reactions.

In addition to acute eruptions, a variety of skin diseases can be induced or exacerbated by prolonged use of drugs (e.g., pruritus, pigmentation, nail or hair disorders, psoriasis, bullous pemphigoid, photosensitivity, and even cutaneous neoplasms). These drug reactions are not frequent; however, neither their incidence nor their impact on public health has been evaluated.

## PATHOGENESIS OF DRUG REACTIONS

Adverse cutaneous responses to drugs can arise as a result of immunologic or nonimmunologic mechanisms.

### NONIMMUNOLOGIC DRUG REACTIONS

Examples of nonimmunologic drug reactions are pigmentary changes due to dermal accumulation of medications or their metabolites, alteration of hair follicles by antimetabolites and signaling inhibitors, and lipodystrophy associated with metabolic effects of anti-HIV medications. These side effects are predictable and sometimes can be prevented.

### IMMUNOLOGIC DRUG REACTIONS

Evidence suggests an immunologic basis for most acute drug eruptions. Drug reactions may result from immediate release of preformed mediators (e.g., urticaria, anaphylaxis), antibody-mediated reactions, immune complex deposition, and antigen-specific responses. Drug-specific CD4+ and CD8+ T-cell clones can be derived from the blood or from skin lesions of patients with a variety of drug allergies, strongly suggesting that these T cells mediate drug allergy in an antigen-specific manner. Drug presentation to T cells is major histocompatibility complex (MHC)-restricted and likely involves drug-peptide complex recognition by specific T-cell receptors (TCRs).

Once a drug has induced an immune response, the phenotype of the reaction is determined by the nature of effectors: cytotoxic (CD8+) T cells in blistering and certain hypersensitivity reactions, chemokines for reactions mediated by neutrophils or eosinophils, and B cell collaboration for production of specific antibodies for urticarial reactions. Immunologic reactions have recently been classified into further subtypes that provide a useful framework for designating adverse drug reactions based on involvement of specific immune pathways (Table 60-1).

**Immediate Reactions** Immediate reactions depend on the release of mediators of inflammation by tissue mast cells or circulating basophils. These mediators include histamine, leukotrienes, prostaglandins, bradykinins, platelet-activating factor, enzymes, and proteoglycans. Drugs can trigger mediator release either directly ("anaphylactoid" reaction) or through IgE-specific antibodies. These reactions usually manifest in the skin and gastrointestinal, respiratory, and cardiovascular systems (Chap. 353). Primary symptoms and signs include pruritus, urticaria, nausea, vomiting, abdominal cramps, bronchospasm, laryngeal edema, and, occasionally, anaphylactic shock with hypotension and death. They occur within minutes of drug exposure. NSAIDs, including aspirin, and radiocontrast media are frequent causes of direct mast cell degranulation or anaphylactoid reactions, which can occur on first exposure. Penicillins and muscle relaxants used in general anesthesia are the most frequent causes of IgE-dependent reactions to drugs, which require prior sensitization. Release of mediators is triggered when polyvalent drug protein conjugates cross-link IgE molecules fixed to sensitized cells. Certain routes of administration favor different clinical patterns (e.g., gastrointestinal effects from oral route, circulatory effects from intravenous route).

**Immune Complex–Dependent Reactions** Serum sickness is produced by tissue deposition of circulating immune complexes with consumption of complement. It is characterized by fever, arthritis, nephritis, neuritis, edema, and an urticarial, papular, or purpuric rash (Chap. 363). First described following administration of nonhuman sera, it currently occurs in the setting of monoclonal antibodies and similar medications. In classic serum sickness, symptoms develop 6 or more days after drug exposure, the latent period representing the time needed to synthesize antibody. Vasculitis, a relatively rare complication

TABLE 60-1 Classification of Adverse Drug Reactions Based on Immune Pathway

TYPE	KEY PATHWAY	KEY IMMUNE MEDIATORS	ADVERSE DRUG REACTION TYPE
Type I	IgE	IgE	Urticaria, angioedema, anaphylaxis
Type II	IgG-mediated cytotoxicity	IgG	Drug-induced hemolysis, thrombocytopenia (e.g., penicillin)
Type III	Immune complex	IgG + antigen	Vasculitis, serum sickness, drug-induced lupus
Type IVa	T lymphocyte-mediated macrophage inflammation	IFN- $\gamma$ , TNF- $\alpha$ T <sub>H</sub> 1 cells	Tuberculin skin test, contact dermatitis
Type IVb	T lymphocyte-mediated eosinophil inflammation	IL-4, IL-5, IL-13 T <sub>H</sub> 2 cells Eosinophils	DIHS Morbilliform eruption
Type IVc	T lymphocyte-mediated cytotoxic T lymphocyte inflammation	Cytotoxic T lymphocytes Granzyme Perforin Granulysin (SJS/TEN) only	SJS/TEN Morbilliform eruption
Type IVd	T lymphocyte-mediated neutrophil inflammation	CXCL8, IL-17, GM-CSF Neutrophils	AGEP

*Abbreviations:* AGEП, acute generalized exanthematous pustulosis; DIHS, drug-induced hypersensitivity syndrome; GM-CSF, granulocyte-macrophage colony-stimulating factor; IFN, interferon; IL, interleukin; SJS, Stevens-Johnson syndrome; TEN, toxic epidermal necrolysis; TNF, tumor necrosis factor.

of drugs, may also be a result of immune complex deposition (Chap. 363). Penicillin, cefaclor, amoxicillin, trimethoprim/sulfamethoxazole, and monoclonal antibodies such as infliximab, rituximab, and omalizumab may be associated with clinically similar "serum sickness-like" reactions (SSLR). The mechanism of this reaction is unknown but is unrelated to immune complex formation and complement activation, and systemic involvement is rare. Whereas serum sickness most commonly occurs in adults, SSLR is more frequently observed in children.

**Delayed Hypersensitivity** While not completely understood, delayed hypersensitivity directed by drug-specific T cells is an important mechanism underlying the most common drug eruptions, that is, morbilliform eruptions, and also rare and severe forms such as drug-induced hypersensitivity syndrome (DIHS) (also known as drug rash with eosinophilia and systemic symptoms [DRESS]), acute generalized exanthematous pustulosis (AGEP), Stevens-Johnson syndrome (SJS), and toxic epidermal necrolysis (TEN) (Table 60-1). Drug-specific T cells have been detected in these types of drug eruptions. In TEN, skin lesions contain T lymphocytes reactive to autologous lymphocytes and keratinocytes in a drug-specific, human leukocyte antigen (HLA)-restricted, and perforin/granzyme-mediated pathway. In the case of carbamazepine, studies have identified cytotoxic T lymphocytes (CTLs) reactive to carbamazepine that use highly restricted V-alpha and V-beta TCR repertoires in patients with carbamazepine hypersensitivity that are not found in carbamazepine-tolerant individuals.

The mechanism(s) by which medications result in T-cell activation is unknown. Two hypotheses prevail: first, that the antigens driving these reactions may be the native drug itself or components of the drug covalently complexed with endogenous proteins, presented in association with HLA molecules to T cells through the classic antigen presentation pathway or, alternatively, through direct interaction of the drug/metabolite with the TCR or peptide-loaded HLA (e.g., the pharmacologic interaction of drugs with immune receptors, or p-i hypothesis). Recent x-ray crystallography data characterizing binding between

specific HLA molecules to drugs known to cause hypersensitivity reactions demonstrate unique alterations to the MHC peptide-binding groove, suggesting a molecular basis for T-cell activation in the development of hypersensitivity reactions.

## ■ GENETIC FACTORS AND CUTANEOUS DRUG REACTIONS

 Genetic determinants may predispose individuals to severe drug reactions by affecting either drug metabolism or immune responses to drugs. Polymorphisms in cytochrome P450 enzymes, drug acetylation, methylation (such as thiopurine methyltransferase activity and azathioprine), and other forms of metabolism (such as glucose-6-phosphate dehydrogenase and dapsone) may increase susceptibility to drug toxicity or underdosing and increase risk for medication interactions, highlighting a role for differential pharmacokinetic or pharmacodynamic effects. The value of routine screening of P450 enzymes for prediction of cutaneous reactions has not been determined, though its cost-effectiveness in certain populations (e.g., patients with seizure disorder, depression) as well as patients considering specific therapies (e.g., tamoxifen, warfarin) has been suggested.

Associations between drug hypersensitivities and HLA haplotypes suggest a key role for immune mechanisms, especially those leading to skin involvement. Hypersensitivity to the anti-HIV medication abacavir is strongly associated with HLA-B\*57:01 (Chap. 202). In Taiwan, within a homogeneous Han Chinese population, a strong association was observed between SJS/TEN (but not DIHS) related to carbamazepine and HLA-B\*15:02. In the same population, a strong association was found between HLA-B\*58:01 and SJS, TEN, or DIHS related to allopurinol. These associations are drug and phenotype specific; that is, HLA-specific T cell stimulation by medications leads to distinct reactions. However, while this genetic association is strong, it is not sufficient to cause severe drug hypersensitivity reactions.

## ■ GLOBAL CONSIDERATIONS

Recognition of HLA associations with drug hypersensitivity has resulted in recommendations to screen high-risk populations. Genetic screening for HLA-B\*57:01 to prevent abacavir hypersensitivity, which carries a 100% negative predictive value when patch test confirmed and 55% positive predictive value generalizable across races, is becoming the clinical standard of care worldwide (number needed to treat = 13). The U.S. Food and Drug Administration has recommended HLA-B\*15:02 screening of Asian individuals prior to a new prescription of carbamazepine. The American College of Rheumatology has recommended HLA-B\*58:01 screening of Han Chinese patients prescribed allopurinol. To date, screening for a single HLA (but not multiple HLA haplotypes) in specific populations has been determined to be cost-effective (e.g., HLA-B\*1301 screening in Chinese patients with leprosy treated with dapsone). Genetic testing for specific HLA haplotypes and functional screening for TCR repertoire to identify patients at risk is becoming more widely available and heralds the era of personalized medicine and pharmacogenomics.

## CLINICAL PRESENTATION OF CUTANEOUS DRUG REACTIONS

### ■ NONIMMUNE CUTANEOUS REACTIONS

**Exacerbation or Induction of Dermatologic Diseases** A variety of drugs can exacerbate preexisting diseases or induce—or unmask—a disease that may or may not disappear after withdrawal of the inducing medication. For example, NSAIDs, lithium, beta blockers, tumor necrosis factor (TNF) antagonists, interferon (IFN)  $\alpha$ , and angiotensin-converting enzyme (ACE) inhibitors can exacerbate plaque psoriasis, whereas antimalarials and withdrawal of systemic glucocorticoids can worsen pustular psoriasis. The situation of TNF- $\alpha$  inhibitors is unusual, as this class of medications is used to treat psoriasis; however, they may induce psoriasis (especially palmoplantar) in patients being treated for other conditions. Acne may be induced by glucocorticoids, androgens, lithium, and antidepressants. Follicular papular or pustular eruptions of the face and trunk resembling

acne frequently occur with epidermal growth factor receptor (EGFR) antagonists, mitogen-activated protein kinase (MEK) inhibitors, and other targeted inhibitors. With EGFR antagonists, the severity of the eruption correlates with a better anticancer effect. This rash is typically responsive to and prevented by tetracycline antibiotics.

Several medications induce or exacerbate autoimmune disease. Checkpoint inhibitors induce a wide array of systemic autoimmune reactions, including in skin. Interleukin (IL) 2, IFN- $\alpha$ , and anti-TNF- $\alpha$  are associated with new-onset systemic lupus erythematosus (SLE). Drug-induced lupus is classically marked by antinuclear and antihistone antibodies and, in some cases, anti-double-stranded DNA (D-penicillamine, anti-TNF- $\alpha$ ) or perinuclear antineutrophil cytoplasmic antibodies (p-ANCA) (minocycline). Subacute cutaneous lupus erythematosus (SCLE) can be induced by a growing list of drugs, including thiazide diuretics, proton pump inhibitors, TNF inhibitors, terbinafine, and minocycline. Drug-induced dermatomyositis may rarely occur with TNF inhibitors or capecitabine; hydroxyurea can induce skin findings of dermatomyositis. IFN and TNF inhibitors, as well as checkpoint inhibitors, can induce granulomatous disease and sarcoidosis. Autoimmune blistering diseases may be drug induced as well: pemphigus by D-penicillamine and ACE inhibitors; bullous pemphigoid by DPP4 inhibitors, furosemide, and PD-1 inhibitors; and linear IgA bullous dermatosis by vancomycin. Other medications may cause highly specific cutaneous reactions. Gadolinium contrast has been associated with nephrogenic systemic fibrosis, a condition of sclerosing skin with rare internal organ involvement; advanced renal compromise may be an important risk factor. Granulocyte colony-stimulating factor, azacitidine, all-trans-retinoic acid, the *FLT3* inhibitor class of drugs, and rarely levamisole-contaminated cocaine may induce neutrophilic dermatoses. In this setting, the hypothesis that a drug may be responsible should always be considered, even after the treatment is complete. In addition, reactions may develop in cases of long-term medication therapy due to changes in dosing or host metabolism. Resolution of the cutaneous reaction may be delayed upon discontinuation of the medication.

**Photosensitivity Eruptions** Photosensitivity eruptions are usually most marked in sun-exposed areas, but they may extend to sun-protected areas. The mechanism is almost always phototoxicity. Phototoxic reactions resemble sunburn and can occur with first exposure to a drug. Blistering may occur in drug-related pseudoporphyria, most commonly with NSAIDs. The severity of the reaction depends on the tissue level of the drug, its efficiency as a photosensitizer, and the extent of exposure to the activating wavelengths of ultraviolet (UV) light (Chap. 61).

Common orally administered photosensitizing drugs include fluoroquinolones, tetracycline antibiotics, and trimethoprim/sulfamethoxazole. Other drugs less frequently implicated are chlorpromazine, thiazides, NSAIDs, and BRAF inhibitors. Voriconazole may result in severe photosensitivity, accelerated photoaging, and cutaneous carcinogenesis.

Because UV-A and visible light, which trigger these reactions, are not easily absorbed by nonopaque sunscreens and are transmitted through window glass, photosensitivity reactions may be difficult to block. Photosensitivity reactions abate with removal of either the drug or UV radiation, use of sunscreens that block UV-A light, and treatment of the reaction as one would a sunburn. Rarely, individuals develop persistent reactivity to light, necessitating long-term avoidance of sun exposure. Some chemotherapeutic agents, such as methotrexate, can induce a UV-recall reaction characterized by an erythematous, slightly scaly eruption at sites of prior severe sun exposure.

**Pigmentation Changes** Drugs, either systemic or topical, may cause a variety of pigmentary changes in the skin by triggering melanocyte production of melanin (as in the case of oral contraceptives causing melasma) or due to deposition of drug or drug metabolites. Long-term minocycline and amiodarone may cause blue-gray pigmentation. Phenothiazine, gold, and bismuth result in gray-brown pigmentation of sun-exposed areas. Numerous cancer chemotherapeutic agents



**FIGURE 60-1** Warfarin necrosis involving the breasts.

may be associated with characteristic patterns of pigmentation (e.g., bleomycin, busulfan, daunorubicin, cyclophosphamide, hydroxyurea, fluorouracil, and methotrexate). Clofazimine causes a drug-induced lipofuscinosis with characteristic red-brown coloration. Hyperpigmentation of the face, mucous membranes, and pretibial and subungual areas occurs with antimalarials. Quinacrine causes generalized yellow discoloration. Pigmentation changes may also occur in mucous membranes (busulfan, bismuth), conjunctiva (chlorpromazine, thioridazine, imipramine, clomipramine), nails (zidovudine, doxorubicin, cyclophosphamide, bleomycin, fluorouracil, hydroxyurea), hair, and teeth (tetracyclines).

**Warfarin Necrosis of Skin** This rare reaction (0.01–0.1%) usually occurs between the third and tenth days of therapy with warfarin, usually in women. Common sites are breasts, thighs, and buttocks (Fig. 60-1). Lesions are sharply demarcated, erythematous, or purpuric, and may progress to form large, hemorrhagic bullae with necrosis and eschar formation.

Warfarin anticoagulation in protein C or S deficiency causes an additional reduction in already low circulating levels of endogenous anticoagulants, permitting hypercoagulability and thrombosis in the cutaneous microvasculature, with consequent areas of necrosis. Heparin-induced necrosis may have clinically similar features but is probably due to heparin-induced platelet aggregation with subsequent occlusion of blood vessels; it can affect areas adjacent to the injection site or more distant sites if infused. Levamisole-tainted cocaine (and more recently, heroin) can induce similar skin necrosis; however, the distribution tends to involve the ears and cheeks predominantly, with stellate or retiform purpura. Patients may have abnormal white blood cell counts and may be dual P- and C-ANCA positive.

**Drug-Induced Hair Disorders • DRUG INDUCED HAIR LOSS** Medications may affect hair follicles at two different phases of their growth cycle: anagen (growth) or telogen (resting). *Anagen effluvium* occurs within days of drug administration, especially with antimetabolite or other chemotherapeutic drugs. In contrast, in *telogen effluvium*, the delay is 2–4 months following initiation of a new medication. Both present as diffuse, nonscarring alopecia most often reversible after discontinuation of the responsible agent.

A considerable number of drugs have been associated with hair loss. These include antineoplastic agents (alkylating agents, bleomycin, vinca alkaloids, platinum compounds), anticonvulsants (carbamazepine, valproate), beta blockers, antidepressants, antithyroid drugs, IFNs, oral contraceptives, and cholesterol-lowering agents.

**DRUG INDUCED HAIR GROWTH** Medications may also cause hair growth. Hirsutism is an excessive growth of terminal hair with masculine hair growth pattern in a female, most often on the face and trunk, due to androgenic stimulation of hormone-sensitive hair follicles (anabolic steroids, oral contraceptives, testosterone, corticotropin). Hypertrichosis is a distinct pattern of hair growth, not in a masculine pattern, typically located on the forehead and temporal regions of the face. Drugs responsible for hypertrichosis include anti-inflammatory drugs, glucocorticoids, vasodilators (diazoxide, minoxidil), diuretics

(acetazolamide), anticonvulsants (phenytoin), immunosuppressive agents (cyclosporine A), psoralens, and zidovudine.

Changes in hair color or structure are uncommon adverse effects from medications. Hair discoloration may occur with chloroquine, IFN- $\alpha$ , chemotherapeutic agents, and tyrosine kinase inhibitors. Changes in hair structure have been observed in patients given EGFR inhibitors, BRAF inhibitors, tyrosine kinase inhibitors, and acitretin.

**Drug-Induced Nail Disorders** Drug-related nail disorders usually involve all 20 nails and need months to resolve after withdrawal of the medication. The pathogenesis is most often toxic. Drug-induced nail changes include Beau's line (transverse depression of the nail plate), onycholysis (detachment of the distal part of the nail plate), onychomadesis (detachment of the proximal part of the nail plate), pigmentation, and paronychia (inflammation of periungual skin).

**ONYCHOLYSIS** Onycholysis occurs with tetracyclines, fluoroquinolones, retinoids, NSAIDs, and others, including many chemotherapeutic agents, and may be triggered by exposure to sunlight.

**ONYCHOMADESIS** Onychomadesis is caused by temporary arrest of nail matrix mitotic activity. Common drugs reported to induce onychomadesis include carbamazepine, lithium, retinoids, and chemotherapeutic agents such as taxanes.

**PARONYCHIA** Paronychia and multiple pyogenic granulomas with progressive and painful periungual abscess of fingers and toes are side effects of systemic retinoids, lamivudine, indinavir, and anti-EGFR monoclonal antibodies.

**NAIL DISCOLORATION** Some drugs—including anthracyclines, taxanes, fluorouracil, psoralens, and zidovudine—may induce nail bed hyperpigmentation through melanocyte stimulation. It appears to be reversible and dose dependent.

**Toxic Erythema of Chemotherapy and Other Chemotherapy Reactions** Because many agents used in cancer chemotherapy inhibit cell division, rapidly proliferating elements of the skin, including hair, mucous membranes, and appendages, are sensitive to their effects. A broad spectrum of chemotherapy-related skin toxicities has been reported, including neutrophilic eccrine hidradenitis, sterile cellulitis, exfoliative dermatitis, and flexural erythema; recent nomenclature classifies these under the unifying diagnosis of toxic erythema of chemotherapy (TEC) (Fig. 60-2). Acral erythema is marked by dysesthesia and an erythematous, edematous eruption of the palms and soles. Common causes include cytarabine, doxorubicin, methotrexate, hydroxyurea, fluorouracil, and capecitabine.

The recent introduction of many new monoclonal antibody and small molecular signaling inhibitors for the treatment of cancer has been accompanied by numerous reports of skin and hair toxicity; only the most common of these are mentioned here. EGFR antagonists induce follicular eruptions and nail toxicity after a mean interval of 10 days in a majority of patients. Xerosis, eczematous eruptions, acneiform eruptions, and pruritus are common. Erlotinib is associated with marked hair textural changes. Sorafenib, a tyrosine kinase inhibitor, may result in follicular eruptions and focal bullous eruptions at palmar/plantar, flexural sites or areas of frictional pressure. BRAF inhibitors are associated with photosensitivity, palmar/plantar hyperkeratosis, hair curling, dyskeratotic (Grover's-like) rash, hyperkeratotic benign cutaneous neoplasms, and keratoacanthoma-like squamous cell carcinomas. Rash, pruritus, and vitiliginous depigmentation have been reported in association with ipilimumab (anti-CTLA4) treatment. Up to 50% of patients experience immune-mediated skin eruptions, including granulomatous reactions, dermatomyositis, panniculitis, and vasculitis. The checkpoint inhibitor class of drugs (including anti-CTLA4, anti-PD-1, and anti-PD-L1 agents) can induce a wide range of cutaneous eruptions beyond vitiligo, including lichenoid, eczematous, granulomatous, papulosquamous, and panniculitis eruptions.

## ■ IMMUNE CUTANEOUS REACTIONS: COMMON

**Maculopapular Eruptions** Morbilliform or maculopapular eruptions (Fig. 60-3) are the most common of all drug-induced reactions,



FIGURE 60-2 Toxic erythema of chemotherapy.

often start on the trunk or intertriginous areas, and consist of blanching erythematous macules and papules that are symmetric and confluent. Nonblanching, dusky, or bright-red macules as well as mucosal involvement should raise concern for a more severe reaction. Facial involvement in morbilliform eruptions is also uncommon, and the presence of extensive facial lesions with facial edema suggests DIHS. Diagnosis of morbilliform eruptions is rarely assisted by laboratory testing or skin biopsy.

Morbilliform eruptions may be associated with moderate to severe pruritus and fever. A viral exanthem is another differential diagnostic consideration, especially in children, and graft-versus-host disease is also a consideration in the proper clinical setting. Absence of enanthems; absence of ear, nose, throat, and upper respiratory tract symptoms; and polymorphism of the skin lesions support a drug rather than a viral eruption. Common offenders include aminopenicillins, cephalosporins, antibacterial sulfonamides, allopurinol, and antiepileptic drugs. Beta blockers, calcium channel blockers, and ACE inhibitors are rarely the culprit; however, any drug can cause a morbilliform exanthem. Certain medications carry very high rates of morbilliform eruption, including nevirapine and lamotrigine, even in the absence of DIHS reactions. Lamotrigine morbilliform rash is associated with higher starting doses,



FIGURE 60-3 Morbilliform drug eruption.

rapid dose escalation, concomitant use of valproate (which increases lamotrigine levels and half-life), and use in children.

Maculopapular reactions usually develop within 1 week of initiation of therapy and last less than 2 weeks. Occasionally, these eruptions resolve despite continued use of the responsible drug. Because the eruption may also worsen, the suspect drug should be discontinued unless it is essential. It is important to note that the rash may continue to progress for a few days up to 1 week following medication discontinuation. Oral antihistamines and emollients may help relieve pruritus. Short courses of potent topical glucocorticoids can reduce inflammation and symptoms. Systemic glucocorticoid treatment is rarely indicated.

**Pruritus** Pruritus is associated with almost all drug eruptions and, in some cases, may represent the only symptom of the adverse cutaneous reaction. It may be alleviated by antihistamines such as hydroxyzine or diphenhydramine. Pruritus stemming from specific medications may require distinct treatment, such as selective opiate antagonists for opiate-related pruritus.

#### Urticaria/ Angioedema/ Anaphylaxis

Urticaria, the second most frequent type of cutaneous reaction to drugs, is characterized by pruritic, red wheals of varying size rarely lasting more than 24 hours. It has been observed in association with nearly all drugs, most frequently ACE inhibitors, aspirin, NSAIDs, penicillin, and blood products. However, medications account for no more than 10–20% of acute urticaria cases. Deep edema within dermal and subcutaneous tissues is known as angioedema and may involve respiratory and gastrointestinal mucous membranes. Urticaria and angioedema may be part of a life-threatening anaphylactic reaction.

Drug-induced urticaria may be caused by three mechanisms: an IgE-dependent mechanism, circulating immune complexes (serum sickness), and nonimmunologic activation of effector pathways. IgE-dependent urticarial reactions usually occur within 36 hours of drug exposure but can occur within minutes. Immune complex-induced urticaria associated with serum sickness reactions usually occurs 6–12 days after first exposure. In this syndrome, the urticarial eruption (typically polycyclic plaques over distal joints) may be accompanied by fever, hematuria, arthralgias, hepatic dysfunction, and neurologic symptoms. Certain drugs, such as NSAIDs, ACE inhibitors, angiotensin II antagonists, radiographic dye, and opiates, may induce urticarial reactions, angioedema, and anaphylaxis in the absence of drug-specific antibodies through direct mast-cell degranulation.

Radiocontrast agents are a common cause of urticaria and, in rare cases, can cause anaphylaxis. High-osmolality radiocontrast media are about five times more likely to induce urticaria (1%) or anaphylaxis than are newer low-osmolality media. About one-third of those with mild reactions to previous exposure react on reexposure. Pretreatment with prednisone and diphenhydramine reduces reaction rates.

The treatment of urticaria or angioedema depends on the severity of the reaction. In severe cases with respiratory or cardiovascular compromise, epinephrine and intravenous glucocorticoids are the mainstay of therapy. For patients with urticaria without symptoms of angioedema or anaphylaxis, drug withdrawal and oral antihistamines are usually sufficient. Future drug avoidance is recommended; rechallenge, especially in individuals with severe reactions, should only occur in an intensive care setting.

**Anaphylactoid Reactions** Vancomycin is associated with red man syndrome, a histamine-related anaphylactoid reaction characterized by flushing, diffuse maculopapular eruption, and hypotension. In rare cases, cardiac arrest may be associated with rapid intravenous (IV) infusion of the medication.



FIGURE 60-4 Allergic contact dermatitis (bullous) due to adhesive tape.

**Irritant/ Allergic Contact Dermatitis** Patients using topical medications may develop an irritant or allergic contact dermatitis to the medication itself or to a preservative or other component of the formulation. Reactions to neomycin sulfate, bacitracin, and polymyxin B are common. Contact dermatitis may be seen to adhesive tapes, leading to irritation or blisters around ports and IV sites (Fig. 60-4). Harsh disinfectant skin cleansers may lead to localized irritant dermatitis.

**Fixed Drug Eruptions** These less common reactions are characterized by one or more sharply demarcated, dull red to brown lesions, sometimes with central dusky violaceous erythema and central bulla (Fig. 60-5). Hyperpigmentation often results after resolution of the acute inflammation. With rechallenge, the process recurs in the same (fixed) location but may spread to new areas as well. Lesions often involve the lips, hands, legs, face, genitalia, and oral mucosa, and cause a burning sensation. Most patients have multiple lesions. Fixed drug eruptions have been associated with pseudoephedrine (frequently a nonpigmenting reaction), phenolphthalein (in laxatives), sulfonamides, tetracyclines, NSAIDs, barbiturates, and others.

#### ■ IMMUNE CUTANEOUS REACTIONS: RARE AND SEVERE

**Drug-Induced Hypersensitivity Syndrome** DIHS is a systemic drug reaction also known as DRESS (drug reaction with eosinophilia and systemic symptoms) syndrome; because eosinophilia is not always present, the term *DIHS* is preferred. Clinically, DIHS presents with a prodrome of fever and flu-like symptoms for several days, followed by



FIGURE 60-5 Fixed drug eruption.



FIGURE 60-6 Drug-induced hypersensitivity syndrome/drug rash with eosinophilia and systemic symptoms (DIHS/DRESS). (Courtesy of Gildo Micheletti, MD.)

the appearance of a diffuse morbilliform eruption, usually involving the face (Fig. 60-6). Facial swelling and hand/foot swelling are often present. Systemic manifestations include lymphadenopathy, fever, and leukocytosis (often with eosinophilia or atypical lymphocytosis), as well as hepatitis, nephritis, pneumonitis, myositis, and gastroenteritis, in descending order. Distinct patterns of timing of onset and organ involvement may exist. For example, allopurinol classically induces DIHS with renal involvement; cardiac and lung involvement are more common with minocycline; gastrointestinal involvement is almost exclusively seen with abacavir; and some medications typically do not induce eosinophilia (abacavir, dapsone, lamotrigine). The cutaneous reaction usually begins 2–8 weeks after the drug is started and persists after drug cessation. Signs and symptoms may continue for several weeks, especially those associated with hepatitis. The eruption recurs with rechallenge, and cross-reactions among aromatic anticonvulsants, including phenytoin, carbamazepine, and phenobarbital, are common. Other drugs causing DIHS include antibacterial sulfonamides and other antibiotics. Hypersensitivity to reactive drug metabolites, hydroxylamine for sulfamethoxazole and arene oxide for aromatic anticonvulsants, may be involved in the pathogenesis of DIHS. Recent research suggests that inciting drugs may reactivate quiescent human herpes viruses, including herpesviruses 6 and 7, EBV, and cytomegalovirus (CMV), resulting in expansion of viral-specific CD8+ T lymphocytes and subsequent end-organ damage. Viral reactivation may be associated with a worse clinical prognosis. Mortality rates as high as 10% have been reported, with most fatalities resulting from liver failure. Systemic glucocorticoids (1.5–2 mg/kg/d prednisone equivalent) should be started and tapered slowly over 8–12 weeks, during which time clinical symptoms and labs (including complete blood count with differential, basic metabolic panel, and liver function tests) should be followed carefully. A steroid-sparing agent such as mycophenolate mofetil, IV immunoglobulin, or cyclosporine may be indicated in cases of rapid recurrence upon steroid taper. In all cases, immediate



FIGURE 60-7 Stevens-Johnson syndrome (SJS).

withdrawal of the suspected culprit drug is required. Given the severe long-term complications of myocarditis, patients should undergo cardiac evaluation in cases of severe DIHS or if heart involvement is suspected due to hypotension or arrhythmia. Patients should be closely monitored for resolution of organ dysfunction and for development of late-onset autoimmune thyroiditis and diabetes (up to 6 months).

**Stevens-Johnson Syndrome and Toxic Epidermal Necrolysis** *SJS* and *TEN* are characterized by blisters and mucosal/epidermal detachment resulting from full-thickness epidermal necrosis in the absence of substantial dermal inflammation. The term *Stevens-Johnson syndrome* (*SJS*) describes cases in which the total body surface area of blistering and eventual detachment is <10% (Fig. 60-7). The term *Stevens-Johnson syndrome/toxic epidermal necrolysis* (*SJS/TEN*) overlap is used to describe cases with 10–30% epidermal detachment (Fig. 60-8), and the term *toxic epidermal necrolysis* (*TEN*) is used to describe cases with >30% detachment (Figs. 60-9 and 60-10).

Other blistering eruptions with concomitant mucositis may be confused with *SJS/TEN*. Erythema multiforme (EM) associated with herpes simplex virus is characterized by painful mucosal erosions and



FIGURE 60-9 Toxic epidermal necrolysis, hand.

target lesions, typically with an acral distribution and limited skin detachment. *Mycoplasma* and other respiratory infections in children cause a clinically distinct presentation with prominent mucositis and limited cutaneous involvement. The term *reactive infectious mucocutaneous eruption (RIME)* has been proposed to help differentiate this clinical entity, which some believe may be the syndrome originally described by Stevens and Johnson.

Patients with *SJS/TEN* initially present with fever >39°C (102.2°F); sore throat; conjunctivitis; and acute onset of painful dusky, atypical, target-like lesions (Fig. 60-11). Intestinal and upper respiratory tract involvement are associated with a poor prognosis, as are older age and greater extent of epidermal detachment. At least 10% of those with



FIGURE 60-8 SJS-TEN overlap.



FIGURE 60-10 Toxic epidermal necrolysis.



FIGURE 60-11 Target-like lesion in SJS.

SJS and 30% of those with TEN die from the disease. Drugs that most commonly cause SJS/TEN are sulfonamides, allopurinol, antiepileptics (e.g., lamotrigine, phenytoin, carbamazepine), oxicam NSAIDs,  $\beta$ -lactam and other antibiotics, and nevirapine. Frozen-section skin biopsy may aid in rapid diagnosis.

At this time, there is no consensus on the most effective treatment for SJS/TEN. The best outcomes stem from early diagnosis, immediate discontinuation of the suspected drug, and meticulous supportive therapy in an intensive care or burn unit. Fluid management, atraumatic wound care, infection prevention and treatment, and ophthalmologic and respiratory support are critical. Early administration of systemic glucocorticoids, intravenous immunoglobulin, cyclosporine, or etanercept may improve disease outcomes, but randomized studies to evaluate potential therapies are lacking and difficult to perform.

**Pustular Eruptions** AGEP is a rare reaction pattern affecting 3–5 people per million per year. It is thought to be secondary to medication exposure in >90% of cases (Fig. 60-12). Patients typically present with diffuse erythema or erythroderma, as well as high spiking fevers and leukocytosis with neutrophilia. One to two days later, innumerable pinpoint pustules develop overlying the erythema. The pustules are most pronounced in body fold areas; however, they may become generalized and, when coalescent, can lead to superficial erosion. In such cases, differentiating the eruption from SJS in its initial stages may be difficult, although in AGEP, any erosions tend to be more superficial, and prominent mucosal involvement is lacking. Skin biopsy shows collections of neutrophils and sparse necrotic keratinocytes in the upper



FIGURE 60-12 Acute generalized exanthematous pustulosis.

part of the epidermis, unlike the full-thickness epidermal necrosis that characterizes SJS. Before the pustules appear, AGEP may also mimic DIHS due to the prominent fever and erythroderma.

The principal differential diagnosis for AGEP is acute pustular psoriasis, which has an identical clinical and histologic appearance. Many patients with AGEP have a personal or family history of psoriasis. AGEP classically begins within 24–48 hours of drug exposure, although it may occur as much as 1–2 weeks later.  $\beta$ -Lactam antibiotics, calcium channel blockers, macrolide antibiotics, and other inciting agents (including radiocontrast and dialysates) have been reported. Patch testing with the responsible drug often results in a localized pustular eruption.

**Overlap Hypersensitivity Syndromes** An important concept in the clinical approach to severe drug eruptions is the presence of “overlap syndromes,” most notably DIHS with TEN-like features, DIHS with pustular eruption (AGEP-like), and AGEP with TEN-like features. In several case series of AGEP, 50% of cases had TEN-like or DRESS-like features, and 20% of cases had mucosal involvement resembling SJS/TEN. In one study, up to 20% of all severe drug eruptions had overlap features, suggesting that AGEP, DIHS, and SJS/TEN represent a clinical spectrum with some common pathophysiologic mechanisms. Designation of a single diagnosis based on cutaneous and extracutaneous involvement may not always be possible in cases of hypersensitivity; in such instances, treatment should be geared toward addressing the dominant clinical features. The timing of rash onset with respect to drug administration, which is usually much more delayed in DIHS, and the presence of systemic manifestations such as hepatitis are helpful clues to that diagnosis.

**Vasculitis** Cutaneous small-vessel vasculitis (CSVV) typically presents with purpuric papules and macules involving the lower extremities and other dependent areas (Fig. 60-13) (Chap. 363). Pustular and hemorrhagic vesicles as well as rounded ulcers also occur. Importantly, vasculitis may involve other organs, including the kidneys,



FIGURE 60-13 Cutaneous small-vessel vasculitis (CSVV, leukocytoclastic vasculitis).

joints, gastrointestinal tract, and lungs, necessitating a thorough clinical evaluation for systemic involvement. Drugs are implicated as a cause of roughly 15% of all cases of small-vessel vasculitis. Antibiotics, particularly  $\beta$ -lactams, are commonly implicated; however, almost any drug can cause vasculitis. Vasculitis may also be idiopathic or due to underlying infection, connective tissue disease, or (rarely) malignancy.

Rare but important types of drug-induced vasculitis include drug-induced ANCA vasculitis. Such patients commonly present with cutaneous manifestations but can develop the full range of symptoms associated with ANCA-associated vasculitis, including crescentic glomerulonephritis and alveolar hemorrhage. Propylthiouracil, methimazole, and hydralazine are common culprits. Drug-induced polyarteritis nodosa has been associated with long-term exposure to minocycline. The presence of perivascular eosinophils on skin biopsy can be a clue to possible drug etiology.

## MANAGEMENT OF THE PATIENT WITH SUSPECTED DRUG ERUPTION

There are four main questions to answer regarding a suspected drug eruption:

1. Is the observed rash caused by a medication?
2. Is the reaction severe or evolving with systemic involvement?
3. Which drug or drugs are suspected, and should they be withdrawn?
4. What recommendation can be made for future medication use?

### ■ EARLY DIAGNOSIS OF SEVERE ERUPTIONS

Rapid recognition of potentially serious or life-threatening reactions is paramount. In this regard, a suspected drug eruption is best defined initially by what it is not (e.g., SJS/TEN, DIHS). Table 60-2 lists clinical and laboratory features that, if present, suggest the presence of a severe reaction. Table 60-3 lists the most important of these reactions, along with their key features and commonly associated medications. Any concern for a serious reaction should prompt immediate consultation with a dermatologist and/or referral of the patient to a specialized center.

### ■ CONFIRMATION OF DRUG REACTION

The probability of drug etiology varies with the pattern of the reaction. Only fixed drug eruptions are always drug-induced. Morbilliform

eruptions are usually viral in children and drug-induced in adults. Among severe reactions, drugs account for 10–20% of anaphylaxis and vasculitis and between 70% and 90% of AGEP, DIHS, SJS, and TEN. Skin biopsy helps characterize the reaction but does not indicate drug causality. Blood counts and liver and renal function tests are important for evaluating organ involvement. The association of mild elevation of liver enzymes and high eosinophil count is frequent but not specific for a drug reaction. Blood tests that could identify an alternative cause, serologic tests (to rule out drug-induced lupus), and serology or polymerase chain reaction for infections may be of great importance to determine a cause.

### ■ WHAT DRUGS TO SUSPECT AND WITHDRAW

Most cases of drug eruptions occur during the first course of treatment with a new medication. A notable exception is IgE-mediated urticaria and anaphylaxis that need presensitization and develop a few minutes to a few hours after rechallenge. Characteristic timing of onset following drug administration is as follows: 4–14 days for morbilliform eruption, 2–4 days for AGEP, 5–28 days for SJS/TEN, and 14–48 days for DIHS. A drug chart, compiling information of all current and past medications/supplements and the timing of administration relative to the rash, is a key diagnostic tool for identifying the inciting drug. Medications introduced for the first time in the relevant time frame are prime suspects. Two other important elements to suspect causality at this stage are (1) previous experience with the drug (or related members of the same pharmacologic class) and (2) alternative etiologic candidates.

The decision to continue or discontinue any medication depends on the severity of the reaction, the severity of the primary disease undergoing treatment, the degree of suspicion of causality, and the feasibility of finding an alternative safer treatment. In any potentially fatal drug reaction, elimination of all possible suspect drugs or unnecessary medications should be immediately attempted. Some rashes may resolve when “treating through” a benign drug-related eruption. The decision to treat through an eruption should, however, remain the exception and withdrawal of every suspect drug the general rule. On the other hand, drugs that are not suspected and are important for the patient (e.g., antihypertensive agents) generally should not be quickly withdrawn. This approach may permit judicious use of these agents in the future.

### ■ RECOMMENDATION FOR FUTURE USE OF DRUGS

The aims are to (1) prevent the recurrence of the drug eruption and (2) avoid compromising future treatment by inaccurately excluding otherwise useful medications.

A thorough assessment of drug causality is based on timing of the reaction, evaluation of other possible causes, and effect of drug withdrawal or continuation. The RegiSCAR group has proposed the Algorithm of Drug Causality for Epidermal Necrolysis (ALDEN) to rank likelihood of drug causality in SJS/TEN; validation of this and other instruments, such as the Naranjo adverse drug reaction probability scale, is limited. Medication(s) with a “definite” or “probable” causality should be contraindicated, a warning card or medical alert tag (e.g., wristband) should be given to the patient, and the drugs should be listed in the patient’s medical chart as allergies.

### ■ CROSS SENSITIVITY

Because of possible cross-sensitivity among chemically related drugs, many physicians recommend avoidance of not only the medication that induced the reaction but also all drugs of the same pharmacologic class.

There are two types of cross-sensitivity. Reactions that depend on a pharmacologic interaction may occur with all drugs that target the same pathway, whether the drugs are structurally similar or not. This is the case with angioedema caused by NSAIDs and ACE inhibitors. In this situation, the risk of recurrence varies from drug to drug in a particular class; however, avoidance of all drugs in the class is usually recommended. Immune recognition of structurally related drugs is the second mechanism by which cross-sensitivity occurs. A classic example

TABLE 60-2 Clinical and Laboratory Findings Suggestive of Severe Cutaneous Adverse Drug Reaction

Cutaneous
Generalized erythema
Facial edema
Skin pain
Palpable purpura
Dusky or target-like lesions
Skin necrosis
Blisters or epidermal detachment
Positive Nikolsky sign
Mucous membrane erosions
Swelling of lips or tongue
General
High fever
Enlarged lymph nodes
Arthralgias or arthritis
Shortness of breath, hoarseness, wheezing, hypotension
Laboratory Results
Eosinophil count >1000/ $\mu$ L
Lymphocytosis with atypical lymphocytes
Abnormal liver or kidney function tests

Source: From JC Roujeau, RS Stern: Severe adverse cutaneous reactions to drugs. *N Engl J Med* 331:1272, 1994. Copyright © 1994 Massachusetts Medical Society. Reprinted with permission from Massachusetts Medical Society.

TABLE 60-3 Clinical Features of Severe Cutaneous Drug Reactions

DIAGNOSIS	MUCOSAL LESIONS	TYPICAL SKIN LESIONS	FREQUENT SIGNS AND SYMPTOMS	MOST COMMON CULPRIT DRUGS
Stevens-Johnson syndrome (SJS)	Erosions usually at two or more sites	Small blisters form from dusky macules or atypical targets; rare areas of confluence; detachment ≤10% body surface area	Most cases involve fever	Sulfonamides, anticonvulsants, allopurinol, nonsteroidal anti-inflammatory drugs (NSAIDs)
Toxic epidermal necrolysis (TEN) <sup>a</sup>	Erosions usually at two or more sites	Individual lesions like those seen in SJS; confluent dusky erythema; large sheets of necrotic epidermis; total detachment of >30% body surface area	Nearly all cases involve fever, "acute skin failure," leukopenia	Same as for SJS
Drug-induced hypersensitivity syndrome/drug rash with eosinophilia and systemic symptoms (DIHS/DRESS)	Mucositis reported in as many as 30%	Diffuse, deep red morbilliform eruption with facial involvement; facial and acral swelling	Fever, lymphadenopathy, hepatitis, nephritis, myocarditis, eosinophilia, atypical lymphocytosis	Anticonvulsants, sulfonamides, allopurinol, minocycline
Acute generalized exanthematous pustulosis (AGEP)	Oral erosions in perhaps 20%	Innumerable pinpoint pustules overlying a diffuse erythematous eruption; may develop superficial erosions	High fever, leukocytosis (neutrophilia), hypocalcemia	β-Lactam antibiotics, calcium channel blockers, macrolide antibiotics
Serum sickness or serum sickness-like reaction	Absent	Urticular serpiginous or polycyclic rash; purpuric eruption along the sides of the feet and hands is characteristic	Fever, arthralgias	Antithymocyte globulin, cephalosporins, monoclonal antibodies
Anticoagulant-induced necrosis	Infrequent	Purpura and necrosis, especially of central, fatty areas	Pain in affected areas	Warfarin, heparin
Angioedema	Often involved	Urticaria or swelling of the central face, other areas	Respiratory distress, cardiovascular collapse	Angiotensin-converting enzyme (ACE) inhibitors, NSAIDs, contrast dye

<sup>a</sup>Overlap of SJS and TEN have features of both, and attachment of 10–30% of body surface area may occur.

Source: From JC Roujeau, RS Stern: Severe adverse cutaneous reactions to drugs. N Engl J Med 331:1272, 1994. Copyright © 1994 Massachusetts Medical Society. Reprinted with permission from Massachusetts Medical Society.

is hypersensitivity to aromatic antiepileptics (barbiturates, phenytoin, carbamazepine) with up to 50% reaction to a second drug in patients who reacted to one. For other drugs, *in vitro* and *in vivo* data have suggested that cross-reactivity exists only between compounds with very similar chemical structures. Sulfamethoxazole-specific lymphocytes may be activated by other antibacterial sulfonamides but not diuretics, antidiabetic drugs, or anti-COX2 NSAIDs with a sulfonamide group. Though it has been previously reported that 10% of patients with penicillin allergies will also develop allergic reactions to cephalosporin class antibiotics, the cross-reactivity is likely much lower, as is the incidence of true penicillin allergy itself, and severe reactions are very rare.

Recent data suggest that although the risk of developing a drug eruption to another drug is increased in persons with a prior reaction, "cross-sensitivity" is probably not the explanation. As an example, those with a history of an allergic-like reaction to penicillin are at greater risk of developing a reaction to antibacterial sulfonamides than to cephalosporins.

These data suggest that the list of drugs to avoid after a drug reaction should be limited to the causative one(s) and to a few very similar medications.

Because of growing evidence that some severe cutaneous reactions to drugs are associated with HLA genes, it is recommended that first-degree family members of patients with severe cutaneous reactions also should avoid causative agents. This may be most relevant for sulfonamides and antiepileptic medications.

### ■ ROLE OF TESTING FOR CAUSALITY AND DRUG RECHALLENGE

The usefulness of laboratory tests, skin-prick, or patch testing to determine causality is debated and may be of limited practical value. Many *in vitro* immunologic assays have been developed for research purposes; however, the predictive value of these tests has not been validated in large series of affected patients. In some cases, diagnostic rechallenge may be appropriate, even for drugs with high rates of adverse reactions.

Skin-prick testing has clinical value in specific settings. In patients with a history suggesting immediate IgE-mediated reactions to penicillin, skin-prick testing with penicillins or cephalosporins has proven useful for identifying patients at risk of anaphylactic reactions to these

agents. Negative skin tests do not totally rule out IgE-mediated reactivity; however, the risk of anaphylaxis in response to penicillin administration in patients with negative skin tests is about 1%. In contrast, two-thirds of patients with a positive skin test experience an allergic response upon rechallenge. The skin tests themselves carry a small risk of anaphylaxis.

For patients with delayed-type hypersensitivity, the clinical utility of skin tests remains questionable. At least one of a combination of several tests (prick, patch, and intradermal) is positive in 50–70% of patients with a reaction "definitely" attributed to a single medication. This low sensitivity corresponds to the observation that readministration of drugs with negative skin testing results in eruptions in 17% of cases.

Desensitization can be considered in those with a history of reaction to a medication that must be used again. Efficacy of such procedures has been demonstrated in cases of immediate reaction to penicillin and positive skin tests, anaphylactic reactions to platinum chemotherapy, and delayed reactions to sulfonamides in patients with AIDS. Desensitization is often successful in HIV-infected patients with morbilliform eruptions to sulfonamides but is not recommended in HIV-infected patients who developed erythroderma or a bullous reaction in response to prior sulfonamide exposure. Various protocols are available, including oral and parenteral approaches. Oral desensitization appears to have a lower risk of serious anaphylactic reaction. Desensitization carries the risk of anaphylaxis regardless of how it is performed and should be performed in monitored clinical settings such as an intensive care unit. After desensitization, many patients experience non-life-threatening reactions during therapy with the culprit drug.

### ■ REPORTING

Any severe reaction to drugs should be reported to a regulatory agency or to pharmaceutical companies. Because severe reactions are too rare to be detected in premarketing clinical trials, spontaneous reports are of critical importance for early detection of unexpected life-threatening events. To be useful, the report should contain enough details to permit ascertainment of severity and drug causality.

A

We acknowledge the contribution of Drs. Jean-Claude Roujeau and Robert S. Stern to this chapter in previous editions.

## FURTHER READING

- A A et al: Genetic testing for prevention of severe drug-induced skin rash. *Cochrane Database Syst Rev* 7:CD010891, 2019.
- C -G JA et al: The genetics of drug hypersensitivity reactions. *J Investig Allergol Clin Immunol* 26:222, 2016.
- D TA et al: Severe cutaneous adverse reactions to drugs. *Lancet* 390:1996, 2017.
- K TM et al: Use of HLA-B 5801 genotyping to prevent allopurinol induced severe cutaneous adverse reactions in Taiwan: National prospective cohort study. *BMJ* 351:h4848, 2015.
- L S et al: Association of dipeptidyl peptidase 4 inhibitor use with risk of bullous pemphigoid in patients with diabetes. *JAMA Dermatol* 155:172, 2018.
- M C et al: In vitro tests for drug hypersensitivity reactions: An ENDA/EAACI Drug Allergy Interest Group position paper. *Allergy* 71:1103, 2016.
- O A et al: Genetic variants associated with drug-induced immediate hypersensitivity reactions: A PRISMA-compliant systematic review. *Allergy* 71:443, 2016.
- P JG et al: Severe delayed cutaneous and systemic reactions to drugs: A global perspective on the science and art of current practice. *J Allergy Clin Immunol Pract* 5:547, 2017.
- P F et al: Antibiotic prophylaxis for skin toxicity induced by antiepidermal growth factor receptor agents: A systematic review and meta-analysis. *Br J Dermatol* 175:1166, 2016.
- S B et al: ALDEN, an algorithm for assessment of drug causality in Stevens-Johnson syndrome and toxic epidermal necrolysis: Comparison with case-control analysis. *Clin Pharmacol Ther* 88:60, 2010.
- S -V L et al: Society of Dermatology Hospitalists supportive care guidelines for the management of Stevens-Johnson syndrome/toxic epidermal necrolysis in adults. *J Am Acad Dermatol* 82:1553, 2020.
- S A et al: Cutaneous adverse reactions to anti-PD-1 treatment: A systematic review. *J Am Acad Dermatol* 83:1415, 2020.
- Z S et al: Systemic immunomodulating therapies for Stevens-Johnson syndrome and toxic epidermal necrolysis: A systematic review and meta-analysis. *JAMA Dermatol* 153:514, 2017.

atmosphere has led to international agreements to reduce production of those chemicals.

Measurements of solar flux showed a 20-fold regional variation in the amount of energy at 300 nm that reaches the earth's surface. This variability relates to seasonal effects, the path that sunlight traverses through ozone and air, the altitude (a 4% increase for each 300 m of elevation), the latitude (increasing intensity with decreasing latitude), and the amount of cloud cover, fog, and pollution.

The major components of the photobiologic action spectrum that can affect human skin include the UV and visible wavelengths between 290 and 700 nm. In addition, the wavelengths beyond 700 nm in the infrared spectrum primarily emit heat and in certain circumstances may exacerbate the pathologic effects of energy in the UV and visible spectra.

The UV spectrum reaching the Earth represents <10% of total incident solar energy and is arbitrarily divided into two major segments, UV-B and UV-A, which constitute the wavelengths from 290 to 400 nm. UV-B consists of wavelengths between 290 and 320 nm. This portion of the photobiologic action spectrum is the most efficient in producing redness or erythema in human skin and thus is sometimes known as the "sunburn spectrum." UV-A includes wavelengths between 320 and 400 nm and is 1000-fold less efficient in producing skin redness than is UV-B.

The wavelengths between 400 and 700 nm are visible to the human eye. The photon energy in the visible spectrum is not capable of damaging human skin in the absence of a photosensitizing chemical. Without the absorption of energy by a molecule, there can be no photosensitivity. Thus, the *absorption spectrum* of a molecule is defined as the range of wavelengths it absorbs, whereas the *action spectrum* for an effect of incident radiation is defined as the range of wavelengths that evoke the response.

Photosensitivity occurs when a photon-absorbing chemical (*chromophore*) present in the skin absorbs incident energy, becomes excited, and transfers the absorbed energy to various structures or to molecular oxygen.

## UV RADIATION UVR AND SKIN STRUCTURE AND FUNCTION

Human skin consists of two major compartments: the outer epidermis, which is a stratified squamous epithelium, and the underlying dermis, which is rich in matrix proteins such as collagens and elastin. Both compartments are susceptible to damage from sun exposure. The epidermis and the dermis contain several chromophores capable of absorbing incident solar energy, including nucleic acids, proteins, and lipids. The outermost epidermal layer, the stratum corneum, is a major absorber of UV-B, and <10% of incident UV-B wavelengths penetrate through the epidermis to the dermis. Approximately 3% of radiation below 300 nm, 20% of radiation below 360 nm, and 33% of short visible radiation reach the basal cell layer in untanned human skin. UV-A readily penetrates to the dermis and is capable of altering structural and matrix proteins that contribute to photoaging of chronically sun-exposed skin, particularly in individuals of light complexion. Thus, longer wavelengths can penetrate more deeply into the skin.

**Molecular Targets for UVR-Induced Skin Effects** Epidermal DNA—predominantly in keratinocytes and in Langerhans cells (dendritic antigen-presenting cells)—absorbs UV-B and undergoes structural changes between adjacent pyrimidine bases (thymine or cytosine), including the formation of cyclobutane dimers and 6,4-photoproducts. These structural changes are potentially mutagenic and are found in nonmelanoma skin cancers (NMSCs), including basal cell carcinoma (BCC), squamous cell carcinoma (SCC), and Merkel cell carcinoma (MCC). They can be repaired by cellular mechanisms that result in their recognition and excision and the restoration of normal base sequences. The efficient repair of these structural aberrations is crucial, since individuals with defective DNA repair are at high risk for the development of cutaneous cancer. For example, patients with xeroderma pigmentosum, an autosomal recessive disorder, have a variably deficient repair of UV-induced photoproducts. The skin of

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## Photosensitivity and Other Reactions to Sunlight

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### SOLAR RADIATION

Sunlight is the most visible and obvious source of comfort in the environment. The sun provides the beneficial effects of warmth and vitamin D synthesis. However, acute and chronic sun exposure also has pathologic consequences. Cutaneous exposure to sunlight is a major cause of human skin cancer and can have immunosuppressive effects as well.

The sun's energy reaching the Earth's surface is limited to components of the ultraviolet (UV) spectrum, the visible spectrum, and portions of the infrared spectrum. The cutoff at the short end of the UV spectrum at 290 nm is due primarily to stratospheric ozone—formed by highly energetic ionizing radiation—that prevents penetration to the earth's surface of the shorter, more energetic, potentially more harmful wavelengths of solar radiation. Indeed, concern about destruction of the ozone layer by chlorofluorocarbons released into the

these patients often shows the dry, leathery appearance of prematurely photoaged skin, and these patients have an increased frequency of skin cancer already in the first two decades of life. Studies in transgenic mice have verified the importance of functional genes that regulate these repair pathways in preventing the development of UV-induced skin cancer. DNA damage to Langerhans cells may also contribute to the known immunosuppressive effects of UV-B (see ‘Photoimmunology’ later).

In addition to DNA, molecular oxygen is a target for incident solar UVR, leading to the generation of reactive oxygen species (ROS). These ROS can damage skin components through oxidative damage to DNA, oxidation of polyunsaturated fatty acids in lipids (lipid peroxidation), or oxidation of amino acids in proteins, or they can lead to oxidative deactivation of specific enzymes. UVR can also promote increased cross-linking and degradation of dermal matrix proteins and accumulation of abnormal dermal elastin, leading to photoaging changes known as *solar elastosis*.

**Cutaneous Optics and Chromophores** *Chromophores* are endogenous or exogenous chemicals that can absorb physical energy. Endogenous chromophores are of two types: (1) normal components of skin, including nucleic acids, proteins, lipids, and 7-dehydrocholesterol (the precursor of vitamin D); and (2) components that are synthesized elsewhere in the body and that circulate in the bloodstream and diffuse into the skin, such as porphyrins. Normally, only trace amounts of porphyrins are present in the skin, but, in selected diseases known as the *porphyrias* (Chap. 416), porphyrins are released into the circulation in increased amounts from the bone marrow and/or the liver and are transported to the skin, where they absorb incident energy both in the Soret band (400 nm; short visible) and, to a lesser extent, in the red portion of the visible spectrum (580–660 nm). This energy absorption results in the generation of ROS that can mediate structural damage to the skin, manifested as erythema, edema, urticaria, or blister formation. It is of interest that photoexcited porphyrins are currently used in the treatment of BCCs and SCCs and their precursor lesions, actinic keratoses. Known as *photodynamic therapy* (PDT), this modality generates ROS in the skin, leading to cell death. Topical photosensitizers used in PDT are the porphyrin precursors 5-aminolevulinic acid and methyl aminolevulinate, which are readily converted to porphyrins in the skin. It is believed that PDT targets tumor cells for destruction more selectively than it targets adjacent nonneoplastic cells. The efficacy of such therapy requires appropriate timing of the application of methyl aminolevulinate or 5-aminolevulinic acid to the affected skin followed by exposure to artificial sources of visible light. High-intensity blue light has been used successfully for PDT of thin actinic keratoses. Red light PDT penetrates more deeply into the skin and is more beneficial in the treatment of superficial BCCs.

**Acute Effects of Sun Exposure** The acute effects of skin exposure to sunlight include sunburn and vitamin D synthesis.

**SUNBURN** This painful skin condition is an acute inflammatory response of the skin, predominantly to UV-B. Generally, an individual’s ability to tolerate sunlight is inversely proportional to that individual’s degree of melanin pigmentation. Melanin, a complex polymer of tyrosine derivatives, is synthesized in specialized epidermal dendritic cells known as *melanocytes* and is packaged into *melanosomes* that are transferred via dendritic processes into *keratinocytes*, thereby providing photoprotection (dissipating the vast majority of absorbed UVR in the skin) and simultaneously darkening the skin. Sun-induced melanogenesis is a consequence of increased tyrosinase activity in melanocytes. Central to the suntan response is the melanocortin-1 receptor (*MC1R*), and mutations in this gene contribute to the wide variation in human skin and hair color; individuals with red hair and fair skin typically have low *MC1R* activity. In the skin, there are two main types of melanin: eumelanin (providing brown and black pigmentation associated with high *MC1R* activity) and pheomelanin (providing red pigmentation associated with low *MC1R* activity). Pheomelanin is a cysteine-containing red polymer of benzothiazine units and has much weaker shielding capacity against UVR compared to eumelanin. This

may explain why individuals with a higher proportion of pheomelanin (red hair/fair skin appearance) have an increased risk of melanoma formation. In addition, pheomelanin may also promote melanoma formation through induction of oxidative damage by amplifying UV-A-induced ROS but also through UVR-independent mechanisms.

The human *MC1R* gene encodes a G protein-coupled receptor that binds  $\alpha$ -melanocyte-stimulating hormone ( $\alpha$ -MSH), which is secreted in the skin mainly by keratinocytes in response to UVR. The UV-induced expression of this hormone is controlled by the tumor suppressor p53, and absence of functional p53 attenuates the tanning response. Activation of the melanocortin receptor leads to increased intracellular cyclic adenosine 5'-monophosphate (cAMP) and protein kinase A activation, resulting in an increased transcription of the microphthalmia-associated transcription factor (MITF), which stimulates melanogenesis. Since the precursor of  $\alpha$ -MSH, proopiomelanocortin produced by keratinocytes, is also the precursor of  $\beta$ -endorphins, UVR may result in not only increased pigmentation but also increased  $\beta$ -endorphin production in the skin, an effect that has been hypothesized to promote sun-seeking behaviors and even mediate addiction to tanning.

The Fitzpatrick classification of human skin phototypes is based on the efficiency of the epidermal-melanin unit, which usually can be ascertained by asking an individual two questions: (1) Do you burn after sun exposure? (2) Do you tan after sun exposure? The answers to these questions permit division of the population into six skin types, varying from type I (always burn, never tan) to type VI (never burn, always tan) (Table 61-1).

Sunburn erythema is due to vasodilation of dermal blood vessels. There is a lag time (usually 4–12 h) between skin exposure to sunlight and the development of visible redness. The action spectrum for sunburn erythema includes UV-B and UV-A, although UV-B is much more efficient than UV-A in evoking the response. However, UV-A may contribute to sunburn erythema at midday, when much more UV-A than UV-B is present in the solar spectrum. The erythema that accompanies the inflammatory response induced by UVR results from the orchestrated release of cytokines along with growth factors and the generation of ROS. Furthermore, UV-induced activation of nuclear factor  $\kappa$ B-dependent gene transcription can augment release of several proinflammatory cytokines and vasoactive mediators. These cytokines and mediators accumulate locally in sunburned skin, providing chemotactic factors that attract neutrophils, macrophages, and T lymphocytes, which promote the inflammatory response. UVR also stimulates infiltration of inflammatory cells through induced expression of adhesion molecules such as E-selectin and intercellular adhesion molecule 1 on endothelial cells and keratinocytes. UVR has been shown to activate phospholipase A<sub>2</sub>, resulting in increases in eicosanoids such as prostaglandin E<sub>2</sub>, which is known to be a potent inducer of sunburn erythema. The role of eicosanoids in this reaction has been verified by studies showing that nonsteroidal anti-inflammatory drugs (NSAIDs) can reduce sunburn erythema.

Epidermal changes in sunburn include the induction of “sunburn cells,” which are keratinocytes undergoing p53-dependent apoptosis as a defense, with elimination of cells that harbor UV-B-induced structural DNA damage.

**VITAMIN D SYNTHESIS AND PHOTOCHEMISTRY** Cutaneous exposure to UV-B causes photolysis of epidermal 7-dehydrocholesterol,

TABLE 61-1 Skin Type and Sunburn Sensitivity (Fitzpatrick Classification)

TYPE	DESCRIPTION
I	Always burn, never tan
II	Always burn, sometimes tan
III	Sometimes burn, sometimes tan
IV	Sometimes burn, always tan
V	Never burn, sometimes tan
VI	Never burn, always tan

converting it to pre-vitamin D<sub>3</sub>, which then undergoes temperature-dependent isomerization to form the stable hormone vitamin D<sub>3</sub>. This compound diffuses to the dermal vasculature and circulates to the liver and kidney, where it is converted to the dihydroxylated functional hormone 1,25-dihydroxyvitamin D<sub>3</sub>. Vitamin D metabolites from the circulation and those produced in the skin itself can augment epidermal differentiation signaling and inhibit keratinocyte proliferation. These effects are exploited therapeutically in psoriasis with the topical application of synthetic vitamin D analogues. In addition, vitamin D is increasingly thought to have beneficial effects in several other inflammatory conditions, and some evidence suggests that—besides its classic physiologic effects on calcium metabolism and bone homeostasis—it is associated with a reduced risk of various internal malignancies. There is controversy regarding the risk-to-benefit ratio of sun exposure for vitamin D homeostasis. At present, it is important to emphasize that no clear-cut evidence suggests that the use of sunscreens substantially diminishes vitamin D levels. Since aging also substantially decreases the ability of human skin to photocatalytically produce vitamin D<sub>3</sub>, the widespread use of sunscreens that filter out UV-B has led to concerns that the elderly might be unduly susceptible to vitamin D deficiency. However, the amount of sunlight needed to produce sufficient vitamin D is small and does not justify the risks of skin cancer and other types of photodamage linked to increased sun exposure or tanning behavior. Nutritional supplementation of vitamin D is a preferable strategy for patients with vitamin D deficiency.

**Chronic Effects of Sun Exposure: Nonmalignant** The clinical features of photoaging (*dermatoheliosis*) consist of wrinkling, blotchiness, and telangiectasia, as well as a roughened, irregular, “weather-beaten” leathery appearance.

UVR is important in the pathogenesis of photoaging in human skin, and ROS are likely involved. The dermis and its connective tissue matrix are major targets for sun-associated chronic damage that manifests as solar elastosis, a massive increase in thickened irregular masses of abnormal-appearing elastic fibers. Collagen fibers are also abnormally clumped in the deeper dermis of sun-damaged skin. The chromophores, the action spectra, and the specific biochemical events orchestrating these changes are only partially understood, although more deeply penetrating UV-A seems to be primarily involved. Chronologically aged sun-protected skin and photoaged skin share important molecular features, including connective tissue damage and elevated levels of matrix metalloproteinases (MMPs). MMPs are enzymes involved in the degradation of the extracellular matrix. UV-A induces expression of some MMPs, including MMP-1 and MMP-3, leading to increased collagen breakdown. In addition, UV-A reduces type I procollagen messenger RNA (mRNA) expression. Thus, chronic UVR alters the structure and function of dermal collagen both by inhibiting its synthesis and enhancing its breakdown. Based on these observations, it is not surprising that high-dose UV-A phototherapy may have beneficial effects in some patients with localized fibrotic diseases of the skin, such as localized scleroderma.

**Chronic Effects of Sun Exposure: Malignant** One of the major known consequences of chronic excessive skin exposure to sunlight is NMSC, including SCCs, BCCs and MCCs (Chap. 76). A model for skin cancer induction involves three major steps: initiation, promotion, and progression. Exposure of human skin to sunlight results in *initiation*, a step by which structural (mutagenic) changes in DNA evoke an irreversible alteration in the target cell (keratinocyte) that begins the tumorigenic process. Exposure to a tumor initiator such as UV-B is believed to be a necessary but not a sufficient step in the malignant process, since initiated skin cells not exposed to tumor promoters generally do not develop into tumors. The second stage in tumor development is *promotion*, a multistep process by which chronic exposure to sunlight evokes further changes that culminate in the clonal expansion of initiated cells and cause the development of premalignant growths known as *actinic keratoses*, which may progress to form SCCs. As a result of extensive studies, it seems clear that UV-B is a *complete carcinogen*, meaning that it can act as both a tumor initiator and a tumor promoter. The third and final step in the malignant

process is *malignant conversion* of benign precursors into cancers, a process thought to enhance genetic instability.

On a molecular level, skin carcinogenesis results from the accumulation of gene mutations that cause inactivation of tumor suppressors, activation of oncogenes, or reactivation of cellular signaling pathways that normally are expressed only during embryologic epidermal development that drive cell proliferation. Interestingly, a large number of UV-induced oncogenic driver mutations that are present in SCCs can already be found in aged sun-exposed normal skin, leading to a growth advantage and innumerable precancerous clones carrying cancer-causing mutations. These mutations occur particularly often in genes that affect proliferation of epidermal stem cells (e.g., NOTCH receptor genes). The pattern of oncogenic gene mutations in aged sun-exposed skin shows considerable overlap with the mutations identified in SCCs, while there is little overlap with the mutations identified in BCCs or melanomas. For example, 20% of normal aged sun-exposed skin cells and 60% of SCCs carry driver mutations in *NOTCH1*. Additionally, the accumulation of mutations in the tumor-suppressor gene *p53* can also promote skin carcinogenesis. Indeed, the majority of both human and murine UV-induced skin cancers have characteristic UVR-induced *p53* mutations (C → T and CC → TT transitions). Studies in mice have shown that sunscreens can substantially reduce the frequency of these signature mutations in *p53* and inhibit the induction of tumors. The comparison of UVR-induced gene mutations between aged sun-exposed normal skin and SCCs supports the hypothesis of a progressive accumulation of additional oncogenic mutations that eventually lead to the transition from precancerous cell clones to SCCs. It has been estimated that SCCs harbor 10 times more oncogenic driver mutations per cell than cells in aged sun-exposed normal skin. Furthermore, while aged sun-exposed skin and SCCs carry similar UVR-induced mutations in *p53* or NOTCH receptors, oncogenic mutations in other genes (e.g., *CDKN2A*) were mainly found in SCCs and not in aged sun-exposed skin, which are thus likely to play a critical role in malignant progression.

Compared to SCCs, BCCs carry a distinct mutational profile in specific genes. BCCs harbor inactivating mutations particularly in the tumor-suppressor gene *patched* or activating mutations in the oncogene *smoothed*, which result in the constitutive activation of the sonic hedgehog signaling pathway and increased cell proliferation. There is also evidence linking alterations in the Wnt/β-catenin signaling pathway, which is known to be critical for hair follicle development, to skin cancer as well. Thus, interactions between this pathway and the hedgehog signaling pathway appear to be involved in both skin carcinogenesis and embryologic development of the skin and hair follicles.

Clonal analysis in mouse models of BCC revealed that tumor cells arise from stem cells of the interfollicular epidermis and the upper infundibulum of the hair follicle. These BCC-initiating cells are reprogrammed to resemble embryonic hair follicle progenitors, whose tumor-initiating ability depends on activation of the Wnt/β-catenin signaling pathway.

SCC initiation occurs both in the interfollicular epidermis and in the hair follicle bulge stem cell populations. In mouse models, the combination of mutant K-Ras and p53 is sufficient to induce invasive SCCs from these cell populations.

The transcription factor Myc is important for stem cell maintenance in the skin, and oncogenic activation of Myc has been implicated in the development of BCCs and SCCs.

The third NMSC is MCC, which is named after its resemblance to Merkel cells in the skin. The incidence of MCCs has been increasing in recent years for unknown reasons. The age-adjusted global incidence is about 1 in 100,000. Just like SCC and BCC, patients with MCCs are usually fair-skinned males in the sixth to eighth decades of life who are living in geographic regions with greater solar UVR. These tumors occur predominantly on the head and neck in older individuals and on the trunk in younger people. MCCs also have a higher incidence among immunosuppressed patients. MCCs are aggressive and life-threatening, poorly differentiated neuroendocrine carcinomas. Overall survival at 5 years is around 50% for local disease, 35% for nodal disease, and 15% for metastatic disease. While the majority of MCCs present

locally, nodal and metastatic disease can occur simultaneously. The pathogenesis of MCCs is closely connected to the Merkel cell polyoma virus (MCPyV). It is now recognized that MCCs can either be MCPyV positive or MCPyV negative. MCPyV-negative MCCs manifest high levels of classic UV-induced signature mutations (C to T or CC to TT) and inactivation of tumor suppressor genes, which could explain the growth of these viral-negative lesions. MCPyV-positive tumors are thought to grow secondary to viral integration into the host genome and acquisition of a truncating mutation of the large T antigen that results in the production of viral oncoproteins. The growth of MCPyV-positive tumors may be further promoted by UVR-induced local immunosuppression. Both forms of MCC are immunogenic, and metastatic MCC has been treated in some patients successfully with PD-1/PD-L1 immune checkpoint inhibitors.

In summary, NMSC involves mutations and alterations in multiple genes and pathways that occur as a result of their chronic accumulation driven by exposure to environmental factors such as solar UVR.

Epidemiologic studies have linked excessive sun exposure to an increased risk of NMSCs and melanoma of the skin; the evidence is far more direct for NMSCs (BCCs, SCCs, and MCCs) than for melanoma. Approximately 80% of NMSCs develop on sun-exposed body areas, including the face, neck, and hands. Major risk factors include male sex, childhood sun exposures, older age, fair skin, and residence at latitudes relatively close to the equator. Individuals with darker-pigmented skin have a lower risk of skin cancer than do fair-skinned individuals. More than 2 million individuals in the United States develop NMSC annually, and the lifetime risk that a fair-skinned individual will develop such a neoplasm is estimated at 15%. The incidence of NMSC in the population is increasing at a rate of 2–3% per year, likely due to earlier detection and increased opportunities for outdoor activities.

The relationship of sun exposure to melanoma development is less direct, but strong evidence supports an association. Clear-cut risk factors include a positive family or personal history of melanoma and multiple dysplastic nevi. Melanomas can occur during adolescence; the implication is that the latent period for tumor growth is shorter than that for NMSC. For reasons that are only partially understood, melanomas are among the most rapidly increasing human malignancies (Chap. 76). One potential explanation is the widespread use of indoor tanning. It is estimated that 30 million people tanindoors in the United States annually, including >2 million adolescents. Furthermore, epidemiologic studies suggest that life in a sunny climate from birth or early childhood may increase the risk of melanoma development. In general, risk does not correlate with cumulative sun exposure but may be related to the duration and extent of exposure in childhood.

However, in contrast to NMSCs, melanoma frequently develops in non-sun-exposed skin, and oncogenic mutations in melanoma may also not be UVR-signature mutations. These observations suggest that UVR-independent factors may contribute to melanomagenesis, which is consistent with findings in mouse models showing that pheomelanin is less efficient in protecting against melanoma than is eumelanin and may promote melanoma through UVR-independent mechanisms.

Importantly, mutations in BRAF and NRAS that lead to activation of a growth-promoting signaling cascade are frequently found in melanoma (but not in SCCs or BCCs), which has led to the development of specific inhibitors of this pathway for the treatment of BRAF-mutant melanoma. However, a high mutational load in melanoma may not be equated with a more unfavorable prognosis. Tumor-specific missense mutations in melanomas can result in neoantigens that facilitate an immune response to the tumor cell. A major advance in treating melanoma, termed immune checkpoint blockade, targets inhibitors of cytotoxic T effector function. For example, the PD-1/PD-L1 interaction inhibits tumor cell apoptosis, promotes peripheral T effector cell exhaustion, and induces conversion of T effector cells to regulatory T cells. Checkpoint inhibitor treatment (e.g., with antibodies that inhibit PD-1 or PD-L1) disrupts this interaction and has resulted in a durable and potent immune destruction of melanoma cells in a subset of patients, leading to prolonged survival of patients with locally advanced or metastatic melanoma. It has recently been shown that a high mutational load in melanomas correlates with improved

therapeutic outcome to immune checkpoint blockade, consistent with the hypothesis that acquired missense mutations in the tumor cells lead to neoantigens that increase the vulnerability of these melanoma cells to attack by activated T cells.

**GLOBAL CONSIDERATIONS** The frequency of skin cancer shows strong geographic variation, depending on the skin phototype of the majority of the population in these geographic areas, but also depending on the intensity of UVR. For example, both melanoma and NMSCs are particularly common in Australia.

**Photoimmunology** Exposure to solar radiation causes both local and systemic immunosuppression and involves both the innate and adaptive immune systems. Local immunosuppression is defined as inhibition of immune responses to antigens applied at the irradiated site, whereas systemic immunosuppression is defined as inhibition of immune responses to antigens applied at remote, unirradiated sites. An example of local immunosuppression is that human skin exposure to modest doses of UV-B can deplete the epidermal antigen-presenting Langerhans cells, thereby reducing the degree of allergic sensitization to topical application of the potent contact allergen dinitrochlorobenzene at the irradiated skin site. An example of the systemic immunosuppressive effects of higher doses of UVR is the diminished immunologic response to antigens introduced either epicutaneously or intracutaneously at sites remote from the irradiated site.

The major chromophores in the upper epidermis that are known to initiate UV-mediated immunosuppression include DNA, *trans*-urocanic acid, and membrane components. The action spectrum for UV-induced immunosuppression closely mimics the absorption spectrum of DNA. UVR-induced cyclobutane pyrimidine dimers in Langerhans cells may inhibit antigen presentation. The absorption spectrum of epidermal urocanic acid closely mimics the action spectrum for UV-B-induced immunosuppression. Urocanic acid is a metabolic product of the essential amino acid histidine and accumulates in the upper epidermis through breakdown of the histidine-rich protein filaggrin due to the absence of its catabolizing enzyme in keratinocytes. Urocanic acid is synthesized as a *trans*-isomer, and UV-induced *trans-cis* isomerization of urocanic acid in the stratum corneum drives immunosuppression. *Cis*-urocanic acid may exert its immunosuppressive effects through a variety of mechanisms, including inhibition of antigen presentation by Langerhans cells.

Various additional immunomodulatory factors and cytokines have been implicated in UVR-induced systemic immunosuppression, including tumor necrosis factor- $\alpha$ , interleukin 4 (IL-4), interleukin 10 (IL-10), and eicosanoids. Keratinocytes can release multiple immunomodulators as a response to UVR-induced cell damage that result in an immunosuppressive environment. Induction of IL-4-producing natural killer T cells and of regulatory T cells and B cells has been linked to cell-mediated and humoral immunosuppression as a consequence of UVR damage to skin. Moreover, UVR-induced formation of damage-associated molecular patterns (DAMPs) from necrotic keratinocytes can lead to a type I interferon innate immune response via activation of Toll-like receptor signaling.

One important consequence of chronic sun exposure and associated immunosuppression is an enhanced risk of skin cancer. In part, UV-B activates regulatory T cells that suppress antitumor immune responses via IL-10 expression, whereas in the absence of high UV-B exposure, epidermal Langerhans cells present tumor-associated antigens and induce protective immunity, thereby inhibiting skin tumorigenesis. UV-induced DNA damage is a major molecular trigger of this immunosuppressive effect.

Perhaps the most graphic demonstration of the role of long-term immunosuppression in enhancing the risk of NMSC comes from studies of organ transplant recipients who require lifelong immunosuppressive/antirejection drug regimens. More than 50% of organ transplant recipients develop BCCs and SCCs, and these skin cancers are the most common types of malignancies arising in these patients. The important contributory role of UVR for the formation of these skin cancers in immunosuppressed individuals is highlighted by the observation that nonwhite transplant recipients develop these skin cancers far less

often than white transplant recipients. Rates of BCC and SCC increase with the duration and degree of immunosuppression. Transplant recipients ideally should be screened prior to organ transplantation, be monitored closely thereafter, and adhere to rigorous photoprotection measures, including the use of sunscreens and protective clothing as well as sun avoidance. Notably, immunosuppressive drugs that target the mTOR pathway, such as sirolimus and everolimus, may reduce the risk of NMSC in organ transplant recipients compared to that associated with the use of calcineurin inhibitors (cyclosporine and tacrolimus). The latter may contribute to NMSC formation not only through their immunosuppressive effects but also through suppression of p53-dependent cancer cell senescence pathways independent of host immunity.

Whereas the immunosuppressive effects of UVR contribute to skin cancer, UVR can also exacerbate autoimmune and inflammatory diseases of the skin, including systemic lupus erythematosus (SLE). It has been proposed that in SLE UVR-induced damage to DNA may promote autoantibody formation.

### ■ PHOTOSENSITIVITY DISEASES

The diagnosis of photosensitivity requires elicitation of a careful history to define the duration of signs and symptoms, the length of time between exposure to sunlight and the development of subjective symptoms and visible changes in the skin. The age of onset can also be a helpful diagnostic clue. For example, the acute photosensitivity of erythropoietic protoporphyrina (EPP) almost always begins in infancy or early childhood, whereas the chronic photosensitivity of porphyria cutanea tarda (PCT) typically begins in the fourth and fifth decades of life. A patient's history of exposure to topical and systemic drugs and chemicals may provide important diagnostic clues. Many classes of drugs can cause photosensitivity on the basis of either phototoxicity or photoallergy.

Examination of the skin may offer important clues. Anatomic areas that are naturally protected from direct sunlight, such as the hairy scalp, the upper eyelids, the retroauricular areas, and the infranasal and submental regions, may be spared, whereas exposed areas show characteristic features of the pathologic process. These anatomic localization patterns are often helpful, but not infallible, in making the diagnosis. For example, airborne contact sensitizers that are blown onto the skin may produce dermatitis that can be difficult to distinguish from photosensitivity despite the fact that such material may trigger skin reactivity in areas shielded from direct sunlight.

Many dermatologic conditions may be caused or aggravated by sunlight (Table 61-2). The role of light in evoking these responses may be dependent on genetic abnormalities ranging from well-described defects in DNA repair that occur in xeroderma pigmentosum to the inherited abnormalities in heme synthesis that characterize the porphyrias.

**Polymorphous Light Eruption** The most common type of photosensitivity disease is *polymorphous light eruption* (PMLE). Many affected individuals may never seek medical attention because the condition is often transient, becoming manifest in the spring with initial sun exposure but then subsiding spontaneously with continuing exposure, a phenomenon known as "hardening." The major manifestations of PMLE include (often intensely) pruritic erythematous papules that may coalesce into plaques in a patchy distribution on exposed areas of the trunk and forearms. The face is usually less affected. Whereas the morphologic skin findings remain similar for each patient with subsequent recurrences, significant interindividual variations in skin findings are characteristic (hence the term *polymorphous*).

A skin biopsy and phototest procedures in which skin is exposed to multiple erythema doses of UV-A and UV-B may aid in the diagnosis. The action spectrum for PMLE is usually within these portions of the solar spectrum.

Whereas the treatment of an acute flare of PMLE may require topical or systemic glucocorticoids, approaches to preventing PMLE are important and include the use of high-SPF broad-spectrum sunscreens as well as the induction of "hardening" by the cautious administration

TABLE 61-2 Classification of Photosensitivity Diseases

TYPE	DISEASE
Genetic	Erythropoietic porphyria Erythropoietic protoporphyrina Porphyria cutanea tarda—familial Variegate porphyria Hepatoerythropoietic porphyria Albinism Xeroderma pigmentosum Rothmund-Thomson syndrome Bloom syndrome Cockayne syndrome Kindler syndrome Phenylketonuria
Metabolic	Porphyria cutanea tarda—sporadic Hartnup disease Kwashiorkor Pellagra Carcinoid syndrome
Phototoxic	
Internal	Drugs
External	Drugs, plants, food
Photoallergic	
Immediate	Solar urticaria
Delayed	Drug photoallergy Persistent light reaction/chronic actinic dermatitis
Neoplastic and degenerative	Photoaging Actinic keratosis Melanoma and nonmelanoma skin cancer
Idiopathic	Polymorphous light eruption Hydroa aestivale Actinic prurigo
Photoaggravated	Lupus erythematosus Systemic Subacute cutaneous Discoid Dermatomyositis Herpes simplex Lichen planus actinicus Acne vulgaris (aestivale)

of artificial UV-B (broad-band or narrow-band) and/or UV-A radiation or the use of psoralen plus UV-A (PUVA) photochemotherapy for 4 weeks before initial sun exposure. Such prophylactic phototherapy or photochemotherapy at the beginning of spring may prevent the occurrence of PMLE throughout the summer.

*Actinic prurigo* is a photo-induced pruritic eruption that shares similarities with PMLE and often occurs in the spring; however, it can persist throughout the summer and extend into the winter months.

**Phototoxicity and Photoallergy** These photosensitivity disorders are related to the topical or systemic administration of drugs and other chemicals that can act as chromophores. Both reactions require the absorption of energy by a drug or chemical with consequent production of an excited-state photosensitizer that can transfer its absorbed energy to a bystander molecule or to molecular oxygen, thereby generating tissue-destructive chemical species, including ROS.

*Phototoxicity* is a nonimmunologic reaction that can be caused by a broad range of drugs and chemicals, some of which are listed in Table 61-3. The usual clinical manifestations include erythema

TABLE 61-3 Drugs That May Cause a Phototoxic Reaction

DRUG	TOPICAL	SYSTEMIC
Amiodarone		+
Dacarbazine		+
Fluoroquinolones		+
5-Fluorouracil	+	+
Furosemide		+
Nalidixic acid		+
Phenothiazines		+
Psoralens	+	+
Retinoids	+/-	+
Sulfonamides		+
Sulfonylureas		+
Tetracyclines		+
Thiazides		+
Vinblastine		+

resembling a sunburn reaction that quickly desquamates, or “peels,” within several days. In addition, edema, vesicles, and bullae may occur. A common phototoxic reaction that occurs after contact with plant-derived furocoumarins and exposure to UV-A radiation is called phytophotodermatitis.

*Photoallergy* is much less common and is distinct in that it is an immunopathologic process. The excited-state photosensitizer may create highly unstable haptic free radicals that bind covalently to macromolecules to form a functional antigen (photoallergen) capable of evoking a delayed-type hypersensitivity response. Most photoallergic reactions are initiated by UV-A rather than UV-B exposure. Some drugs and chemicals that can produce photoallergy are listed in Table 61-4. The clinical manifestations typically differ from those of phototoxicity in that an intensely pruritic eczematous dermatitis tends to predominate and evolves into lichenified, thickened, “leathery” changes in sun-exposed areas. A small subset (perhaps 5–10%) of patients with photoallergy may develop a persistent exquisite hypersensitivity to light even when the offending drug or chemical is identified and eliminated, a condition known as *persistent light reaction*.

An uncommon type of persistent photosensitivity is known as *chronic actinic dermatitis*. The affected patients are typically elderly men with a long history of preexisting allergic contact dermatitis or photosensitivity. Common photoallergens associated with this condition are sunscreen ingredients and plant photoallergens. These individuals are usually exquisitely sensitive to UV-B, UV-A, and visible wavelengths.

Phototoxicity and photoallergy often can be diagnostically confirmed by phototest procedures. In patients with suspected phototoxicity,

determining the minimal erythema dose (MED) while the patient is exposed to a suspected agent and then repeating the MED after discontinuation of the agent may provide a clue to the causative drug or chemical. Photopatch testing can be performed to confirm the diagnosis of photoallergy. In this simple variant of ordinary patch testing, a series of known photoallergens is applied to the skin in duplicate, and one set is irradiated with a suberythema dose of UV-A. The development of eczematous changes at sites exposed to sensitizer and light is a positive result. The characteristic abnormality in patients with persistent light reaction is a diminished threshold to erythema evoked by UV-B. Patients with chronic actinic dermatitis usually manifest a broad spectrum of UV hyperresponsiveness and require meticulous photoprotection, including avoidance of sun exposure, use of high-SPF (>30) sunscreens, and, in severe cases, systemic immunosuppression, such as with azathioprine.

The management of drug photosensitivity involves first and foremost the elimination of exposure to the chemical agents responsible for the reaction and the minimization of sun exposure. The acute symptoms of phototoxicity may be ameliorated by cool moist compresses, topical glucocorticoids, and systemically administered NSAIDs. In severely affected individuals, a tapered course of systemic glucocorticoids may be useful. Judicious use of analgesics may be necessary.

Photoallergic reactions require a similar management approach. Furthermore, patients with persistent light reaction and chronic actinic dermatitis must be meticulously protected against light exposure. In selected patients to whom chronic systemic high-dose glucocorticoids pose unacceptable risks, it may be necessary to employ an immunosuppressive drug such as azathioprine, cyclophosphamide, cyclosporine, or mycophenolate mofetil.

**Porphyria** The porphyrias (Chap. 416) are a group of diseases that have in common inherited or acquired derangements in the synthesis of heme. Heme is an iron-chelated tetrapyrrole or porphyrin, and only the nonmetal chelated porphyrins are potent photosensitizers that absorb light intensely in both the short (400–410 nm) and the long (580–650 nm) portions of the visible spectrum.

Heme cannot be reutilized and must be synthesized continuously. The two body compartments with the largest capacity for its production are the bone marrow and the liver. Accordingly, the porphyrias originate in one or the other of these organs, with an end result of excessive endogenous production of potent photosensitizing porphyrins. The porphyrins circulate in the bloodstream and diffuse into the skin, where they absorb solar energy, become photoexcited, generate ROS, and evoke cutaneous photosensitivity. The mechanism of porphyrin photosensitization is known to be photodynamic, or oxygen-dependent, and is mediated by ROS such as singlet oxygen and superoxide anions.

The group of cutaneous porphyrias can be classified as causing either (1) chronic blistering photosensitivity or (2) acute nonblistering photosensitivity. Chronic cutaneous porphyrias include PCT, congenital erythropoietic porphyria (CEP), hepatoerythropoietic porphyria (HEP), hereditary coproporphyria (HCP), and variegate porphyria (VP). CEP, HEP, and PCT manifest only with cutaneous symptoms, while HCP and VP have acute neurovisceral symptoms in addition to the skin photosensitivity. Acute cutaneous nonblistering porphyrias include EPP and X-linked protoporphyrina (XLP). Representative examples of chronic and acute cutaneous porphyrias are discussed below.

*Porphyria cutanea tarda* (PCT) is the most common type of porphyria and is associated with decreased activity of the heme pathway enzyme uroporphyrinogen decarboxylase (UROD) to <20% of normal. Increased iron and various acquired factors (e.g., alcohol consumption, estrogens, smoking, hepatitis C or HIV infection) can reduce UROD activity. There are two basic types of PCT: (1) the sporadic or acquired type, generally seen in individuals ingesting ethanol or receiving estrogens; and (2) the inherited type, in which there is autosomal dominant transmission of deficient enzyme activity (resulting in heterozygosity for UROD with a reduction to 50% of UROD enzymatic activity and, thus, predisposing the individual to PCT). Both forms are associated with increased hepatic iron stores.

TABLE 61-4 Drugs That May Cause a Photoallergic Reaction

DRUG	TOPICAL	SYSTEMIC
6-Methylcoumarin	+	
Aminobenzoic acid and esters	+	
Bithionol	+	
Chlorpromazine		+
Diclofenac		+
Fluoroquinolones		+
Halogenated salicylanilides	+	
Hypericin (St. John's wort)	+	+
Musk ambrette	+	
Piroxicam		+
Promethazine		+
Sulfonamides		+
Sulfonylureas		+

In both types of PCT, the predominant feature is chronic photosensitivity characterized by increased fragility of sun-exposed skin, particularly areas subject to repeated trauma such as the dorsa of the hands, the forearms, the face, and the ears. The predominant skin lesions are vesicles and bullae that rupture, producing moist erosions (often with a hemorrhagic base) that heal slowly, with crusting and purplish discoloration of the affected skin. Hypertrichosis, mottled pigmentary change, and scleroderma-like induration are associated features. The diagnosis can be confirmed biochemically by measurement of urinary porphyrin excretion, plasma porphyrin assay, and assay of erythrocyte and/or hepatic UROD. Multiple mutations of the *UROD* gene have been identified in human populations. Some patients with PCT have associated mutations in the *HFE* gene, which is linked to hemochromatosis and leads to increased iron absorption by reducing hepcidin expression; these mutations could contribute to the iron overload precipitating PCT, although iron status as measured by serum ferritin, iron levels, and transferrin saturation is no different from that in PCT patients without *HFE* mutations.

Treatment of PCT consists of repeated phlebotomies to diminish the excessive hepatic iron stores and/or intermittent (twice weekly) low doses of orally administered hydroxychloroquine. This treatment is highly effective for PCT but not suited for treatment of other porphyrias. Long-term remission of the disease can often be achieved if the patient eliminates exposure to porphyrinogenic agents, such as ethanol or estrogens, and avoids sun exposure.

*Erythropoietic protoporphyrria* (EPP) is an acute nonblistering cutaneous porphyria, originates in the bone marrow, and is due to genetic mutations that in most cases decrease the activity of the mitochondrial enzyme ferrochelatase. The major clinical features include acute photosensitivity characterized by painful burning and stinging of exposed skin that often develops during or just after sun exposure. There may be associated skin swelling and, after repeated episodes, a waxlike scarring.

Detection of increased plasma protoporphyrin (PROTO) helps distinguish EPP from lead poisoning and iron-deficiency anemia, in both of which erythrocyte PROTO levels are elevated in the absence of cutaneous photosensitivity. This can be explained by the fact that metal-chelated PROTO is not a photosensitizer.

Rigorous sunlight protection is essential in the management of EPP. Notably, the U.S. Food and Drug Administration (FDA) has approved a synthetic peptide analogue of  $\alpha$ -MSH, afamelanotide, in patients with EPP. This drug increases skin pigmentation through melanogenesis, and patients receiving it tolerate sun exposure without pain for longer periods of time and have an improved quality of life as compared to untreated patients. Interestingly, initial studies suggest that afamelanotide may also be beneficial when combined with narrow-band UV-B in the treatment of patients with vitiligo (in patients with skin phototypes IV–VI). Some studies reported that patients with EPP had a moderate increase in tolerance to sunlight after taking oral  $\beta$ -carotene, which may provide this effect by quenching oxygen free radicals.

An algorithm for managing patients with photosensitivity is presented in Fig. 61-1.

## PHOTOPROTECTION

Since photosensitivity of the skin results from exposure to sunlight, it follows that absolute avoidance of sunlight will eliminate these disorders. However, contemporary lifestyles make this approach impractical for most individuals. Thus, better approaches to photoprotection have been sought. Natural photoprotection is provided by structural proteins in the epidermis, particularly keratins and melanin. The amount of melanin and its distribution in cells are genetically regulated, and individuals of darker complexion (skin types IV–VI) are at decreased risk for the development of acute sunburn and cutaneous malignancy. Other forms of photoprotection include clothing and sunscreens. Clothing constructed of tightly woven sun-protective fabrics, irrespective of color, affords substantial protection. Wide-brimmed hats, long sleeves, and trousers all reduce direct exposure.

Sunscreens are now considered over-the-counter drugs, and a monograph from the FDA has recognized category I ingredients as safe

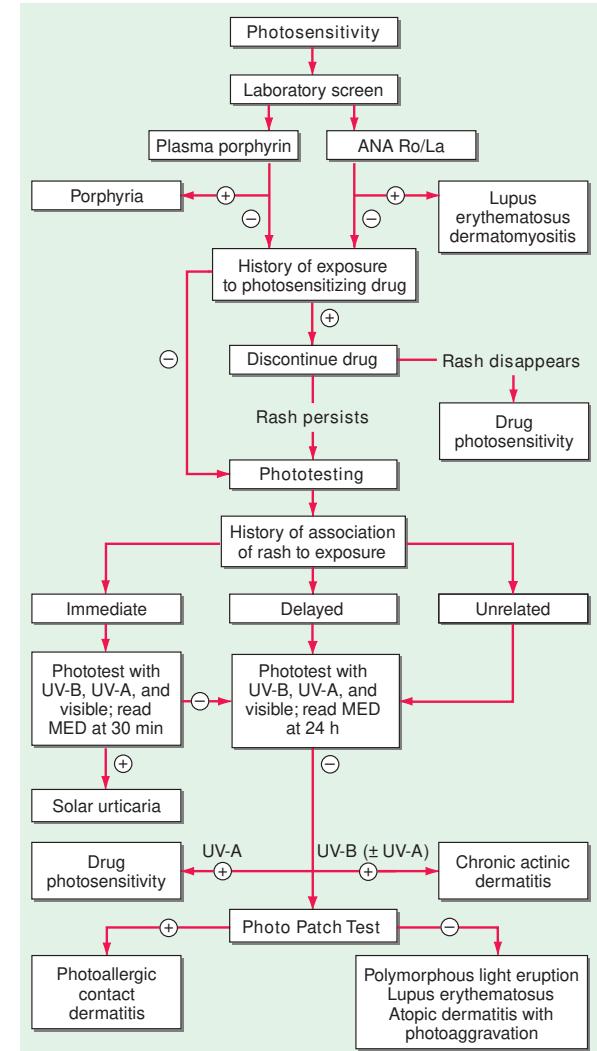


FIGURE 61-1 Algorithm for the diagnosis of a patient with photosensitivity. ANA, antinuclear antibody; MED, minimal erythema dose; UV-A and UV-B, ultraviolet spectrum segments including wavelengths of 320–400 nm and 290–320 nm, respectively.

and effective. Those ingredients are listed in Table 61-5. Sunscreens are rated for their photoprotective effect by their sun protection factor (SPF). The SPF is simply a ratio of the time required to produce sunburn erythema with and without sunscreen application. The SPF of most sunscreens reflects protection from UV-B but not from UV-A. The FDA monograph stipulates that sunscreens must be rated on a scale ranging from minimal (SPF  $\geq 2$  and  $<12$ ) to moderate (SPF  $\geq 12$  and  $<30$ ) to high (SPF  $\geq 30$ , labeled as 30+).

Broad-spectrum sunscreens contain both UV-B-absorbing and UV-A-absorbing chemicals (organic filters). These chemicals absorb UVR and transfer the absorbed energy to surrounding cells. Among these sunscreen ingredients, cinnamates, PABA derivatives, and salicylates absorb UV-B. Benzophenones or ecamulse (terephthalylidene dicamphor sulfonic acid) offer protection against UV-B and UV-A<sub>2</sub>, whereas avobenzene protects mainly against UV-A<sub>1</sub>. In contrast, physical UV blockers (zinc oxide and titanium dioxide) absorb or reflect UVR and offer broad-spectrum protection against UV-B and UV-A. In addition to light absorption, a critical determinant of the sustained photoprotective effect of sunscreens is their water resistance. Sunscreen products with an SPF of 30 or higher, broad-spectrum

TABLE 61-5 FDA Category I Monographed Sunscreen Ingredients

INGREDIENTS	MAXIMUM CONCENTRATION, %
p-Aminobenzoic acid (PABA)	15
Avobenzene	3
Ginoxate	3
Dioxybenzone (benzophenone-8)	3
Ecamsule	15
Homosalate	15
Methyl anthranilate	5
Octocrylene	10
Octyl methoxycinnamate	7.5
Octyl salicylate	5
Oxybenzone (benzophenone-3)	6
Padimate O (octyl dimethyl PABA)	8
Phenylbenzimidazole sulfonic acid	4
Sulisobenzene (benzophenone-4)	10
Titanium dioxide	25
Trolamine salicylate	12
Zinc oxide	25

Abbreviation: FDA, U.S. Food and Drug Administration.

coverage, and water or sweat resistance are recommended for adequate sun protection.

Some degree of photoprotection can be achieved by limiting the time of sun exposure during the day. Since a large part of an individual's total lifetime sun exposure may occur by age 18, it is important to educate parents and young children about the hazards of sunlight. Eliminating exposure at midday will substantially reduce lifetime UVR exposure.

## PHOTOTHERAPY AND PHOTOCHEMOTHERAPY

UVR can be used therapeutically. The administration of UV-B alone or in combination with topically applied agents can induce remissions of many dermatologic diseases, including psoriasis, atopic dermatitis, and vitiligo. In particular, narrow-band UV-B treatments (with fluorescent bulbs emitting radiation at 311 nm) have enhanced efficacy over that obtained with broad-band UV-B in the treatment of psoriasis.

Photochemotherapy in which topically applied or systemically administered psoralens are combined with UV-A (PUVA) is effective in treating psoriasis and the early stages of cutaneous T-cell lymphoma and vitiligo. Psoralens are tricyclic furanocoumarins that, when intercalated into DNA and exposed to UV-A, form adducts with pyrimidine bases and eventually form DNA cross-links. These structural changes are thought to decrease DNA synthesis and to be related to the amelioration of psoriasis. Why PUVA photochemotherapy is effective in cutaneous T-cell lymphoma is only partially understood, but it has been shown to induce apoptosis of atypical T lymphocyte populations in the skin. Consequently, direct treatment of circulating atypical lymphocytes by extracorporeal photochemotherapy (photopheresis) has been used in Sézary syndrome as well as in other severe systemic diseases with circulating atypical lymphocytes, such as graft-versus-host disease.

In addition to its effects on DNA, PUVA photochemotherapy stimulates epidermal thickening and melanin synthesis; the latter property, together with its anti-inflammatory effects, provides the rationale for use of PUVA in the depigmenting disease vitiligo. Oral 8-methoxysoralen and UV-A appear to be most effective in this regard, but as many as 100 treatments extending over 12–18 months may be required for satisfactory repigmentation.

Not surprisingly, the major side effects of long-term UV-B phototherapy and PUVA photochemotherapy mimic those seen in individuals with chronic sun exposure. Despite these risks, the therapeutic index of these modalities continues to be excellent. It is important to

choose the most appropriate phototherapeutic approach for a specific dermatologic disease. For example, narrow-band UV-B has been reported in several studies to be as effective as PUVA photochemotherapy in the treatment of psoriasis but to pose a lower risk of skin cancer development than PUVA.

## FURTHER READING

- B JJ et al: Photoimmunology: How ultraviolet radiation affects the immune system. *Nat Rev Immunol* 11:688, 2019.
- F GL et al: Skin beta-endorphin mediates addiction to UV light. *Cell* 157:1527, 2014.
- H PW et al: The biology and treatment of Merkel cell carcinoma: Current understanding and research priorities. *Nat Rev Clin Oncol* 15:763, 2018.
- J R et al: Photoprotection: Part II. Sunscreen: Development, efficacy, and controversies. *J Am Acad Dermatol* 69:867, 2013.
- L JA et al: The melanoma revolution: From UV carcinogenesis to a new era in therapeutics. *Science* 346:945, 2014.
- M I et al: Tumor evolution. High burden and pervasive positive selection of somatic mutations in normal human skin. *Science* 348:880, 2015.
- S -D A et al: Defining the clonal dynamics leading to mouse skin tumour initiation. *Nature* 536:298, 2016.

## Section 9 Hematologic Alterations

### 62

### Interpreting Peripheral Blood Smears

Dan L. Longo



Some of the relevant findings in peripheral blood, enlarged lymph nodes, and bone marrow are illustrated in this chapter. Systematic histologic examination of the bone marrow and lymph nodes is beyond the scope of a general medicine textbook. However, every internist should know how to examine a peripheral blood smear.

The examination of a peripheral blood smear is one of the most informative exercises a physician can perform. Although advances in automated technology have made the examination of a peripheral blood smear by a physician seem less important, the technology is not a completely satisfactory replacement for a blood smear interpretation by a trained medical professional who also knows the patient's clinical history, family history, social history, and physical findings. It is useful to ask the laboratory to generate a Wright's-stained peripheral blood smear and examine it.

The best place to examine blood cell morphology is the feathered edge of the blood smear where red cells lie in a single layer, side by side, just barely touching one another but not overlapping. The author's approach is to look at the smallest cellular elements, the platelets, first and work his way up in size to red cells and then white cells.

Using an oil immersion lens that magnifies the cells 100-fold, one counts the platelets in five to six fields, averages the number per field, and multiplies by 20,000 to get a rough estimate of the platelet count. The platelets are usually 1–2  $\mu\text{m}$  in diameter and have a blue granulated appearance. There is usually 1 platelet for every 20 or so red cells. Of course, the automated counter is much more accurate, but gross disparities between the automated and manual counts should be assessed. Large platelets may be a sign of rapid platelet turnover, as young platelets are often larger than old ones; alternatively, certain rare inherited syndromes can produce large platelets. If the platelet count is low, the absence of large (young) platelets may be an indicator of marrow production problems. Platelet clumping visible on the smear

can be associated with falsely low automated platelet counts. Clumping may be caused by the anticoagulant into which the blood is drawn. Similarly, neutrophil fragmentation can be a source of falsely elevated automated platelet counts. The absence of platelet granules may be an artifact of the handling of the blood or may indicate marrow disease or a rare congenital anomaly, gray platelet syndrome. Elevated platelet counts usually signify a myeloproliferative disorder or a reaction to systemic inflammation.

Next one examines the red blood cells. One can gauge their size by comparing the red cell to the nucleus of a small lymphocyte. Both are normally about 8- $\mu\text{m}$  wide. Red cells that are smaller than the small lymphocyte nucleus may be microcytic; those larger than the small lymphocyte nucleus may be macrocytic. Macrocytic cells also tend to be more oval than spherical in shape and are sometimes called macroovalocytes. The automated mean corpuscular volume (MCV) can assist in making a classification. However, some patients may have both iron and vitamin B<sub>12</sub> deficiency, which will produce an MCV in the normal range but wide variation in red cell size. When the red cells vary greatly in size, *anisocytosis* is said to be present. When the red cells vary greatly in shape, *poikilocytosis* is said to be present. The electronic cell counter provides an independent assessment of variability in red cell size. It measures the range of red cell volumes and reports the results as “red cell distribution width” (RDW). This value is calculated from the MCV; thus, cell width is not being measured but cell volume is. The term is derived from the curve displaying the frequency of cells at each volume, also called the distribution. The width of red cell volume distribution curve is what determines the RDW. The RDW is calculated as follows: RDW = (standard deviation of MCV ÷ mean MCV) × 100. In the presence of morphologic anisocytosis, RDW (normally 11–14%) increases to 15–18%. The RDW is useful in at least two clinical settings. In patients with microcytic anemia, the differential diagnosis is generally between iron deficiency and thalassemia. In thalassemia, the small red cells are generally of uniform size with a normal small RDW. In iron deficiency, the size variability and the RDW are large. In addition, a large RDW can suggest a dimorphic anemia when a chronic atrophic gastritis can produce both vitamin B<sub>12</sub> malabsorption to produce macrocytic anemia and blood loss to produce iron deficiency. In such settings, RDW is also large. An elevated RDW also has been reported as a risk factor for all-cause mortality in population-based studies, a finding that is unexplained currently.

After red cell size is assessed, one examines the hemoglobin content of the cells. They are either normal in color (*normochromic*) or pale in color (*hypochromic*). They are never “hyperchromic.” If more than the normal amount of hemoglobin is made, the cells get larger—they do not become darker. In addition to hemoglobin content, the red cells are examined for inclusions. Red cell inclusions are the following:

- Basophilic stippling*—diffuse fine or coarse blue dots in the red cell usually representing RNA residue—especially common in lead poisoning
- Howell-Jolly bodies*—dense blue circular inclusions that represent nuclear remnants—their presence implies defective splenic function
- Nuclei*—red cells may be released or pushed out of the marrow prematurely before nuclear extrusion—often implies a myelophthisic process or a vigorous narrow response to anemia, usually hemolytic anemia
- Parasites*—red cell parasites include malaria and babesia (Chap. A6)
- Polychromatophilia*—the red cell cytoplasm has a bluish hue, reflecting the persistence of ribosomes still actively making hemoglobin in a young red cell

Vital stains are necessary to see precipitated hemoglobin called *Heinz bodies*.

Red cells can take on a variety of different shapes. All abnormally shaped red cells are *poikilocytes*. Small red cells without the central pallor are *spherocytes*; they can be seen in hereditary spherocytosis, hemolytic anemias of other causes, and clostridial sepsis. *Dacrocytes* are teardrop-shaped cells that can be seen in hemolytic anemias, severe iron deficiency, thalassemias, myelofibrosis, and myelodysplastic syndromes. *Schistocytes* are helmet-shaped cells that reflect

microangiopathic hemolytic anemia or fragmentation on an artificial heart valve. *Echinocytes* are spiculated red cells with the spikes evenly spaced; they can represent an artifact of abnormal drying of the blood smear or reflect changes in stored blood. They also can be seen in renal failure and malnutrition and are often reversible. *Acanthocytes* are spiculated red cells with the spikes irregularly distributed. This process tends to be irreversible and reflects underlying renal disease, abetalipoproteinemia, or splenectomy. *Elliptocytes* are elliptical-shaped red cells that can reflect an inherited defect in the red cell membrane, but they also are seen in iron deficiency, myelodysplastic syndromes, megaloblastic anemia, and thalassemias. *Stomatocytes* are red cells in which the area of central pallor takes on the morphology of a slit instead of the usual round shape. Stomatocytes can indicate an inherited red cell membrane defect and also can be seen in alcoholism. *Target cells* have an area of central pallor that contains a dense center, or bull's eye. These cells are seen classically in thalassemia, but they are also present in iron deficiency, cholestatic liver disease, and some hemoglobinopathies. They also can be generated artificially by improper slide making.

One last feature of the red cells to assess before moving to the white blood cells is the distribution of the red cells on the smear. In most individuals, the cells lie side by side in a single layer. Some patients have red cell clumping (called *agglutination*) in which the red cells pile upon one another; it is seen in certain paraproteinemias and autoimmune hemolytic anemias. Another abnormal distribution involves red cells lying in single cell rows on top of one another like stacks of coins. This is called *rouleaux formation* and reflects abnormal serum protein levels.

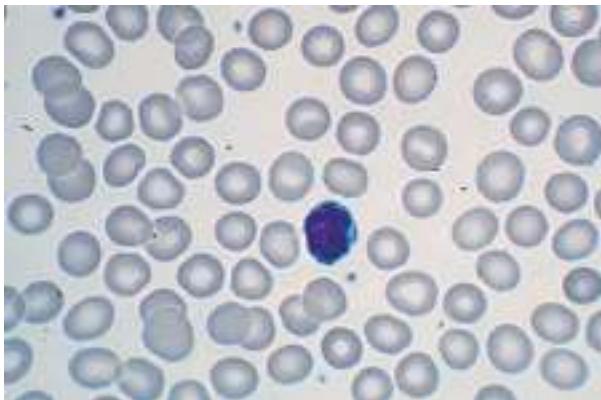
Finally, one examines the white blood cells. Three types of granulocytes are usually present: neutrophils, eosinophils, and basophils, in decreasing frequency. Neutrophils are generally the most abundant white cell. They are round, are 10–14  $\mu\text{m}$  wide, and contain a lobulated nucleus with two to five lobes connected by a thin chromatin thread. Bands are immature neutrophils that have not completed nuclear condensation and have a U-shaped nucleus. Bands reflect a left shift in neutrophil maturation in an effort to make more cells more rapidly. Neutrophils can provide clues to a variety of conditions. Vacuolated neutrophils may be a sign of bacterial sepsis. The presence of 1- to 2- $\mu\text{m}$  blue cytoplasmic inclusions, called *Döhle bodies*, can reflect infections, burns, or other inflammatory states. If the neutrophil granules are larger than normal and stain a darker blue, “toxic granulations” are said to be present, and they also suggest a systemic inflammation. The presence of neutrophils with more than five nuclear lobes suggests megaloblastic anemia. Large misshapen granules may reflect the inherited Chédiak-Higashi syndrome.

Eosinophils are slightly larger than neutrophils, have bilobed nuclei, and contain large red granules. Diseases of eosinophils are associated with too many of them rather than any morphologic or qualitative change. They normally total less than one-thirtieth the number of neutrophils. Basophils are even more rare than eosinophils in the blood. They have large dark blue granules and may be increased as part of chronic myeloid leukemia.

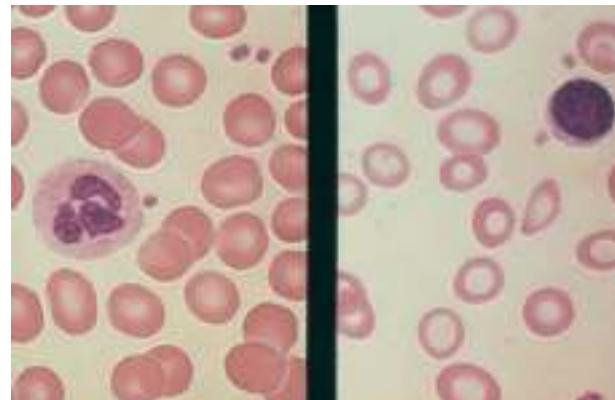
Lymphocytes can be present in several morphologic forms. Most common in healthy individuals are small lymphocytes with a small dark nucleus and scarce cytoplasm. In the presence of viral infections, more of the lymphocytes are larger, about the size of neutrophils, with abundant cytoplasm and a less condensed nuclear chromatin. These cells are called *reactive lymphocytes*. About 1% of lymphocytes are larger and contain blue granules in a light blue cytoplasm; they are called *large granular lymphocytes*. In chronic lymphoid leukemia, the small lymphocytes are increased in number, and many of them are ruptured in making the blood smear, leaving a smudge of nuclear material without a surrounding cytoplasm or cell membrane; they are called *smudge cells* and are rare in the absence of chronic lymphoid leukemia.

Monocytes are the largest white blood cells, ranging from 15 to 22  $\mu\text{m}$  in diameter. The nucleus can take on a variety of shapes but usually appears to be folded; the cytoplasm is gray.

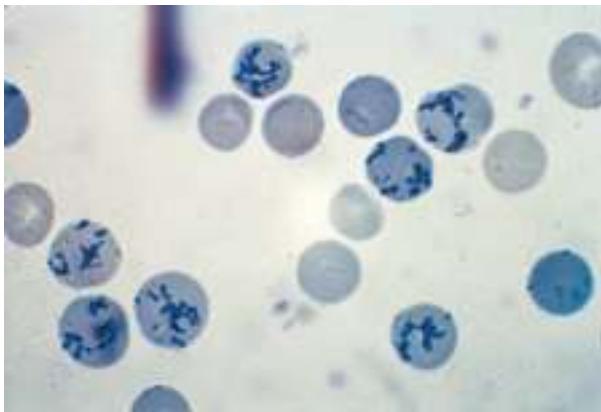
Abnormal cells may appear in the blood. Most often, the abnormal cells originate from neoplasms of bone marrow-derived cells, including lymphoid cells, myeloid cells, and occasionally red cells. More rarely, other types of tumors can get access to the bloodstream, and rare



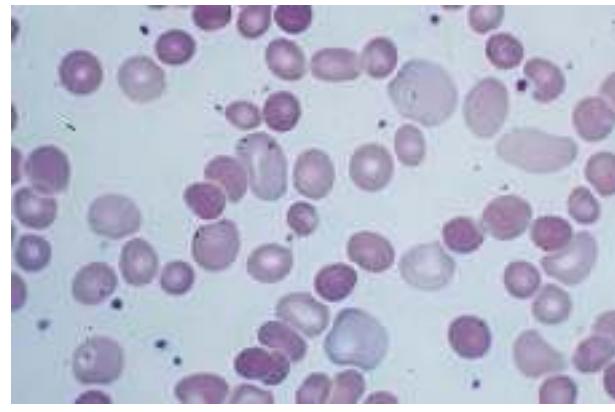
**FIGURE 62-1** Normal peripheral blood smear. Small lymphocyte in center of field. Note that the diameter of the red blood cell is similar to the diameter of the small lymphocyte nucleus. (Source: From M Lichtman et al (eds). *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault, *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



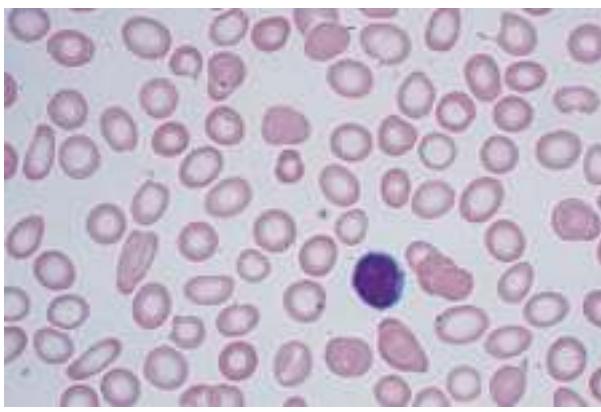
**FIGURE 62-4** Iron deficiency anemia next to normal red blood cells. Microcytes (right panel) are smaller than normal red blood cells (cell diameter  $<7\text{ }\mu\text{m}$ ) and may or may not be poorly hemoglobinized (hypochromic). (Source: From M Lichtman et al (eds). *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault, *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



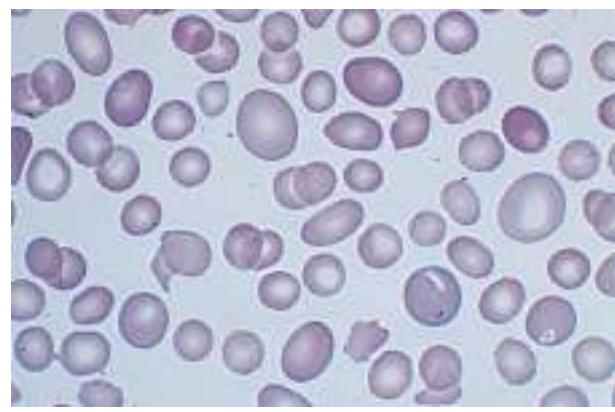
**FIGURE 62-2** Reticulocyte count preparation. This new methylene blue-stained blood smear shows large numbers of heavily stained reticulocytes (the cells containing the dark blue-staining RNA precipitates). (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



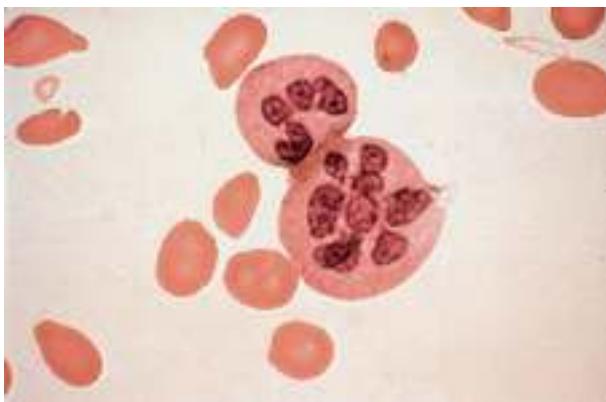
**FIGURE 62-5** Polychromatophilia. Note large red cells with light purple coloring. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



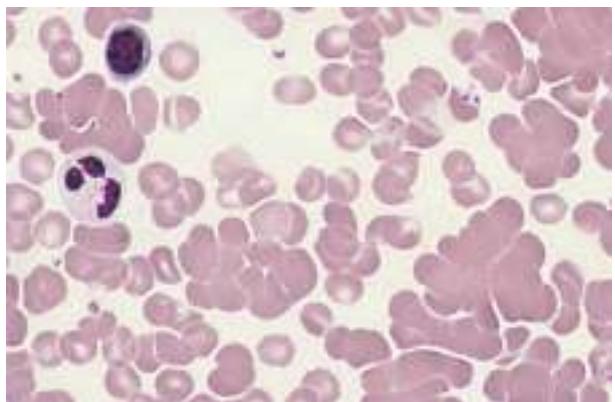
**FIGURE 62-3** Hypochromic microcytic anemia of iron deficiency. Small lymphocyte in field helps assess the red blood cell size. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



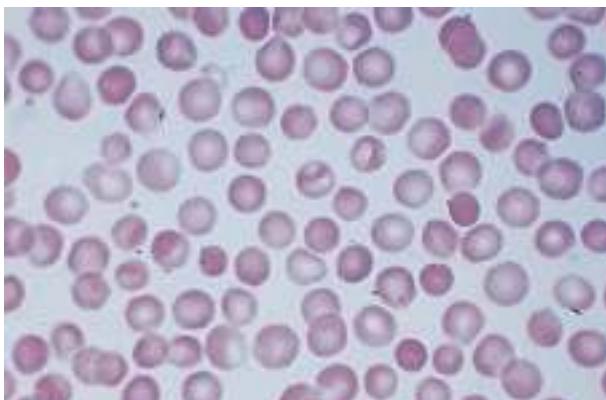
**FIGURE 62-6** Macrocytosis. These cells are both larger than normal (mean corpuscular volume  $>100$ ) and somewhat oval in shape. Some morphologists call these cells macroovalocytes. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



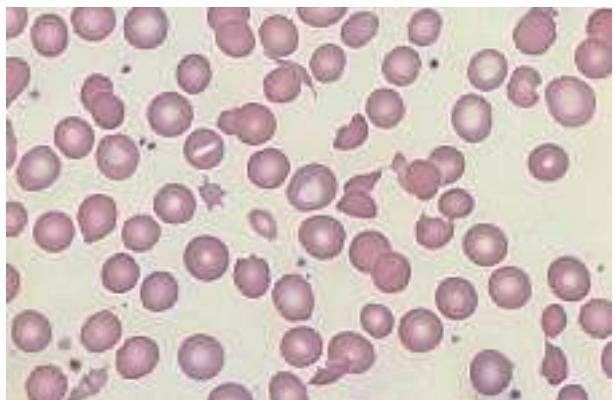
**FIGURE 62-7** Hypersegmented neutrophils. Hypersegmented neutrophils (multilobed polymorphonuclear leukocytes) are larger than normal neutrophils with five or more segmented nuclear lobes. They are commonly seen with folic acid or vitamin B<sub>12</sub> deficiency. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



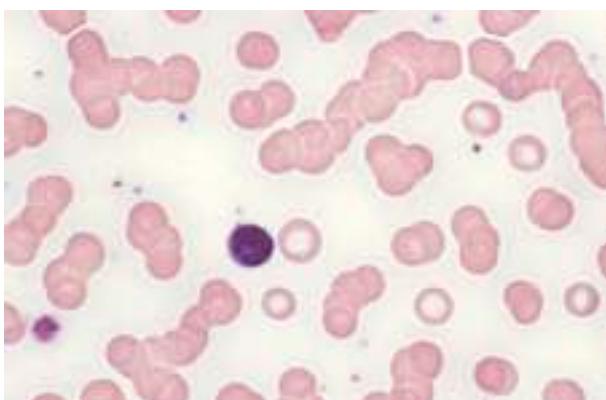
**FIGURE 62-10** Red cell agglutination. Small lymphocyte and segmented neutrophil in upper left center. Note irregular collections of aggregated red cells. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



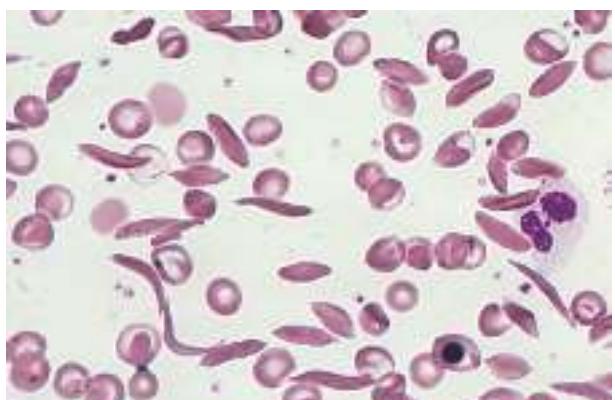
**FIGURE 62-8** Spherocytosis. Note small hyperchromatic cells without the usual clear area in the center. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



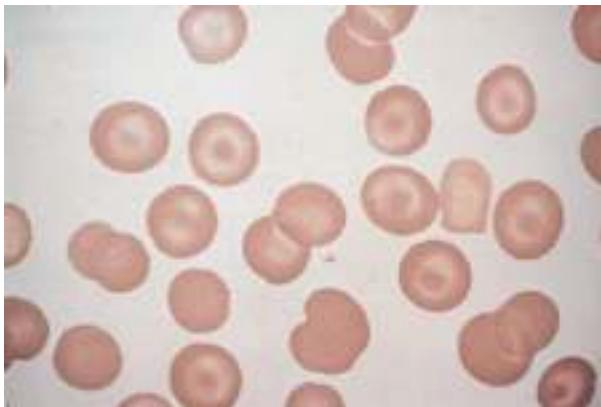
**FIGURE 62-11** Fragmented red cells. Heart valve hemolysis. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



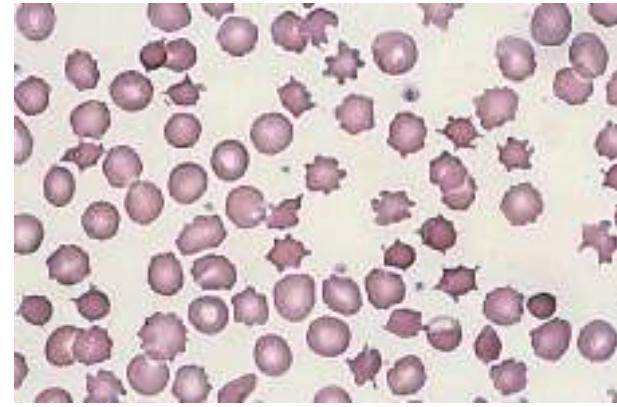
**FIGURE 62-9** Rouleaux formation. Small lymphocyte in center of field. These red cells align themselves in stacks and are related to increased serum protein levels. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



**FIGURE 62-12** Sickled cells. Homozygous sickle cell disease. A nucleated red cell and neutrophil are also in the field. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



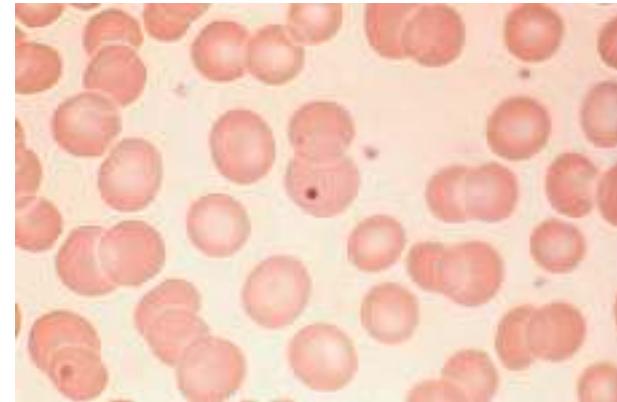
**FIGURE 62-13 Target cells.** Target cells are recognized by the bull's-eye appearance of the cell. Small numbers of target cells are seen with liver disease and thalassemia. Larger numbers are typical of hemoglobin C disease. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



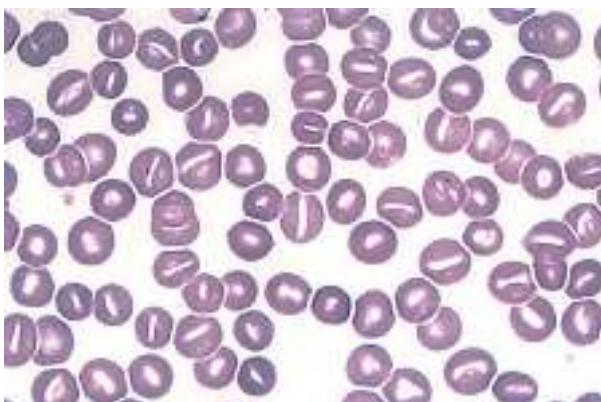
**FIGURE 62-16 Acanthocytosis.** Spiculated red cells are of two types: *acanthocytes* are contracted dense cells with irregular membrane projections that vary in length and width; *echinocytes* have small, uniform, and evenly spaced membrane projections. Acanthocytes are present in severe liver disease, in patients with abetalipoproteinemia, and in rare patients with McLeod blood group. Echinocytes are found in patients with severe uremia, in glycolytic red cell enzyme defects, and in microangiopathic hemolytic anemia. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



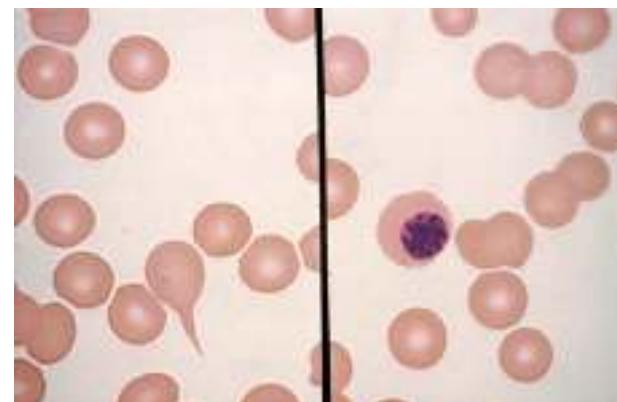
**FIGURE 62-14 Elliptocytosis.** Small lymphocyte in center of field. Elliptical shape of red cells related to weakened membrane structure, usually due to mutations in spectrin. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



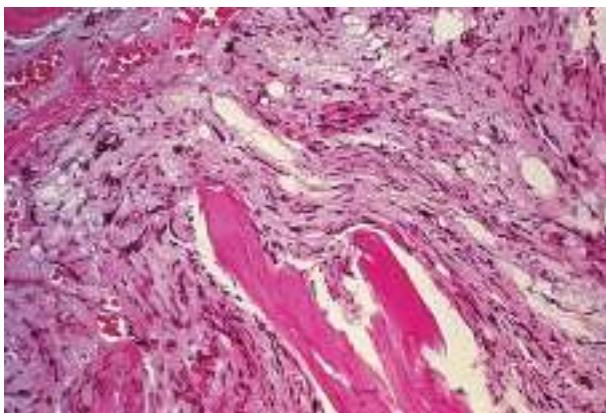
**FIGURE 62-17 Howell-Jolly bodies.** Howell-Jolly bodies are tiny nuclear remnants that normally are removed by the spleen. They appear in the blood after splenectomy (defect in removal) and with maturation/dysplastic disorders (excess production). (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



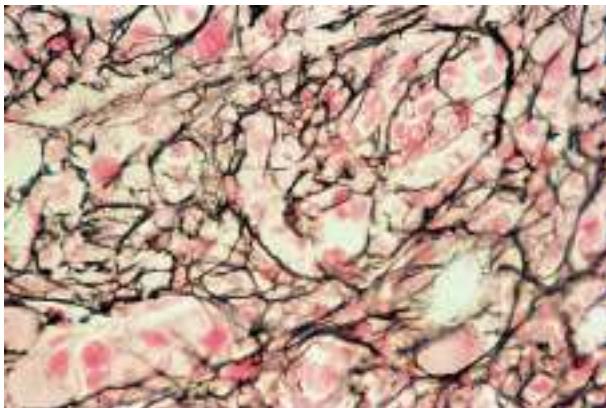
**FIGURE 62-15 Stomatocytosis.** Red cells characterized by a wide transverse slit or stoma. This often is seen as an artifact in a dehydrated blood smear. These cells can be seen in hemolytic anemias and in conditions in which the red cell is overhydrated or dehydrated. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



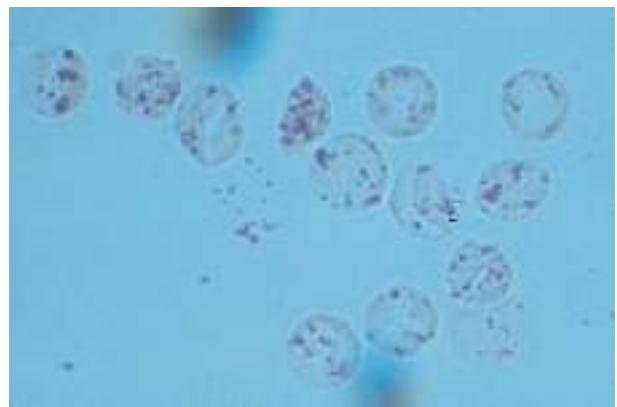
**FIGURE 62-18 Teardrop cells and nucleated red blood cells characteristic of myelofibrosis.** A teardrop-shaped red blood cell (left panel) and a nucleated red blood cell (right panel) as typically seen with myelofibrosis and extramedullary hematopoiesis. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



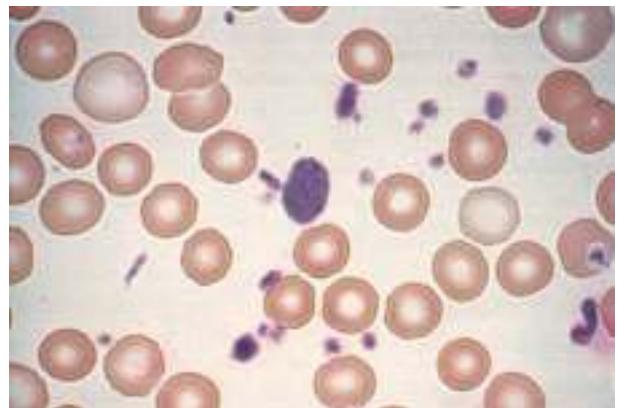
**FIGURE 62-19** Myelofibrosis of the bone marrow. Total replacement of marrow precursors and fat cells by a dense infiltrate of reticulin fibers and collagen (hematoxylin and eosin stain). (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



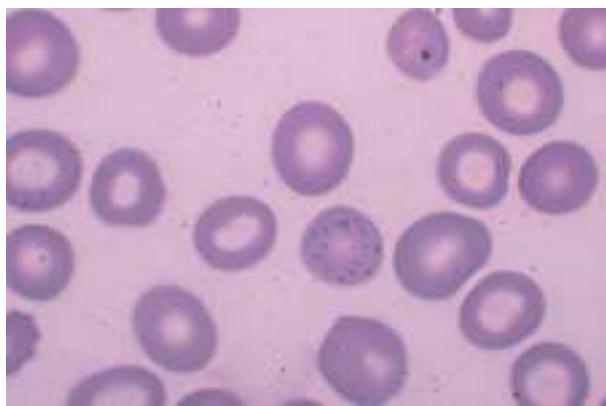
**FIGURE 62-20** Reticulin stain of marrow myelofibrosis. Silver stain of a myelofibrotic marrow showing an increase in reticulin fibers (black-staining threads). (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



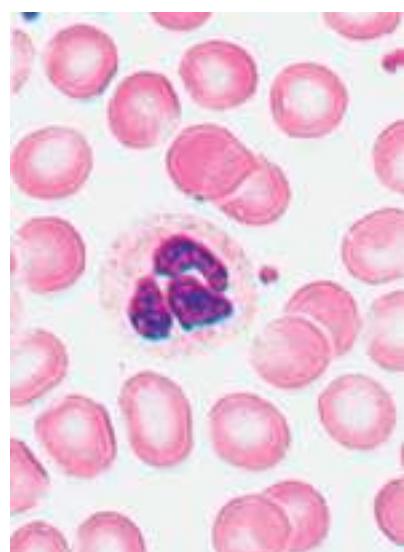
**FIGURE 62-22** Heinz bodies. Blood mixed with hypotonic solution of crystal violet. The stained material is precipitates of denatured hemoglobin within cells. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



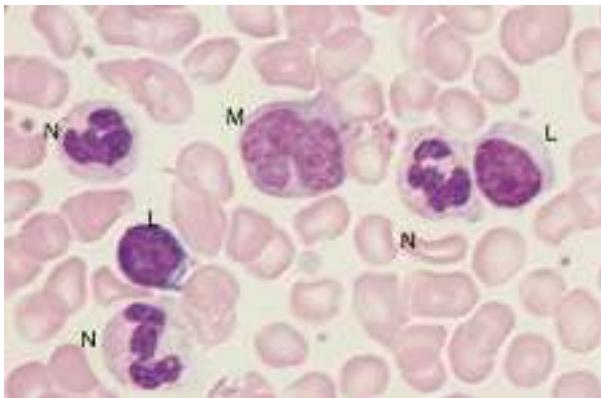
**FIGURE 62-23** Giant platelets. Giant platelets, together with a marked increase in the platelet count, are seen in myeloproliferative disorders, especially primary thrombocythemia. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



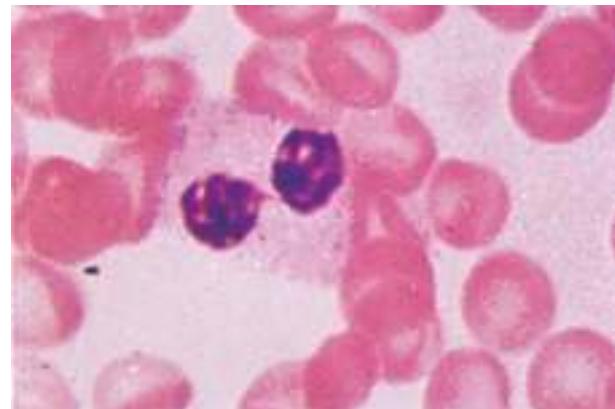
**FIGURE 62-21** Stippled red cell in lead poisoning. Mild hypochromia. Coarsely stippled red cell. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



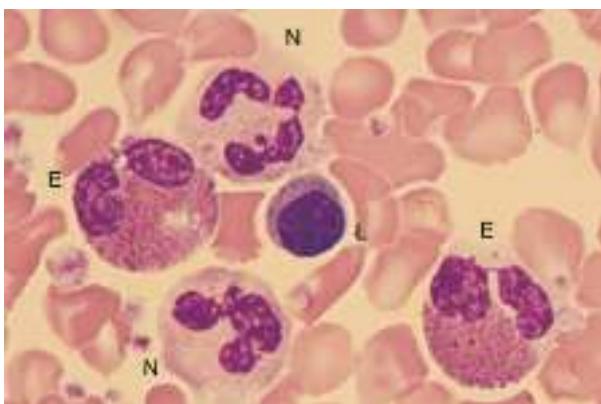
**FIGURE 62-24** Normal granulocytes. The normal granulocyte has a segmented nucleus with heavy, clumped chromatin; fine neutrophilic granules are dispersed throughout the cytoplasm. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



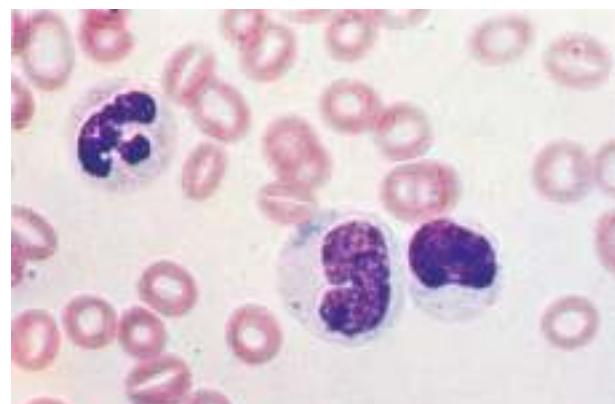
**FIGURE 62-25** Normal monocytes. The film was prepared from the buffy coat of the blood from a normal donor. L, lymphocyte; M, monocyte; N, neutrophil. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



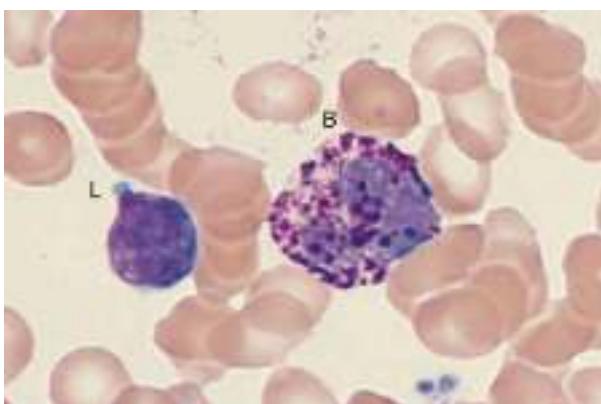
**FIGURE 62-28** Pelger-Hüet anomaly. In this benign disorder, the majority of granulocytes are bilobed. The nucleus frequently has a spectacle-like, or “pince-nez,” configuration. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



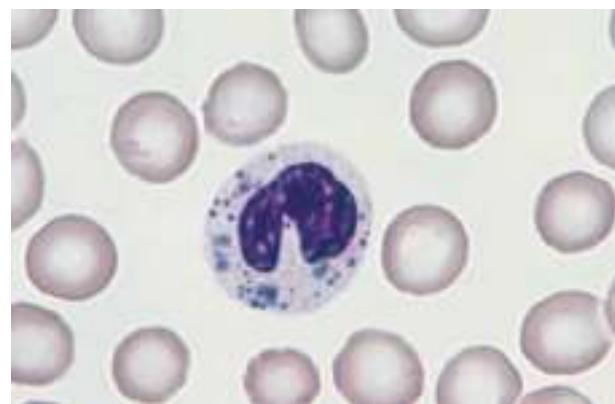
**FIGURE 62-26** Normal eosinophils. The film was prepared from the buffy coat of the blood from a normal donor. E, eosinophil; L, lymphocyte; N, neutrophil. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



**FIGURE 62-29** Döhle body. Neutrophil band with Döhle body. The neutrophil with a sausage-shaped nucleus in the center of the field is a band form. Döhle bodies are discrete, blue-staining nongranular areas found in the periphery of the cytoplasm of the neutrophil in infections and other toxic states. They represent aggregates of rough endoplasmic reticulum. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



**FIGURE 62-27** Normal basophil. The film was prepared from the buffy coat of the blood from a normal donor. B, basophil; L, lymphocyte. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



**FIGURE 62-30** Chédiak-Higashi disease. Note giant granules in neutrophil. (Source: From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)

epithelial malignant cells may be identified. The chances of seeing such abnormal cells are increased by examining blood smears made from buffy coats, the layer of cells that is visible on top of sedimenting red cells when blood is left in the test tube for an hour. Smears made from finger sticks may include rare endothelial cells.

A

*Figures in this chapter were borrowed from Williams Hematology, 7th edition, M Lichtman et al (eds). New York, McGraw-Hill, 2005; Hematology in General Practice, 4th edition, RS Hillman, KA Ault. New York, McGraw-Hill, 2005.*

## 63

# Anemia and Polycythemia

John W. Adamson, Dan L. Longo

## HEMATOPOIESIS AND THE PHYSIOLOGIC BASIS OF RED CELL PRODUCTION

**Hematopoiesis** is the process by which the formed elements of blood are produced. The process is regulated through a series of steps beginning with the hematopoietic stem cell. Stem cells are capable of producing red cells, all classes of granulocytes, monocytes, platelets, and the cells of the immune system. The precise molecular mechanism by which the stem cell becomes committed to a given lineage is not fully defined. However, experiments in mice suggest that erythroid cells come from a common erythroid/megakaryocyte progenitor that does not develop in the absence of expression of the GATA-1 and FOG-1 (friend of GATA-1) transcription factors (Chap. 96). Following lineage commitment, hematopoietic progenitor and precursor cells come increasingly under the regulatory influence of growth factors and hormones. For red cell production, erythropoietin (EPO) is the primary regulatory hormone. EPO is required for the maintenance of committed erythroid progenitor cells that, in the absence of the hormone, undergo programmed cell death (*apoptosis*). The regulated process of red cell production is *erythropoiesis*, and its key elements are illustrated in Fig. 63-1.

In the bone marrow, the first morphologically recognizable erythroid precursor is the pronormoblast. This cell can undergo four to five cell divisions, which result in the production of 16–32 mature red cells. With increased EPO production, or the administration of EPO as a drug, early progenitor cell numbers are amplified and, in turn, give rise to increased numbers of erythrocytes. The regulation of EPO production itself is linked to tissue oxygenation.

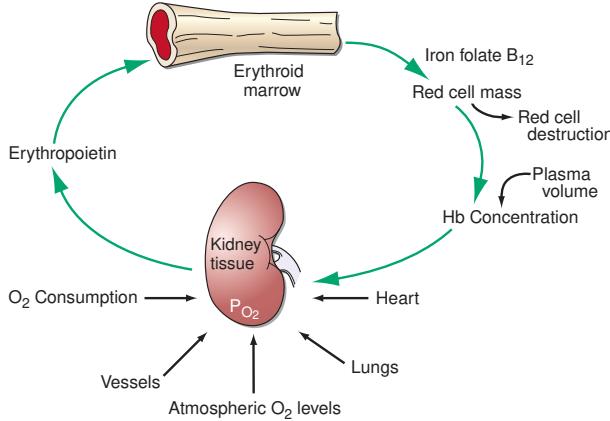


FIGURE 63-1 The physiologic regulation of red cell production by tissue oxygen tension. Hb, hemoglobin.

In mammals, O<sub>2</sub> is transported to tissues bound to the hemoglobin contained within circulating red cells. The mature red cell is 8 μm in diameter, anucleate, discoid in shape, and extremely pliable in order to traverse the microcirculation successfully; its membrane integrity is maintained by the intracellular generation of ATP. Normal red cell production results in the daily replacement of 0.8–1% of all circulating red cells in the body, since the average red cell lives 100–120 days. The organ responsible for red cell production is called the *erythron*. The erythron is a dynamic organ made up of a rapidly proliferating pool of marrow erythroid precursor cells and a large mass of mature circulating red blood cells. The size of the red cell mass reflects the balance of red cell production and destruction. The physiologic basis of red cell production and destruction provides an understanding of the mechanisms that can lead to anemia.

The physiologic regulator of red cell production, the glycoprotein hormone EPO, is produced and released by peritubular capillary lining cells within the kidney. These cells are highly specialized epithelial-like cells. A small amount of EPO is produced by hepatocytes. The fundamental stimulus for EPO production is the availability of O<sub>2</sub> for tissue metabolic needs. Key to EPO gene regulation is hypoxia-inducible factor (HIF)-1α. In the presence of O<sub>2</sub>, HIF-1α is hydroxylated at a key proline, allowing HIF-1α to be ubiquitinated and degraded via the proteasome pathway. If O<sub>2</sub> becomes limiting, this critical hydroxylation step does not occur, allowing HIF-1α to partner with other proteins, translocate to the nucleus, and upregulate the expression of the EPO gene, among others.

Impaired O<sub>2</sub> delivery to the kidney can result from a decreased red cell mass (*anemia*), impaired O<sub>2</sub> loading of the hemoglobin molecule or a high O<sub>2</sub> affinity mutant hemoglobin (*hypoxemia*), or, rarely, impaired blood flow to the kidney (e.g., renal artery stenosis). EPO governs the day-to-day production of red cells, and ambient levels of the hormone can be measured in the plasma by sensitive immunoassays—the normal level being 10–25 U/L. When the hemoglobin concentration falls below 100–120 g/L (10–12 g/dL), plasma EPO levels increase in proportion to the severity of the anemia (Fig. 63-2). In circulation, EPO has a half-clearance time of 6–9 h. EPO acts by binding to specific receptors on the surface of marrow erythroid precursors, inducing them to proliferate and to mature. With EPO stimulation, red cell production can increase four- to fivefold within a 1- to 2-week period, but only in the presence of adequate nutrients, especially iron. The functional capacity of the erythron, therefore, requires normal renal production of EPO, a functioning erythroid marrow, and an adequate supply of substrates for hemoglobin synthesis. A defect in any of these key components can lead to anemia. Generally, anemia is recognized in the laboratory when a patient's hemoglobin level or hematocrit is reduced below an expected value (the normal range).

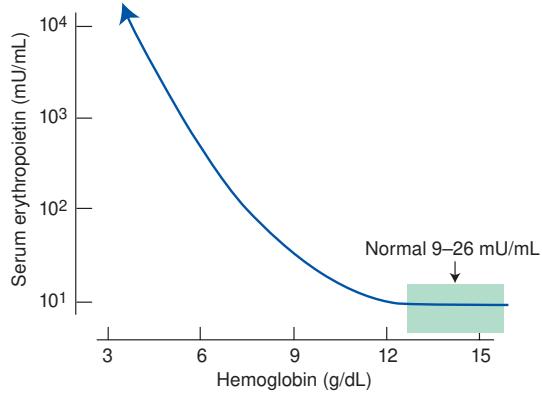


FIGURE 63-2 Erythropoietin (EPO) levels in response to anemia. When the hemoglobin level falls to 120 g/L (12 g/dL), plasma EPO levels increase logarithmically. In the presence of chronic kidney disease or chronic inflammation, EPO levels are typically lower than expected for the degree of anemia. As individuals age, the level of EPO needed to sustain normal hemoglobin levels appears to increase. (Reproduced with permission from RS Hillman et al: *Hematology in Clinical Practice*, 5th ed. New York, McGraw-Hill, 2010.)

The likelihood and severity of anemia are defined based on the deviation of the patient's hemoglobin/hematocrit from values expected for age- and sex-matched normal subjects. The hemoglobin concentration in adults has a Gaussian distribution. The normal range of hemoglobin values for adult males is 13.5–17.5 g/dL (135–175 g/L) and that for adult females is 12–15 g/dL (120–150 g/L). The World Health Organization (WHO) defines anemia as a hemoglobin level <13 g/dL (130 g/L) in men and <12 g/dL (120 g/L) in women. Hematocrit levels are less useful than hemoglobin levels in assessing anemia because they are calculated rather than measured directly. Suspected low hemoglobin or hematocrit values are more easily interpreted if previous values for the same patient are known for comparison.

The critical elements of erythropoiesis—EPO production, iron availability, the proliferative capacity of the bone marrow, and effective maturation of red cell precursors—are used for the initial classification of anemia (see below).

## ANEMIA

### ■ CLINICAL PRESENTATION OF ANEMIA

**Signs and Symptoms** Anemia is most often recognized by abnormal screening laboratory tests. Patients less commonly present with advanced anemia and its attendant signs and symptoms. Acute anemia is due to blood loss or hemolysis. If blood loss is mild, enhanced O<sub>2</sub> delivery is achieved through changes in the O<sub>2</sub>-hemoglobin dissociation curve mediated by a decreased pH or increased CO<sub>2</sub> (*Bohr effect*). With acute blood loss, hypovolemia dominates the clinical picture, and the hematocrit and hemoglobin levels do not reflect the volume of blood lost. Signs of vascular instability appear with acute losses of 10–15% of the total blood volume. In such patients, the issue is not anemia but hypotension and decreased organ perfusion. When >30% of the blood volume is lost suddenly, patients are unable to compensate with the usual mechanisms of vascular contraction and changes in regional blood flow. The patient prefers to remain supine and will show postural hypotension and tachycardia. If the volume of blood lost is >40% (i.e., >2 L in the average-sized adult), signs of hypovolemic shock including confusion, dyspnea, diaphoresis, hypotension, and tachycardia appear (*Chap. 101*). Such patients have significant deficits in vital organ perfusion and require immediate volume replacement.

With acute hemolysis, the signs and symptoms depend on the mechanism that leads to red cell destruction. Intravascular hemolysis with release of free hemoglobin may be associated with acute back pain, free hemoglobin in the plasma and urine, and renal failure. Symptoms associated with more chronic or progressive anemia depend on the age of the patient and the adequacy of blood supply to critical organs. Symptoms associated with moderate anemia include fatigue, loss of stamina, breathlessness, and tachycardia (particularly with physical exertion). However, because of the intrinsic compensatory mechanisms that govern the O<sub>2</sub>-hemoglobin dissociation curve, the gradual onset of anemia—particularly in young patients—may not be associated with signs or symptoms until the anemia is severe (hemoglobin <70–80 g/L [7–8 g/dL]). When anemia develops over a period of days or weeks, the total blood volume is normal to slightly increased, and changes in cardiac output and regional blood flow help compensate for the overall loss in O<sub>2</sub>-carrying capacity. Changes in the position of the O<sub>2</sub>-hemoglobin dissociation curve account for some of the compensatory response to anemia. With chronic anemia, intracellular levels of 2,3-bisphosphoglycerate rise, shifting the dissociation curve to the right and facilitating O<sub>2</sub> unloading. This compensatory mechanism can only maintain normal tissue O<sub>2</sub> delivery in the face of a 20–30 g/L (2–3 g/dL) deficit in hemoglobin concentration. Finally, further protection of O<sub>2</sub> delivery to vital organs is achieved by the shunting of blood away from organs that are relatively rich in blood supply, particularly the kidney, gut, and skin.

Certain disorders are commonly associated with anemia. Chronic inflammatory states (e.g., infection, rheumatoid arthritis, cancer) are associated with mild to moderate anemia, whereas lymphoproliferative disorders, such as chronic lymphocytic leukemia and certain other B-cell neoplasms, may be associated with autoimmune hemolysis.

## APPROACH TO THE PATIENT

### Anemia

The evaluation of the patient with anemia requires a careful history and physical examination. Nutritional history related to drugs or alcohol intake and family history of anemia should always be assessed. Certain geographic backgrounds and ethnic origins are associated with an increased likelihood of an inherited disorder of the hemoglobin molecule or intermediary metabolism. Glucose-6-phosphate dehydrogenase (G6PD) deficiency and certain hemoglobinopathies are seen more commonly in those of Middle Eastern or African origin, including blacks who have a high frequency of G6PD deficiency. Other information that may be useful includes exposure to certain toxic agents or drugs and symptoms related to other disorders commonly associated with anemia. These include symptoms and signs such as bleeding, fatigue, malaise, fever, weight loss, night sweats, and other systemic symptoms. Clues to the mechanisms of anemia may be provided on physical examination by findings of infection, blood in the stool, lymphadenopathy, splenomegaly, or petechiae. Splenomegaly and lymphadenopathy suggest an underlying lymphoproliferative disease, whereas petechiae suggest platelet dysfunction. Past laboratory measurements are helpful to determine a time of onset.

In the anemic patient, physical examination may demonstrate a forceful heartbeat, strong peripheral pulses, and a systolic “flow” murmur. The skin and mucous membranes may be pale if the hemoglobin is <8–10 g/dL (80–100 g/L). This part of the physical examination should focus on areas where vessels are close to the surface such as the mucous membranes, nail beds, and palmar creases. If the palmar creases are lighter in color than the surrounding skin when the hand is hyperextended, the hemoglobin level is usually <8 g/dL (80 g/L).

### LABORATORY EVALUATION

**Table 63-1** lists the tests used in the initial workup of anemia. A routine complete blood count (CBC) is required as part of the evaluation and includes the hemoglobin, hematocrit, and red cell indices: the mean cell volume (MCV) in femtoliters, mean cell hemoglobin (MCH) in picograms per cell, and mean concentration of hemoglobin per volume of red cells (MCHC) in grams per liter (non-SI: grams per deciliter). The MCH is the least useful of the indices; it tends to track with the MCV. The red cell indices are calculated as shown in *Table 63-2*, and the normal variations in the hemoglobin and hematocrit with age are shown in *Table 63-3*. A number of physiologic factors affect the CBC, including age, sex, pregnancy, smoking, and altitude. High-normal hemoglobin values may be seen in men and women who live at altitude or smoke heavily. Hemoglobin elevations due to smoking reflect normal compensation due to the displacement of O<sub>2</sub> by CO in hemoglobin binding. Other important information is provided by the reticulocyte count and measurements of iron supply including *serum iron*, *total iron-binding capacity* (TIBC; an indirect measure of serum transferrin), and *serum ferritin*. Marked alterations in the red cell indices usually reflect disorders of maturation or iron deficiency. A careful evaluation of the peripheral blood smear is important, and clinical laboratories often provide a description of both the red and white cells, a white cell differential count, and the platelet count. In patients with severe anemia and abnormalities in red blood cell morphology and/or low reticulocyte counts, a bone marrow aspiration or biopsy can assist in the diagnosis. Other tests of value in the diagnosis of specific anemias are discussed in chapters on specific disease states.

The components of the CBC also help in the classification of anemia. *Microcytosis* is reflected by a lower than normal MCV (<80), whereas high values (>100) reflect *macrocytosis*. The MCHC reflects defects in hemoglobin synthesis (*hypochromia*). Automated cell counters describe the red cell volume distribution width (RDW). The MCV (representing the peak of the distribution curve)

TABLE 63-1 Laboratory Tests in Anemia Diagnosis

- I. Complete blood count (CBC)
  - A. Red blood cell count
    - 1. Hemoglobin
    - 2. Hematocrit
    - 3. Reticulocyte count
  - B. Red blood cell indices
    - 1. Mean cell volume (MCV)
    - 2. Mean cell hemoglobin (MCH)
    - 3. Mean cell hemoglobin concentration (MCHC)
    - 4. Red cell distribution width (RDW)
  - C. White blood cell count
    - 1. Cell differential
    - 2. Nuclear segmentation of neutrophils
  - D. Platelet count
  - E. Cell morphology
    - 1. Cell size
    - 2. Hemoglobin content
    - 3. Anisocytosis
    - 4. Poikilocytosis
    - 5. Polychromasia
- II. Iron supply studies
  - A. Serum iron
  - B. Total iron-binding capacity
  - C. Serum ferritin
- III. Marrow examination
  - A. Aspirate
    - 1. M/E ratio<sup>a</sup>
    - 2. Cell morphology
    - 3. Iron stain
  - B. Biopsy
    - 1. Cellularity
    - 2. Morphology

<sup>a</sup>M/E ratio, ratio of myeloid to erythroid precursors.

TABLE 63-2 Red Blood Cell Indices

INDEX	NORMAL VALUE
Mean cell volume (MCV) = (hematocrit × 10)/ (red cell count × 10 <sup>6</sup> )	90 ± 8 fL
Mean cell hemoglobin (MCH) = (hemoglobin × 10)/ (red cell count × 10 <sup>6</sup> )	30 ± 3 pg
Mean cell hemoglobin concentration = (hemoglobin × 10)/hematocrit, or MCH/MCV	33 ± 2%

TABLE 63-3 Changes in Normal Hemoglobin/Hematocrit Values with Age, Sex, and Pregnancy

AGE/SEX	HEMOGLOBIN, g/dL	HEMATOCRIT, %
At birth	17	52
Childhood	12	36
Adolescence	13	40
Adult man	16 (±2)	47 (±6)
Adult woman (menstruating)	13 (±2)	40 (±6)
Adult woman (postmenopausal)	14 (±2)	42 (±6)
During pregnancy	12 (±2)	37 (±6)

Source: From RS Hillman et al: *Hematology in Clinical Practice*, 5th ed. New York, McGraw-Hill, 2010.



FIGURE 63-3 Normal blood smear (Wright stain). High-power field showing normal red cells, a neutrophil, and a few platelets. (From RS Hillman et al: *Hematology in Clinical Practice*, 5th ed. New York, McGraw-Hill, 2010.)

is insensitive to the appearance of small populations of macrocytes or microcytes. An experienced laboratory technician will be able to identify minor populations of large or small cells or hypochromic cells on the peripheral blood film before the red cell indices change.

**Peripheral Blood Smear** The peripheral blood smear provides important information about defects in red cell production (Chap. 62). As a complement to the red cell indices, the blood smear also reveals variations in cell size (*anisocytosis*) and shape (*poikilocytosis*). The degree of anisocytosis usually correlates with increases in the RDW or the range of cell sizes. Poikilocytosis suggests a defect in the maturation of red cell precursors in the bone marrow or fragmentation of circulating red cells. The blood smear may also reveal *polychromasia*—red cells that are slightly larger than normal and grayish blue in color on the Wright-Giemsa stain. These cells are reticulocytes that have been released prematurely from the bone marrow and their color represents residual amounts of ribosomal RNA. These cells appear in circulation in response to EPO stimulation or to architectural damage of the bone marrow (fibrosis, infiltration of the marrow by malignant cells, etc.) that results in their disordered release from the marrow. The appearance of nucleated red cells, Howell-Jolly bodies, target cells, sickle cells, and other changes may provide clues to specific disorders (Figs. 63-3 to 63-11).

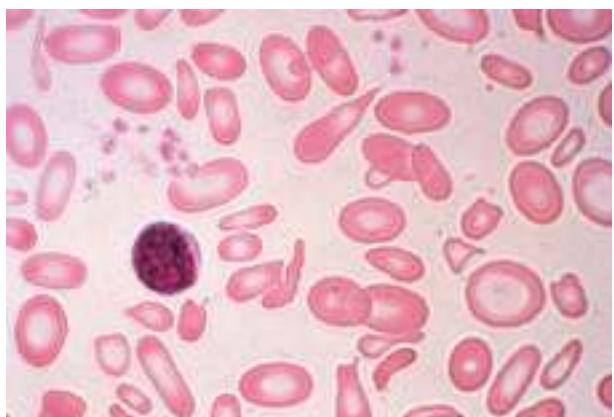
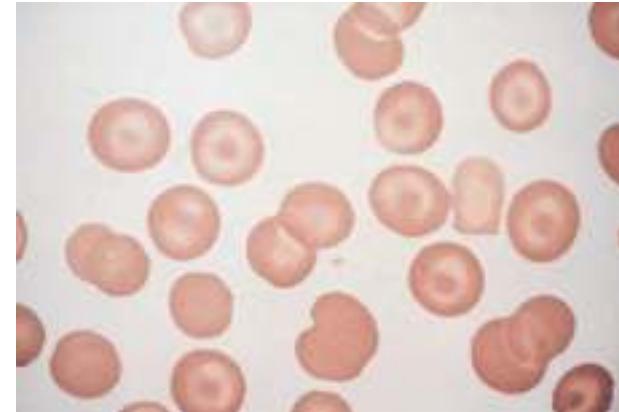


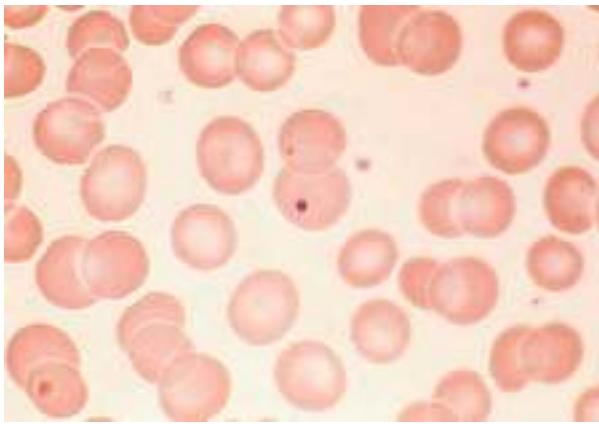
FIGURE 63-4 Severe iron-deficiency anemia. Microcytic and hypochromic red cells smaller than the nucleus of a lymphocyte associated with marked variation in size (anisocytosis) and shape (poikilocytosis). (From RS Hillman et al: *Hematology in Clinical Practice*, 5th ed. New York, McGraw-Hill, 2010.)



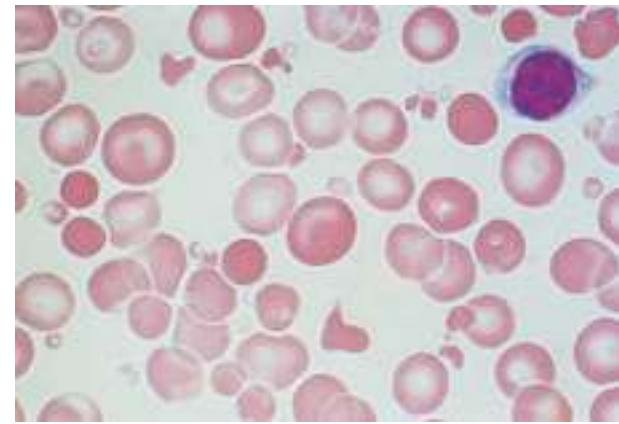
**FIGURE 63-5** Macrocytosis. Red cells are larger than a small lymphocyte and well hemoglobinized. Often macrocytes are oval shaped (macro-ovalocytes). (From RS Hillman et al: *Hematology in Clinical Practice*, 5th ed. New York, McGraw-Hill, 2010.)



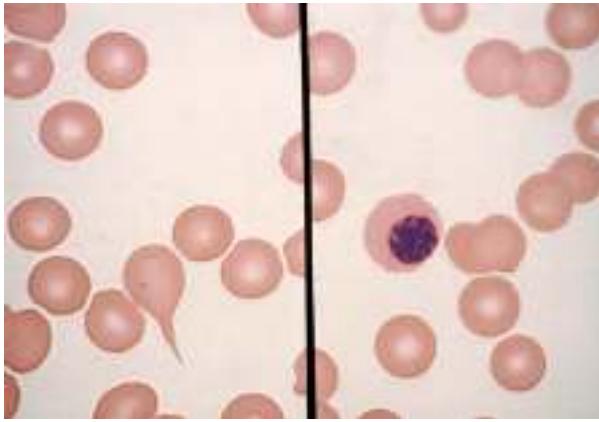
**FIGURE 63-8** Target cells. Target cells have a bull's-eye appearance and are seen in thalassemia and in liver disease. (From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



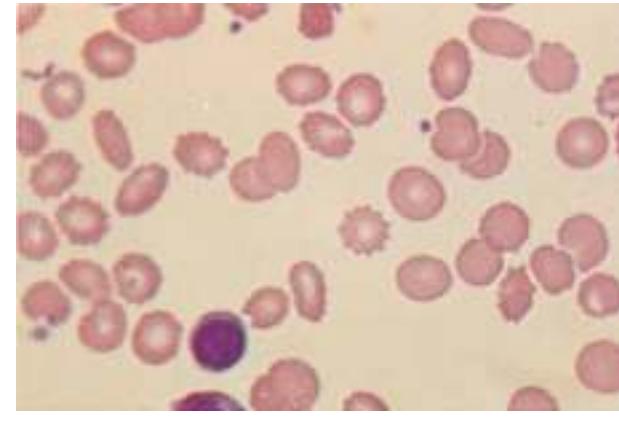
**FIGURE 63-6** Howell-Jolly bodies. In the absence of a functional spleen, nuclear remnants are not culled from the red cells and remain as small homogeneously staining blue inclusions on Wright stain. (From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw-Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw-Hill, 2005.)



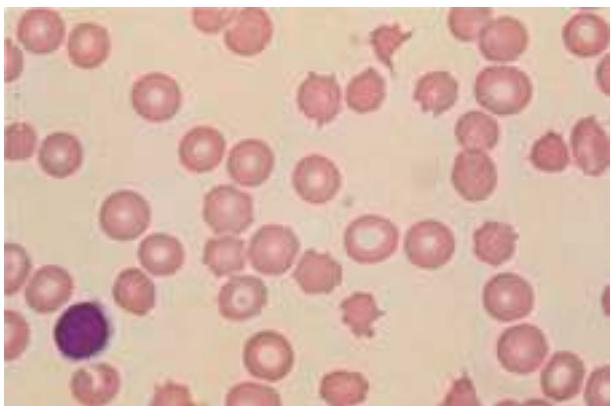
**FIGURE 63-9** Red cell fragmentation. Red cells may become fragmented in the presence of foreign bodies in the circulation, such as mechanical heart valves, or in the setting of thermal injury. (From RS Hillman et al: *Hematology in Clinical Practice*, 5th ed. New York, McGraw-Hill, 2010.)



**FIGURE 63-7** Red cell changes in myelofibrosis. The left panel shows a teardrop-shaped cell. The right panel shows a nucleated red cell. These forms can be seen in myelofibrosis. (From RS Hillman et al: *Hematology in Clinical Practice*, 5th ed. New York, McGraw-Hill, 2010.)



**FIGURE 63-10** Uremia. The red cells in uremia may acquire numerous regularly spaced, small, spiny projections. Such cells, called burr cells or echinocytes, are readily distinguishable from irregularly spiculated acanthocytes shown in Fig. 63-11. (From RS Hillman et al: *Hematology in Clinical Practice*, 5th ed. New York, McGraw-Hill, 2010.)



**FIGURE 63-11** Spur cells. Spur cells are recognized as distorted red cells containing several irregularly distributed thorn-like projections. Cells with this morphologic abnormality are also called acanthocytes. (From RS Hillman et al: *Hematology in Clinical Practice*, 5th ed. New York, McGraw-Hill, 2010.)

**Reticulocyte Count** An accurate reticulocyte count is key to the initial classification of anemia. Reticulocytes are red cells that have been recently released from the bone marrow. They are identified by staining with a supravital dye that precipitates the ribosomal RNA (Fig. 63-12). These precipitates appear as blue or black punctate spots and can be counted manually or, currently, by fluorescent emission of dyes that bind to RNA. This residual RNA is metabolized over the first 24–36 h of the reticulocyte's life span in circulation. Normally, the reticulocyte count ranges from 1% to 2% and reflects the daily replacement of 0.8–1.0% of the circulating red cell population. A corrected reticulocyte percentage or the absolute number of reticulocytes provides a reliable measure of effective red cell production.

In the initial classification of anemia, the patient's reticulocyte count is compared with the expected reticulocyte response. In general, if the EPO and erythroid marrow responses to moderate anemia [hemoglobin <100 g/L (10 g/dL)] are intact, the red cell production rate increases to two to three times normal within 10 days following the onset of anemia. In the face of established anemia, a reticulocyte response less than two to three times normal indicates an inadequate marrow response.

To use the reticulocyte count to estimate marrow response, two corrections are necessary. The first correction adjusts the reticulocyte count based on the reduced number of circulating red cells. With anemia, the percentage of reticulocytes may be increased



**FIGURE 63-12** Reticulocytes. Methylene blue stain demonstrates residual RNA in newly made red cells. (From RS Hillman et al: *Hematology in Clinical Practice*, 5th ed. New York, McGraw-Hill, 2010.)

**TABLE 63-4** Calculation of Reticulocyte Production Index

**Correction #1 for Anemia:**

This correction produces the corrected reticulocyte count.

In a person whose reticulocyte count is 9%, hemoglobin 7.5 g/dL, and hematocrit 23%, the absolute reticulocyte count =  $9 \times (7.5/15)$  [or  $\times (23/45)$ ] = 4.5%

Note. This correction is not done if the reticulocyte count is reported in absolute numbers (e.g., 50,000/ $\mu$ L of blood)

**Correction #2 for Longer Life of Prematurely Released Reticulocytes in the Blood:**

This correction produces the reticulocyte production index.

In a person whose reticulocyte count is 9%, hemoglobin 7.5 g/dL, and hematocrit 23%, the reticulocyte production index

$$= 9 \times \frac{(7.5/15)(\text{hemoglobin correction})}{2(\text{maturation time correction})} = 2.25$$

while the absolute number is unchanged. To correct for this effect, the reticulocyte percentage is multiplied by the ratio of the patient's hemoglobin or hematocrit to the expected hemoglobin/hematocrit for the age and sex of the patient (Table 63-4). This provides an estimate of the reticulocyte count corrected for anemia. To convert the corrected reticulocyte count to an index of marrow production, a further correction is required, depending on whether some of the reticulocytes in circulation have been released from the marrow prematurely. For this second correction, the peripheral blood smear is examined to see if there are polychromatophilic macrocytes present.

These cells, representing prematurely released reticulocytes, are referred to as "shift" cells, and the relationship between the degree of shift and the necessary shift correction factor is shown in Fig. 63-13. The correction is necessary because these prematurely released cells survive as reticulocytes in circulation for >1 day, thereby providing a falsely high estimate of daily red cell production. If polychromasia is increased, the reticulocyte count, already corrected for anemia, should be corrected again by 2 to account for the prolonged reticulocyte maturation time. The second correction factor varies from 1 to 3 depending on the severity of anemia. To simplify things, a correction of 2 is used. An appropriate correction is shown in Table 63-4. If polychromatophilic cells are not seen on

Hematocrit (%)	Marrow normoblasts and reticulocytes (days)	Peripheral blood reticulocytes (days)
45	3.5	1.0
35	3.0	1.5
25	2.5	2.0
15	1.5	2.5

↓

"SHIFT" correction factor

**FIGURE 63-13** Correction of the reticulocyte count. To use the reticulocyte count as an indicator of effective red cell production, the reticulocyte number must be corrected based on the level of anemia and the circulating life span of the reticulocytes. Erythroid cells take 4.5 days to mature. At a normal hemoglobin, reticulocytes are released to the circulation with 1 day left as reticulocytes. However, with different levels of anemia, reticulocytes (and even earlier erythroid cells) may be released from the marrow prematurely. Most patients come to clinical attention with hematocrits in the mid-20s, and thus a correction factor of 2 is commonly used because the observed reticulocytes will live for 2 days in the circulation before losing their RNA.

TABLE 63-5 Normal Marrow Response to Anemia

HEMOGLOBIN	PRODUCTION INDEX	RETICULOCYTE COUNT
15 g/dL	1	50,000/ $\mu$ L
11 g/dL	2.0–2.5	100–150,000/ $\mu$ L
8 g/dL	3.0–4.0	300–400,000/ $\mu$ L

the blood smear, the second correction is not indicated. The now doubly corrected reticulocyte count is the *reticulocyte production index*, and it provides an estimate of marrow production relative to normal. In many hospital laboratories, the reticulocyte count is reported not only as a percentage but also in absolute numbers. If so, no correction for dilution is required. A summary of the appropriate marrow response to varying degrees of anemia is shown in Table 63-5.

Premature release of reticulocytes is normally due to increased EPO stimulation. However, if the integrity of the bone marrow release process is lost through tumor infiltration, fibrosis, or other disorders, the appearance of nucleated red cells or polychromatophilic macrocytes should still invoke the second reticulocyte correction. The shift correction should always be applied to a patient with anemia and a very high reticulocyte count to provide a true index of effective red cell production. Patients with severe chronic hemolytic anemia may increase red cell production as much as six- to sevenfold. This measure alone confirms the fact that the patient has an appropriate EPO response, a normally functioning bone marrow, and sufficient iron available to meet the demands for new red cell formation. If the reticulocyte production index is  $<2$  in the face of established anemia, a defect in erythroid marrow proliferation or maturation must be present.

**Tests of Iron Supply and Storage** The laboratory measurements that reflect the availability of iron for hemoglobin synthesis include the serum iron, the TIBC, and the percent transferrin saturation. The percent transferrin saturation is derived by dividing the serum iron level ( $\times 100$ ) by the TIBC. The normal serum iron ranges from 9 to 27  $\mu$ mol/L (50–150  $\mu$ g/dL), whereas the normal TIBC is 54–64  $\mu$ mol/L (300–360  $\mu$ g/dL); the normal transferrin saturation ranges from 25 to 50%. A diurnal variation in the serum iron leads to a variation in the percent transferrin saturation. The serum ferritin is used to evaluate total body iron stores. Adult males have serum ferritin levels that average 100  $\mu$ g/L, corresponding to iron stores of 1 g. Adult premenopausal females have lower serum ferritin levels averaging 30  $\mu$ g/L, reflecting lower iron stores (300 mg). A serum ferritin level of 10–15  $\mu$ g/L indicates depletion of body iron stores. However, ferritin is also an acute-phase reactant and, in the presence of acute or chronic inflammation, may rise several-fold above baseline levels. As a rule, a serum ferritin  $>200 \mu\text{g/L}$  means there is at least some iron in tissue stores.

**Bone Marrow Examination** A bone marrow aspirate and smear or a needle biopsy can be useful in the evaluation of some patients with anemia. In patients with hypoproliferative anemia, normal renal function, and normal iron status, a bone marrow is indicated. Marrow examination can diagnose primary marrow disorders such as myelofibrosis, a red cell maturation defect, or an infiltrative disease (Figs. 63-14 to 63-16). The increase or decrease of one cell lineage (myeloid vs erythroid) compared to another is obtained by a differential count of nucleated cells in a bone marrow smear (the myeloid/erythroid [M/E] ratio). A patient with a hypoproliferative anemia (see below) and a reticulocyte production index  $<2$  will demonstrate an M/E ratio of 2 or 3:1. In contrast, patients with hemolytic disease and a production index  $>3$  will have an M/E ratio of at least 1:1. Maturation disorders are identified from the discrepancy between the M/E ratio and the reticulocyte production index (see below). Either the marrow smear or biopsy can be stained for the presence of iron stores or iron in developing red cells. The

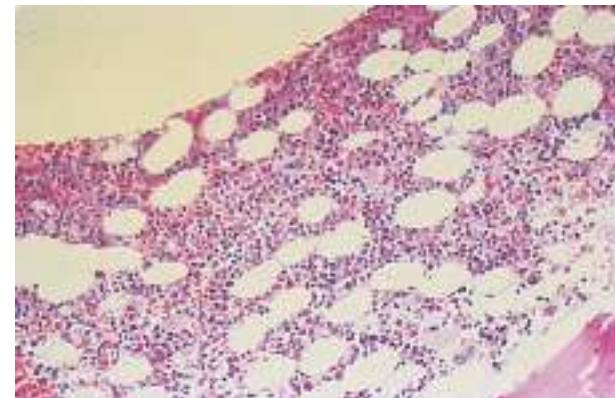


FIGURE 63-14 Normal bone marrow. This is a low-power view of a section of a normal bone marrow biopsy stained with hematoxylin and eosin (H&E). Note that the nucleated cellular elements account for 40–50% and the fat (clear areas) accounts for 50–60% of the area. (From RS Hillman et al: Hematology in Clinical Practice, 5th ed. New York, McGraw-Hill, 2010.)

storage iron is in the form of ferritin or *hemosiderin*. On carefully prepared bone marrow smears, small ferritin granules can normally be seen under oil immersion in 20–40% of developing erythroblasts. Such cells are called *sideroblasts*.

#### OTHER LABORATORY MEASUREMENTS

Additional laboratory tests may be of value in confirming specific diagnoses. For details of these tests and how they are applied in individual disorders, see Chaps. 97 to 101.

### ■ DEFINITION AND CLASSIFICATION OF ANEMIA

**Initial Classification of Anemia** The functional classification of anemia has three major categories. These are (1) marrow production defects (*hypoproliferation*), (2) red cell maturation defects (*ineffective erythropoiesis*), and (3) decreased red cell survival (*blood loss/hemolysis*). The classification is shown in Fig. 63-17. A hypoproliferative anemia is typically seen with a low reticulocyte production index together with little or no change in red cell morphology (a normocytic, normochromic anemia) (Chap. 97). Maturation disorders typically have a slight to moderately elevated reticulocyte production index that is accompanied by either macrocytic (Chap. 99) or microcytic (Chaps. 97, 98) red cell

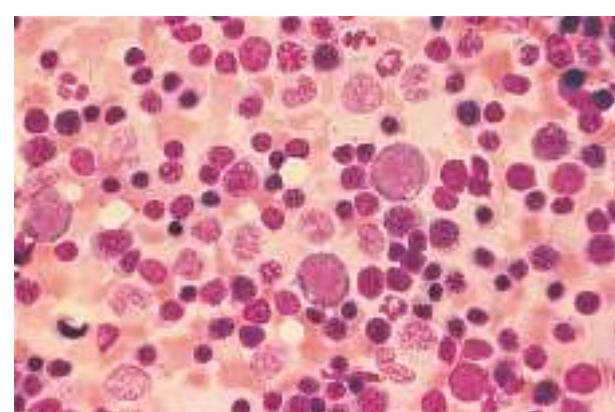
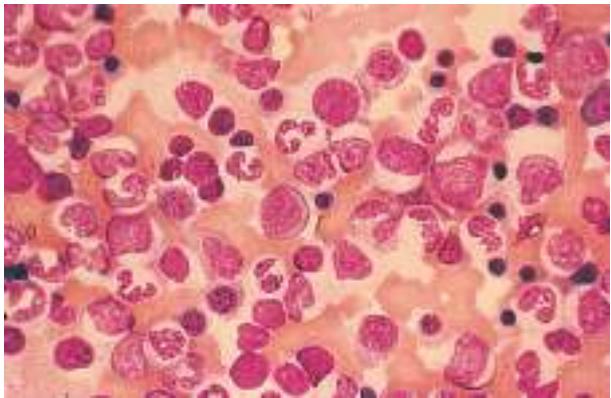


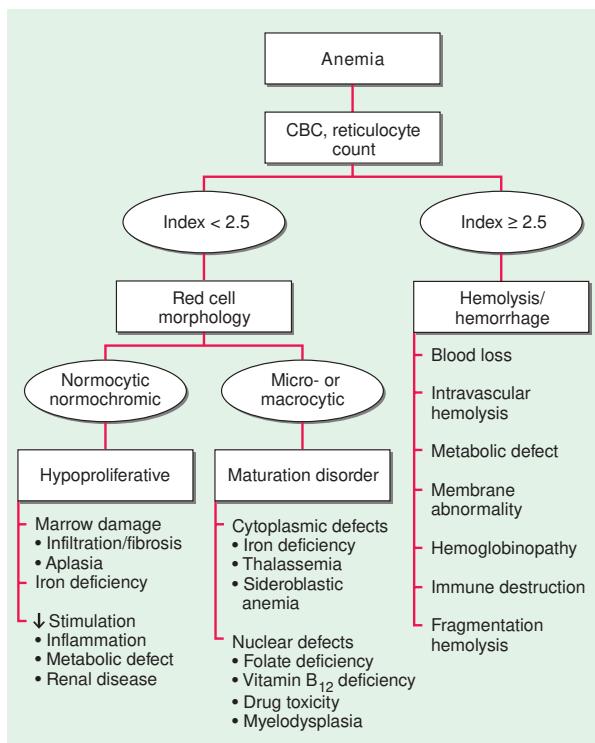
FIGURE 63-15 Erythroid hyperplasia. This marrow shows an increase in the fraction of cells in the erythroid lineage as might be seen when a normal marrow compensates for acute blood loss or hemolysis. The myeloid/erythroid (M/E) ratio is about 1:1. (From RS Hillman et al: Hematology in Clinical Practice, 5th ed. New York, McGraw-Hill, 2010.)



**FIGURE 63-16** Myeloid hyperplasia. This marrow shows an increase in the fraction of cells in the myeloid or granulocytic lineage as might be seen in a normal marrow responding to infection. The myeloid/erythroid (M/E) ratio is >3:1. (From RS Hillman et al: *Hematology in Clinical Practice*, 5th ed. New York, McGraw-Hill, 2010.)

indices. Increased red blood cell destruction secondary to hemolysis results in an increase in the reticulocyte production index to at least three times normal (Chap. 100), provided sufficient iron is available. Hemorrhagic anemia does not typically result in production indices of more than 2.0–2.5 times normal because of the limitations placed on expansion of the erythroid marrow by iron availability (Chap. 101).

In the first branch point of the classification of anemia, a reticulocyte production index  $>2.5$  indicates that hemolysis is most likely. A reticulocyte production index  $<2$  indicates either a hypoproliferative anemia or maturation disorder. The latter two possibilities can often be distinguished by the red cell indices, by examination of the peripheral blood smear, or by a marrow examination. If the red cell indices are normal, the anemia is almost certainly hypoproliferative.



**FIGURE 63-17** The physiologic classification of anemia. CBC, complete blood count.

in nature. Maturation disorders are characterized by ineffective red cell production and a low reticulocyte production index. Bizarre red cell shapes—macrocytes or hypochromic microcytes—are seen on the peripheral blood smear. With a hypoproliferative anemia, no erythroid hyperplasia is noted in the marrow, whereas patients with ineffective red cell production have erythroid hyperplasia and an M/E ratio  $<1:1$ .

**Hypoproliferative Anemias** At least 75% of all cases of anemia are hypoproliferative in nature. A hypoproliferative anemia reflects absolute or relative marrow failure in which the erythroid marrow has not proliferated appropriately for the degree of anemia. The majority of hypoproliferative anemias are due to mild to moderate iron deficiency or inflammation. A hypoproliferative anemia can result from marrow damage, iron deficiency, or inadequate EPO stimulation. The last may reflect impaired renal function, suppression of EPO production by inflammatory cytokines such as interleukin 1, or reduced tissue needs for  $O_2$  from metabolic disease such as hypothyroidism. Only occasionally is the marrow unable to produce red cells at a normal rate, and this is most prevalent in patients with renal failure. With diabetes mellitus or myeloma, the EPO deficiency may be more marked than would be predicted by the degree of renal insufficiency. In general, hypoproliferative anemias are characterized by normocytic, normochromic red cells, although microcytic, hypochromic cells may be observed with mild iron deficiency or long-standing chronic inflammatory disease. The key laboratory tests in distinguishing between the various forms of hypoproliferative anemia include the serum iron and iron-binding capacity, evaluation of renal and thyroid function, a marrow biopsy or aspirate to detect marrow damage or infiltrative disease, and serum ferritin to assess iron stores. An iron stain of the marrow will determine the pattern of iron distribution. Patients with the anemia of acute or chronic inflammation show a distinctive pattern of serum iron (low), TIBC (normal or low), percent transferrin saturation (low), and serum ferritin (normal or high). These changes in iron values are brought about by hepcidin, the iron regulatory hormone that is produced by the liver and is increased in inflammation (Chap. 97). A distinct pattern of results is noted in mild to moderate iron deficiency (low serum iron, high TIBC, low percent transferrin saturation, low serum ferritin) (Chap. 97). Marrow damage by drugs, infiltrative disease such as leukemia or lymphoma, or marrow aplasia is diagnosed from the peripheral blood and bone marrow morphology. With infiltrative disease or fibrosis, a marrow biopsy is required.

**Maturation Disorders** The presence of anemia with an inappropriately low reticulocyte production index, macro- or microcytosis on smear, and abnormal red cell indices suggests a maturation disorder. Maturation disorders are divided into two categories: nuclear maturation defects, associated with macrocytosis, and cytoplasmic maturation defects, associated with microcytosis and hypochromia usually from defects in hemoglobin synthesis. The inappropriately low reticulocyte production index is a reflection of the ineffective erythropoiesis that results from the destruction within the marrow of developing erythroblasts. Bone marrow examination shows erythroid hyperplasia.

Nuclear maturation defects result from vitamin B<sub>12</sub> or folic acid deficiency, drug damage, or myelodysplasia. Drugs that interfere with cellular DNA synthesis, such as methotrexate or alkylating agents, can produce a nuclear maturation defect. Alcohol, alone, is also capable of producing macrocytosis and a variable degree of anemia, but this is usually associated with folic acid deficiency. Measurements of folic acid and vitamin B<sub>12</sub> are critical not only in identifying the specific vitamin deficiency but also because they reflect different pathogenetic mechanisms (Chap. 99).

Cytoplasmic maturation defects result from severe iron deficiency or abnormalities in globin or heme synthesis. Iron deficiency occupies an unusual position in the classification of anemia. If the iron-deficiency anemia is mild to moderate, erythroid marrow proliferation is blunted and the anemia is classified as hypoproliferative. However, if the anemia is severe and prolonged, the erythroid marrow will become hyperplastic despite the inadequate iron supply, and the anemia will be classified as ineffective erythropoiesis with a cytoplasmic maturation defect. In either case, an inappropriately low reticulocyte

production index, microcytosis, and a classic pattern of iron values make the diagnosis clear and easily distinguish iron deficiency from other cytoplasmic maturation defects such as the thalassemias. Defects in heme synthesis, in contrast to globin synthesis, are less common and may be acquired or inherited (Chap. 416). Acquired abnormalities are usually associated with myelodysplasia, may lead to either a macro- or microcytic anemia, and are frequently associated with mitochondrial iron loading. In these cases, iron is taken up by the mitochondria of the developing erythroid cell but not incorporated into heme. The iron-encrusted mitochondria surround the nucleus of the erythroid cell, forming a ring. Based on the distinctive finding of so-called ringed sideroblasts on the marrow iron stain, patients are diagnosed as having a sideroblastic anemia—almost always reflecting myelodysplasia. Again, studies of iron parameters are helpful in the differential diagnosis of these patients.

**Blood Loss/Hemolytic Anemia** In contrast to anemias associated with an inappropriately low reticulocyte production index, hemolysis is associated with red cell production indices  $\geq 2.5$  times normal. The stimulated erythropoiesis is reflected in the blood smear by the appearance of increased numbers of polychromatophilic macrocytes. A marrow examination is rarely indicated if the reticulocyte production index is increased appropriately. The red cell indices are typically normocytic or slightly macrocytic, reflecting the increased number of reticulocytes. Acute blood loss is not associated with an increased reticulocyte production index because of the time required to increase EPO production and, subsequently, marrow proliferation (Chap. 101). Subacute blood loss may be associated with modest reticulocytosis. Anemia from chronic blood loss presents more often as iron deficiency than with the picture of increased red cell production.

The evaluation of blood loss anemia is usually not difficult. Most problems arise when a patient presents with an increased red cell production index from an episode of acute blood loss that went unrecognized. The cause of the anemia and increased red cell production may not be obvious. The confirmation of a recovering state may require observations over a period of 2–3 weeks, during which the hemoglobin concentration will rise and the reticulocyte production index fall (Chap. 101).

Hemolytic disease, while dramatic, is among the least common forms of anemia. The ability to sustain a high reticulocyte production index reflects the ability of the erythroid marrow to compensate for hemolysis and, in the case of extravascular hemolysis, the efficient recycling of iron from the destroyed red cells to support red cell production. With intravascular hemolysis, such as paroxysmal nocturnal hemoglobinuria, the loss of iron may limit the marrow response. The level of response depends on the severity of the anemia and the nature of the underlying disease process.

Hemoglobinopathies, such as sickle cell disease and the thalassemias, present a mixed picture. The reticulocyte index may be high but is inappropriately low for the degree of marrow erythroid hyperplasia (Chap. 98).

Hemolytic anemias present in different ways. Some appear suddenly as an acute, self-limited episode of intravascular or extravascular hemolysis, a presentation pattern often seen in patients with autoimmune hemolysis or with inherited defects of the Embden-Meyerhof pathway or the glutathione reductase pathway. Patients with inherited disorders of the hemoglobin molecule or red cell membrane generally have a lifelong clinical history typical of the disease process. Those with chronic hemolytic disease, such as hereditary spherocytosis, may actually present not with anemia but with a complication stemming from the prolonged increase in red cell destruction such as symptomatic bilirubin gallstones or splenomegaly. Patients with chronic hemolysis are also susceptible to aplastic crises if an infectious process interrupts red cell production.

The differential diagnosis of an acute or chronic hemolytic event requires the careful integration of family history, the pattern of clinical presentation, and—whether the disease is congenital or acquired—careful examination of the peripheral blood smear. Precise diagnosis may require more specialized laboratory tests, such as hemoglobin

electrophoresis or a screen for red cell enzymes. Acquired defects in red cell survival are often immunologically mediated and require a direct or indirect antiglobulin test or a cold agglutinin titer to detect the presence of hemolytic antibodies or complement-mediated red cell destruction (Chap. 100).

## TREATMENT

### Anemia

An overriding principle is to initiate treatment of mild to moderate anemia only when a specific diagnosis is made. Rarely, in the acute setting, anemia may be so severe that red cell transfusions are required before a specific diagnosis is available. Whether the anemia is of acute or gradual onset, the selection of the appropriate treatment is determined by the documented cause(s) of the anemia. Often, the cause of the anemia is multifactorial. For example, a patient with severe rheumatoid arthritis who has been taking anti-inflammatory drugs may have a hypoproliferative anemia associated with chronic inflammation as well as chronic blood loss associated with intermittent gastrointestinal bleeding. In every circumstance, it is important to evaluate the patient's iron status fully before and during the treatment of any anemia. Transfusion is discussed in Chap. 113; iron therapy is discussed in Chap. 97; treatment of megaloblastic anemia is discussed in Chap. 99; treatment of other entities is discussed in their respective chapters (sickle cell anemia, Chap. 98; megaloblastic anemia, Chap. 99; hemolytic anemias, Chap. 100; aplastic anemia and myelodysplasia, Chap. 102).

Therapeutic options for the treatment of anemias have expanded dramatically during the past 30 years. Blood component therapy is available and safe. Recombinant EPO as an adjunct to anemia management has transformed the lives of patients with chronic renal failure on dialysis and reduced transfusion needs of anemic cancer patients receiving chemotherapy. Eventually, patients with inherited disorders of globin synthesis or mutations in the globin gene, such as sickle cell disease, may benefit from the successful introduction of targeted genetic therapy (Chap. 470).

## POLYCYTHEMIA

*Polycythemia* is defined as an increase in the hemoglobin above normal. This increase may be real or only apparent because of a decrease in plasma volume (spurious or relative polycythemia). The term *erythrocytosis* may be used interchangeably with polycythemia, but some draw a distinction between them: erythrocytosis implies documentation of increased red cell mass, whereas polycythemia refers to any increase in red cells. Often patients with polycythemia are detected through an incidental finding of elevated hemoglobin or hematocrit levels. Concern that the hemoglobin level may be abnormally high is usually triggered at 17 g/dL (170 g/L) for men and 15 g/dL (150 g/L) for women. Hematocrit levels  $>50\%$  in men or  $>45\%$  in women may be abnormal. Hematocrits  $>60\%$  in men and  $>55\%$  in women are almost invariably associated with an increased red cell mass. Given that the machine that quantitates red cell parameters actually measures hemoglobin concentrations and calculates hematocrits, hemoglobin levels may be a better index.

Features of the clinical history that are useful in the differential diagnosis include smoking, current living at high altitude, a history of diuretic use, congenital heart disease, sleep apnea, or chronic lung disease.

Patients with polycythemia may be asymptomatic or experience symptoms related to the increased red cell mass or the underlying disease process that leads to the increased red cell mass. The dominant symptoms from an increased red cell mass are related to hyperviscosity and thrombosis (both venous and arterial), because the blood viscosity increases logarithmically at hematocrits  $>55\%$ . Manifestations include neurologic symptoms such as vertigo, tinnitus, headache, and visual disturbances. Hypertension is often present. Patients with *polycythemia vera* may have aquagenic pruritus, symptoms related to

hepatosplenomegaly, easy bruising, epistaxis, or bleeding from the gastrointestinal tract. Peptic ulcer disease is common. Such patients also may present with digital ischemia, Budd-Chiari syndrome, or hepatic or splenic/mesenteric vein thrombosis. Patients with hypoxemia may develop cyanosis on minimal exertion or have headache, impaired mental acuity, and fatigue.

The physical examination usually reveals a ruddy complexion. Splenomegaly favors polycythemia vera as the diagnosis (Chap. 103). The presence of cyanosis or evidence of a right-to-left shunt suggests congenital heart disease presenting in the adult, particularly tetralogy of Fallot or Eisenmenger's syndrome (Chap. 269). Increased blood viscosity raises pulmonary artery pressure; hypoxemia can lead to increased pulmonary vascular resistance. Together, these factors can produce cor pulmonale.

Polycythemia can be spurious (related to a decrease in plasma volume; Gaisböck's syndrome), primary, or secondary in origin. The secondary causes are all mediated by EPO: either a physiologically adapted appropriate level based on tissue hypoxia (lung disease, high altitude, CO poisoning, high-affinity hemoglobinopathy) or an abnormal overproduction (renal cysts, renal artery stenosis, tumors with ectopic EPO production). A rare familial form of polycythemia is associated with normal EPO levels but hyperresponsive EPO receptors due to mutations.

## APPROACH TO THE PATIENT

### Polycythemia

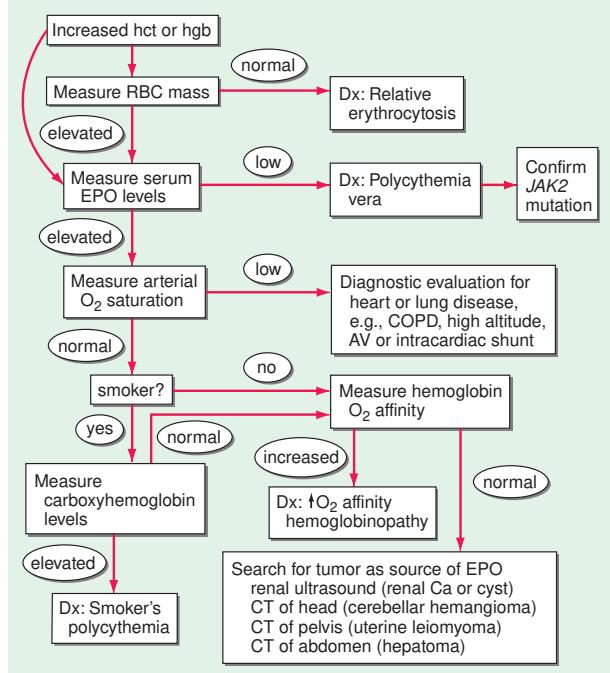
As shown in Fig. 63-18, the first step is to document the presence of an increased red cell mass using the principle of isotope dilution by administering  $^{51}\text{Cr}$ -labeled autologous red blood cells to the patient and sampling blood radioactivity over a 2-h period. If the red cell mass is normal (<36 mL/kg in men, <32 mL/kg in women), the patient has spurious or relative polycythemia. If the red cell mass is

increased (>36 mL/kg in men, >32 mL/kg in women), serum EPO levels should be measured. It must be acknowledged that measurement of red cell mass is a physiologic approach to distinguishing polycythemia, and because of the use of radionuclide-labeled red cells, it is rarely performed. It is more common to measure EPO levels in a person with an elevated hemoglobin level or hematocrit. If EPO levels are low or unmeasurable, the patient most likely has polycythemia vera. A mutation in *JAK2* (Val617Phe), a key member of the cytokine intracellular signaling pathway, can be found in 90–95% of patients with polycythemia vera. Many of those without this particular *JAK2* mutation have mutations in exon 12. If EPO levels are low, check for *JAK2* mutation(s), and perform an abdominal ultrasound to assess spleen size. Tests that support the diagnosis of polycythemia vera include elevated white blood cell count, increased absolute basophil count, and thrombocytosis. In practice, many physicians order EPO levels and assessment for *JAK2* mutations at the same time.

If serum EPO levels are elevated, one needs to distinguish whether the elevation is a physiologic response to hypoxia or related to autonomous EPO production. Patients with low arterial  $\text{O}_2$  saturation (<92%) should be further evaluated for the presence of heart or lung disease, if they are not living at high altitude. Patients with normal  $\text{O}_2$  saturation who are smokers may have elevated EPO levels because of CO displacement of  $\text{O}_2$ . If carboxyhemoglobin (COHb) levels are high, the diagnosis is "smoker's polycythemia." Such patients should be urged to stop smoking. Those who cannot stop smoking require phlebotomy to control their polycythemia. Patients with normal  $\text{O}_2$  saturation who do not smoke either have an abnormal hemoglobin that does not deliver  $\text{O}_2$  to the tissues (evaluated by finding elevated  $\text{O}_2$ -hemoglobin affinity) or have a source of EPO production that is not responding to the normal feedback inhibition. Further workup is dictated by the differential diagnosis of EPO-producing neoplasms. Hepatoma, uterine leiomyoma, and renal cancer or cysts are all detectable with abdominopelvic computed tomography scans. Cerebellar hemangiomas may produce EPO, but they present with localizing neurologic signs and symptoms rather than polycythemia-related symptoms.

## FURTHER READING

- H RS et al: *Hematology in Clinical Practice*, 5th ed. New York, McGraw-Hill, 2010.
- M M MF et al: Guidelines for the diagnosis, investigation and management of polycythaemia/erythrocytosis. *Br J Haematol* 130:174, 2005.
- S VG, W MJ: Anemia: progress in molecular mechanisms and therapies. *Nat Med* 21:221, 2015.
- S JL: How I manage polycythemia vera. *Blood* 134:341, 2019.



**FIGURE 63-18** An approach to the differential diagnosis of patients with an elevated hemoglobin (possible polycythemia). AV, atrioventricular; Ca, calcium; COPD, chronic obstructive pulmonary disease; CT, computed tomography; EPO, erythropoietin; hct, hematocrit; hgb, hemoglobin; IVP, intravenous pyelogram; RBC, red blood cell.

## 64 Disorders of Granulocytes and Monocytes

Steven M. Holland, John I. Gallin

Leukocytes, the major cells comprising inflammatory and immune responses, include neutrophils, T and B lymphocytes, natural killer (NK) cells, monocytes, eosinophils, and basophils. These cells have specific functions, such as antibody production by B lymphocytes or destruction of bacteria by neutrophils, but in no single infectious disease is the exact role of the cell types completely established. Thus, whereas neutrophils are classically thought to be critical to host defense

against bacteria, they may also play important roles in defense against viral infections.

The blood delivers leukocytes to the various tissues from the bone marrow, where they are produced. Normal blood leukocyte counts are  $4.3\text{--}10.8 \times 10^9/\text{L}$ , with neutrophils representing 45–74% of the cells, bands 0–4%, lymphocytes 16–45%, monocytes 4–10%, eosinophils 0–7%, and basophils 0–2%. Variation among individuals and among different ethnic groups can be substantial, with lower leukocyte numbers for certain African-American ethnic groups. Lower granulocyte numbers in African-Americans are often in the 1500–2000/ $\mu\text{L}$  range and are generally without sequelae. The condition is termed benign ethnic neutropenia. The lower number of granulocytes is associated with null expression of the Duffy antigen receptor for cytokines (*DARC*) gene, a receptor for malarial parasites, the absence of which conveys resistance to malaria. The various leukocytes are derived from a common stem cell in the bone marrow. Three-fourths of the nucleated cells of bone marrow are committed to the production of leukocytes. Leukocyte maturation in the marrow is under the regulatory control of a number of different factors, known as colony-stimulating factors (CSFs) and interleukins (ILs). Because an alteration in the number and type of leukocytes is often associated with disease processes, total white blood cell (WBC) count (cells per  $\mu\text{L}$ ) and differential counts are informative. This chapter focuses on neutrophils, monocytes, and eosinophils. *Lymphocytes and basophils* are discussed in Chaps. 349 and 353, respectively.

## NEUTROPHILS

### MATURATION

Important events in neutrophil life are summarized in Fig. 64-1. In normal humans, neutrophils are produced only in the bone marrow. The minimum number of stem cells necessary to support hematopoiesis is estimated to be 400–500 at any one time. Human blood monocytes, tissue macrophages, and stromal cells produce CSFs, hormones required for the growth of monocytes and neutrophils in the bone marrow. The hematopoietic system not only produces enough neutrophils ( $1.3 \times 10^{11}$  cells per 80-kg person per day) to carry out physiologic functions but also has a large reserve stored in the marrow, which can be mobilized in response to inflammation or infection. An increase in the number of blood neutrophils is called *neutrophilia*, and the presence of immature cells is termed a *shift to the left*. A decrease in the number of blood neutrophils is called *neutropenia*.

Neutrophils and monocytes evolve from pluripotent stem cells under the influence of cytokines and CSFs (Fig. 64-2). The proliferation phase through the metamyelocyte takes about 1 week, while the maturation phase from metamyelocyte to mature neutrophil takes another week. The myeloblast is the first recognizable precursor cell and is followed by the *promyelocyte*. The promyelocyte evolves when the classic lysosomal granules, called the *primary*, or *azurophil*, granules are produced. The primary granules contain hydrolases, elastase, myeloperoxidase, cathepsin G, cationic proteins, and bactericidal/permeability-increasing protein, which is important for killing gram-negative bacteria. Azurophil granules also contain *defensins*, a family of cysteine-rich polypeptides with broad antimicrobial activity against bacteria, fungi and certain enveloped viruses. The promyelocyte divides to produce the *myelocyte*, a cell responsible for the synthesis of the *specific*, or *secondary*, granules, which contain unique (specific) constituents such as lactoferrin, vitamin  $B_{12}$ -binding protein, membrane components of the reduced nicotinamide-adenine dinucleotide phosphate (NADPH) oxidase required for hydrogen peroxide production, histaminase, and receptors for certain chemoattractants and adherence-promoting factors (CR3) as well as receptors for the basement membrane component, laminin. The secondary granules do not contain acid hydrolases and therefore are not classic lysosomes. Packaging of secondary granule contents during myelopoiesis is controlled by CCAAT/enhancer binding protein- $\epsilon$ . Secondary granule contents are readily released extracellularly, and their mobilization is important in modulating inflammation. During the final stages of maturation, no cell division occurs, and the cell passes through the metamyelocyte stage and then to the band neutrophil with a sausage-shaped nucleus (Fig. 64-3). As the band cell matures, the nucleus assumes a lobulated configuration. The nucleus of neutrophils normally contains up to four segments (Fig. 64-4). Excessive segmentation (>5 nuclear lobes) may be a manifestation of folate or vitamin  $B_{12}$  deficiency or the congenital neutropenia syndrome of warts, hypogammaglobulinemia, infections, and myelokathexis (WHIM) described below. The Pelger-Hüet anomaly (Fig. 64-5), an infrequent dominant benign inherited trait caused by heterozygous mutations in the lamin B receptor, results in neutrophils with distinctive bilobed nuclei that must be distinguished from band forms. Acquired bilobed nuclei, pseudo-Pelger-Hüet anomaly, can occur with acute infections or in myelodysplastic syndromes. The physiologic role of the normal multilobed nucleus of neutrophils is

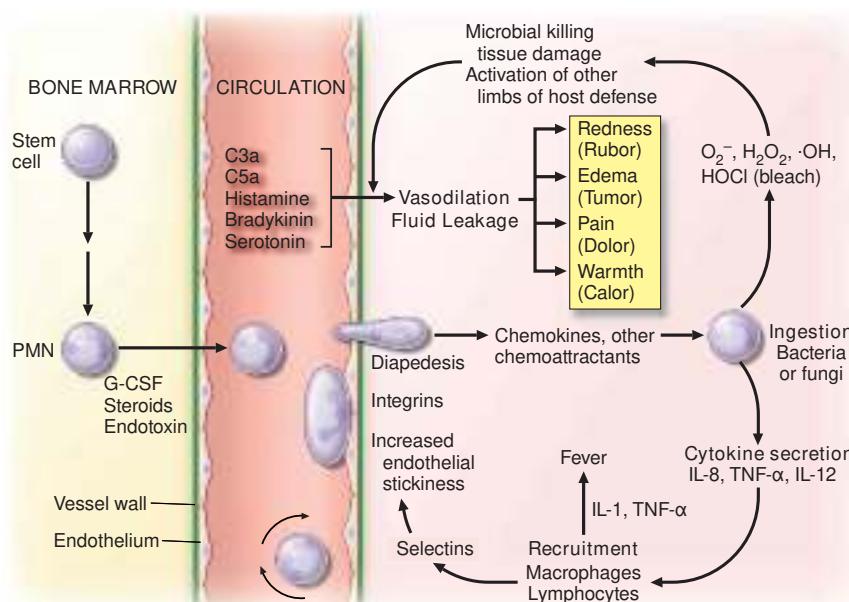


FIGURE 64-1 Schematic events in neutrophil production, recruitment, and inflammation. The four cardinal signs of inflammation (rubor, tumor, calor, dolor) are indicated, as are the interactions of neutrophils with other cells and cytokines. G-CSF, granulocyte colony-stimulating factor; IL, interleukin; PMN, polymorphonuclear leukocyte; TNF- $\alpha$ , tumor necrosis factor  $\alpha$ .

Cell	Stage	Surface Markers <sup>a</sup>	Characteristics
	MYELOBLAST	CD33, CD13, CD15	Prominent nucleoli
	PROMYELOCYTE	CD33, CD13, CD15	Large cell Primary granules appear
	MYELOCYTE	CD33, CD13, CD15, CD14, CD11b	Secondary granules appear
	METAMYELOCYTE	CD33, CD13, CD15, CD14, CD11b	Kidney bean-shaped nucleus
	BAND FORM	CD33, CD13, CD15, CD14, CD11b, CD10, CD16	Condensed, band-shaped nucleus
	NEUTROPHIL	CD33, CD13, CD15, CD14, CD11b, CD10, CD16	Condensed, multilobed nucleus

<sup>a</sup>CD = Cluster Determinant; ● Nucleolus; ● Primary granule; ● Secondary granule.

FIGURE 64-2 Stages of neutrophil development shown schematically. Granulocyte colony-stimulating factor (G-CSF) and granulocyte-macrophage colony-stimulating factor (GM-CSF) are critical to this process. Identifying cellular characteristics and specific cell-surface markers are listed for each maturational stage.

unknown, but it may allow great deformation of neutrophils during migration into tissues at sites of inflammation.

In severe acute bacterial infection, prominent neutrophil cytoplasmic granules, called *toxic granulations*, are occasionally seen.



FIGURE 64-3 Neutrophil band with Döhle body. The neutrophil with a sausage-shaped nucleus in the center of the field is a band form. Döhle bodies are discrete, blue-staining, nongranular areas found in the periphery of the cytoplasm of the neutrophil in infections and other toxic states. They represent aggregates of rough endoplasmic reticulum.

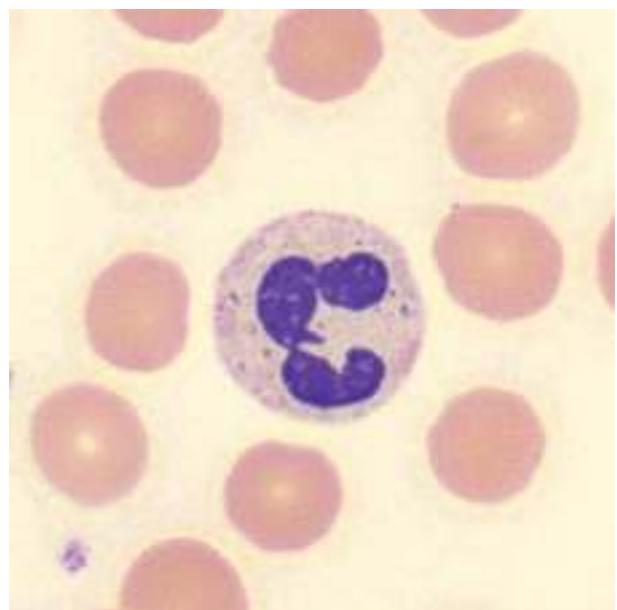


FIGURE 64-4 Normal granulocyte. The normal granulocyte has a segmented nucleus with heavy, clumped chromatin; fine neutrophilic granules are dispersed throughout the cytoplasm.

Toxic granulations are immature or abnormally staining azurophil granules. Cytoplasmic inclusions, also called *Döhle bodies* (Fig. 64-3), can be seen during infection and are fragments of ribosome-rich endoplasmic reticulum. Large neutrophil vacuoles are often present in acute bacterial infection in some viral infections such as COVID-19 and probably represent pinocytosed (internalized) membrane (Fig. 64-6).

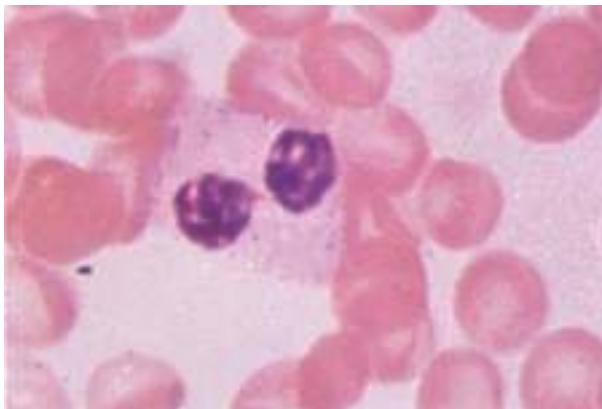
Neutrophils are heterogeneous in function. Monoclonal antibodies have been developed that recognize only a subset of mature neutrophils. The meaning of neutrophil heterogeneity is not known.

The morphology of eosinophils and basophils is shown in Fig. 64-7.

### MARROW RELEASE AND CIRCULATING COMPARTMENTS

Specific signals, including IL-1, tumor necrosis factor  $\alpha$  (TNF- $\alpha$ ), the CSFs, complement fragments, and chemokines, mobilize leukocytes from the bone marrow and deliver them to the blood in an unstimulated state. Under normal conditions, 90% of the neutrophil pool is in the bone marrow, 2–3% in the circulation, and the remainder in the tissues (Fig. 64-8).

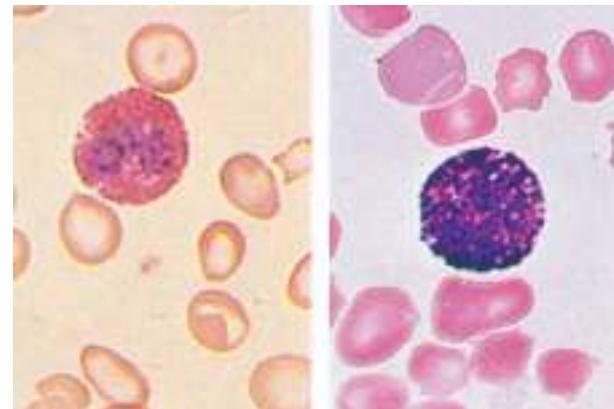
The circulating pool exists in two dynamic compartments: one freely flowing and one margined. The freely flowing pool is about one-half the neutrophils in the basal state and is composed of those cells that are in the blood and not in contact with the endothelium. Marginated leukocytes are those that are in close physical contact with the endothelium (Fig. 64-9). In the pulmonary circulation, where an extensive capillary bed (~1000 capillaries per alveolus) exists, margination occurs because the capillaries are about the same size as a mature neutrophil. Therefore, neutrophil fluidity and deformability are necessary to make the transit through the pulmonary bed. Increased neutrophil rigidity and



**FIGURE 64-5** Pelger-Hüet anomaly. In this benign disorder, the majority of granulocytes are bilobed. The nucleus frequently has a spectacle-like, or “pince-nez,” configuration. (From M Lichtman et al (eds): *Williams Hematology*, 7th ed. New York, McGraw Hill, 2005; RS Hillman, KA Ault: *Hematology in General Practice*, 4th ed. New York, McGraw Hill, 2005.)

decreased deformability lead to augmented neutrophil trapping and margination in the lung. In contrast, in the systemic postcapillary venules, margination is mediated by the interaction of specific cell-surface molecules called *selectins*. Selectins are glycoproteins expressed on neutrophils and endothelial cells, among others, that cause a low-affinity interaction, resulting in “rolling” of the neutrophil along the endothelial surface. On neutrophils, the molecule L-selectin (cluster determinant [CD] 62L) binds to glycosylated proteins on endothelial cells (e.g., glycosylation-dependent cell adhesion molecule [GlyCAM1] and CD34). Glycoproteins on neutrophils, most importantly sialyl-Lewis<sup>x</sup> (SLe<sup>x</sup>, CD15s), are targets for binding of selectins expressed on endothelial cells (E-selectin [CD62E] and P-selectin [CD62P]) and other leukocytes. In response to chemoattractant stimuli from injured tissues (e.g., complement product C5a, leukotriene B<sub>4</sub>, IL-8) or bacterial products (e.g., N-formylmethionylleucylphenylalanine [f-met-leu-phe]), neutrophil adhesiveness increases through mobilization of intracellular adhesion proteins stored in specific granules to the cell surface, and the cells “stick” to the endothelium through *integrins*. The integrins are leukocyte glycoproteins that exist as complexes of a common CD18  $\beta$  chain with CD11a (LFA-1), CD11b (called Mac-1, CR3, or the C3bi receptor), and CD11c (called p150,95 or CR4). CD11a/CD18 and CD11b/CD18 bind to specific endothelial receptors (intercellular adhesion molecules [ICAM] 1 and 2).

On cell stimulation, L-selectin is shed from neutrophils, and E-selectin increases in the blood, presumably because it is shed from endothelial cells; receptors for chemoattractants and opsonins are mobilized; and the phagocytes orient toward the chemoattractant source in the extravascular space, increase their motile activity (chemokinesis),

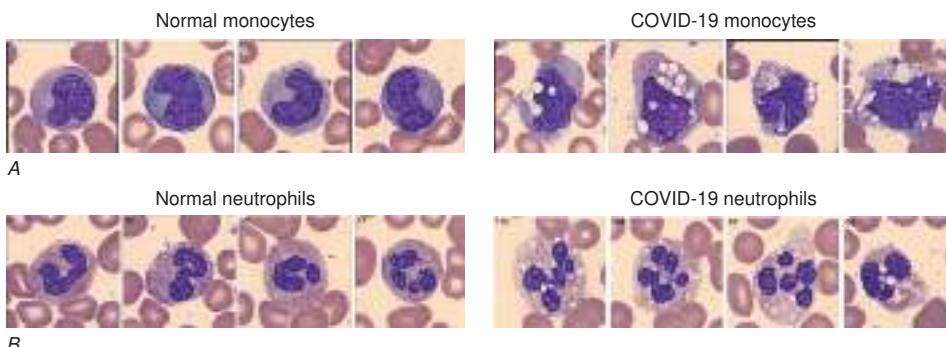


**FIGURE 64-7** Normal eosinophil (left) and basophil (right). The eosinophil contains large, bright orange granules and usually a bilobed nucleus. The basophil contains large purple-black granules that fill the cell and obscure the nucleus.

and migrate directionally (chemotaxis) into tissues. The process of migration into tissues is called *diapedesis* and involves the crawling of neutrophils between postcapillary endothelial cells that open junctions between adjacent cells to permit leukocyte passage. Diapedesis involves platelet/endothelial cell adhesion molecule (PECAM) 1 (CD31), which is expressed on both the emigrating leukocyte and the endothelial cells. The endothelial responses (increased blood flow from increased vasodilation and permeability) are mediated by anaphylatoxins (e.g., C3a and C5a) as well as vasodilators such as histamine, bradykinin, serotonin, nitric oxide, vascular endothelial growth factor (VEGF), and prostaglandins E and I. Cytokines regulate some of these processes (e.g., TNF- $\alpha$  induction of VEGF, interferon [IFN]  $\gamma$  inhibition of prostaglandin E).

In the healthy adult, most neutrophils leave the body by migration through the mucous membrane of the gastrointestinal tract. Normally, neutrophils spend a short time in the circulation (half-life, 6–7 h). Senescent neutrophils are cleared from the circulation by macrophages in the lung and spleen. Once in the tissues, neutrophils release enzymes, such as collagenase and elastase, which may help establish abscess cavities. Neutrophils ingest pathogenic materials that have been opsonized by IgG and C3b. Fibronectin and the tetrapeptide tuftsin also facilitate phagocytosis.

With phagocytosis comes a burst of oxygen consumption and activation of the hexose-monophosphate shunt. A membrane-associated NADPH oxidase, consisting of membrane and cytosolic components, is assembled and catalyzes the univalent reduction of oxygen to superoxide anion, which is then converted by superoxide dismutase to hydrogen peroxide and other toxic oxygen products (e.g.,



**FIGURE 64-6** COVID-19: Vacuolization in peripheral blood monocytes and neutrophils of COVID-19 patients. Peripheral blood smear showing vacuolization in (A) monocytes and (B) neutrophils from hospitalized hypoxic COVID-19 patients relative to healthy volunteers. Increased vacuoles were noted in 80% of monocytes and 50% of neutrophils in each COVID-19 patient throughout their hospitalization.

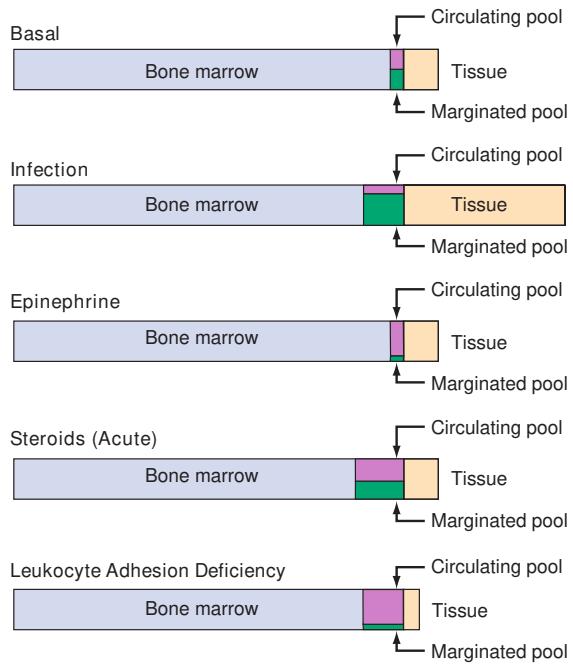


FIGURE 64-8 Schematic neutrophil distribution and kinetics between the different anatomic and functional pools.

hydroxyl radical). Hydrogen peroxide + chloride + neutrophil myeloperoxidase generates hypochlorous acid (bleach), hypochlorite, and chlorine. These products oxidize and halogenate microorganisms and tumor cells and, when uncontrolled, can damage host tissue. Strongly

cationic proteins, defensins, elastase, cathepsins, and probably nitric oxide also participate in microbial killing. Lactoferrin chelates iron, an important growth factor for microorganisms, especially fungi. Other enzymes, such as lysozyme and acid proteases, help digest microbial debris. After 1–4 days in tissues, neutrophils die. The apoptosis of neutrophils is also cytokine-regulated; granulocyte colony-stimulating factor (G-CSF) and IFN- $\gamma$  prolong their life span. Neutrophil extracellular traps (NETs) consisting of a DNA scaffold decorated with neutrophil-granule derived proteins, such as enzymatically active proteases and antimicrobial peptides, have been described recently and are thought to be formed as a defense mechanism to immobilize invading microorganisms. Under certain conditions, such as in delayed-type hypersensitivity, monocyte accumulation occurs within 6–12 h of initiation of inflammation. Neutrophils, monocytes, microorganisms in various states of digestion, and altered local tissue cells make up the inflammatory exudate, pus. Myeloperoxidase confers the characteristic green color to pus and may participate in turning off the inflammatory process by inactivating chemoattractants and immobilizing phagocytic cells.

Neutrophils respond to certain cytokines (IFN- $\gamma$ , granulocyte-macrophage colony-stimulating factor [GM-CSF], IL-8) and produce cytokines and chemotactic signals (TNF- $\alpha$ , IL-8, macrophage inflammatory protein [MIP] 1) that modulate the inflammatory response. In the presence of fibrinogen, f-met-leu-phe or leukotriene B<sub>4</sub>, IL-8 production by neutrophils is induced, providing autocrine amplification of inflammation. *Chemokines* (*chemoattractant cytokines*) are small proteins produced by many different cell types, including endothelial cells, fibroblasts, epithelial cells, neutrophils, and monocytes, that regulate neutrophil, monocyte, eosinophil, and lymphocyte recruitment and activation. Chemokines transduce their signals through heterotrimeric G protein-linked receptors that have seven cell membrane-spanning domains, the same type of cell-surface receptor that mediates the response to the classic chemoattractants f-met-leu-phe and C5a. Four major groups of chemokines are recognized based on the cysteine structure near the N terminus: C, CC, CXC, and CXXXC. The CXC cytokines such as IL-8 mainly attract neutrophils; CC chemokines such as MIP-1 attract lymphocytes, monocytes, eosinophils, and basophils; the C chemokine lymphotactin is T-cell tropic; the CXXXC chemokine fractalkine attracts neutrophils, monocytes, and T cells. These molecules and their receptors not only regulate the trafficking and activation of inflammatory cells, but specific chemokine receptors also serve as co-receptors for HIV infection (Chap. 202), while others have roles in other viral infections (e.g., West Nile virus), susceptibility and response to *Candida*, and atherogenesis.

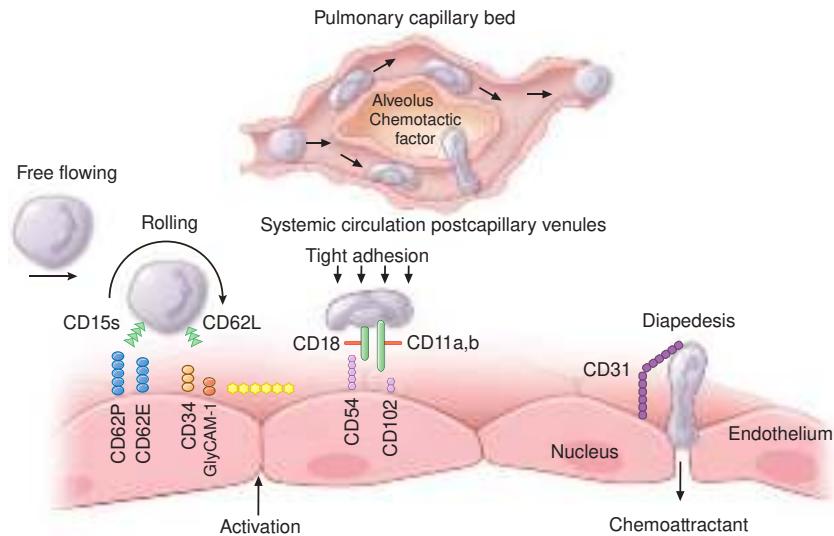


FIGURE 64-9 Neutrophil travel through the pulmonary capillaries is dependent on neutrophil deformability. Neutrophil rigidity (e.g., caused by C5a) enhances pulmonary trapping and response to pulmonary pathogens in a way that is not so dependent on cell-surface receptors. Intraalveolar chemotactic factors, such as those caused by certain bacteria (e.g., *Streptococcus pneumoniae*), lead to diapedesis of neutrophils from the pulmonary capillaries into the alveolar space. Neutrophil interaction with the endothelium of the systemic postcapillary venules is dependent on molecules of attachment. The neutrophil "rolls" along the endothelium using selectins: neutrophil CD15s (sialyl-Lewis<sup>x</sup>) binds to CD62E (E-selectin) and CD62P (P-selectin) on endothelial cells; CD62L (L-selectin) on neutrophils binds to CD34 and other molecules (e.g., GlyCAM-1) expressed on endothelium. Chemokines or other activation factors stimulate integrin-mediated "tight adhesion": CD11a/CD18 (LFA-1) and CD11b/CD18 (Mac-1, CR3) bind to CD54 (ICAM-1) and CD102 (ICAM-2) on the endothelium. Diapedesis occurs between endothelial cells: CD31 (PECAM-1) expressed by the emigrating neutrophil interacts with CD31 expressed at the endothelial cell-cell junction. CD, cluster determinant; GlyCAM, glycosylation-dependent cell adhesion molecule; ICAM, intercellular adhesion molecule; PECAM, platelet/endothelial cell adhesion molecule.

## ■ NEUTROPHIL ABNORMALITIES

Defects in the neutrophil life cycle can lead to dysfunction and compromised host defenses. When inflammation is severely depressed the clinical result is often recurrent, severe bacterial and fungal infections. Aphthous ulcers of mucous membranes (gray ulcers without pus) and gingivitis and periodontal disease suggest a phagocytic cell disorder. Patients with congenital phagocyte defects can have infections within the first few days of life. Skin, ear, upper and lower respiratory tract, and bone infections are common. Sepsis and meningitis are rare. In some disorders, the frequency

of infection is variable, and patients can go for months or even years without major infection. Aggressive management of these congenital diseases, including hematopoietic stem cell transplantation and gene therapy, has extended the life span of patients well into adulthood.

**Neutropenia** The consequences of absent neutrophils are dramatic. Susceptibility to infectious diseases increases sharply when neutrophil counts fall to <1000 cells/ $\mu$ L. When the absolute neutrophil count (ANC; band forms and mature neutrophils combined) falls to <500 cells/ $\mu$ L, control of endogenous microbial flora (e.g., mouth, gut) is impaired; when the ANC is <200/ $\mu$ L, the local inflammatory process is absent. Neutropenia can be due to depressed production, increased peripheral destruction, or excessive peripheral pooling. A falling neutrophil count or a significant decrease in the number of neutrophils below steady-state levels, together with a failure to increase neutrophil counts in the setting of infection or other challenge, requires investigation. Acute neutropenia, such as that caused by cancer chemotherapy, is more likely to be associated with increased risk of infection than chronic neutropenia (months to years) that reverses in response to infection or carefully controlled administration of endotoxin (see “Laboratory Diagnosis and Management,” below).

Some causes of inherited and acquired neutropenia are listed in Table 64-1. The most common neutropenias are iatrogenic, resulting from the use of cytotoxic or immunosuppressive therapies for malignancy or control of autoimmune disorders. These drugs cause neutropenia because they result in decreased production of rapidly growing progenitor (stem) cells of the marrow. Certain antibiotics such as chloramphenicol, trimethoprim-sulfamethoxazole, flucytosine, vidarabine, and the antiretroviral drug zidovudine may cause neutropenia by inhibiting proliferation of myeloid precursors. Azathioprine and 6-mercaptopurine are metabolized by the enzyme thiopurine methyltransferase (TMPT); hypofunctional polymorphisms that are found in 11% of whites can lead to accumulation of 6-thioguanine and profound marrow toxicity. The marrow suppression is generally dose-related and dependent on continued administration of the drug. Cessation of the offending agent and recombinant human G-CSF usually reverse these forms of neutropenia.

Another important mechanism for iatrogenic neutropenia is the effect of drugs that serve as immune haptens and sensitize neutrophils or neutrophil precursors to immune-mediated peripheral

destruction. This form of drug-induced neutropenia can be seen within 7 days of exposure to the drug; with previous drug exposure, resulting in preexisting antibodies, neutropenia may occur a few hours after administration of the drug. Although any drug can cause this form of neutropenia, the most frequent causes are commonly used antibiotics, such as sulfa-containing compounds, penicillins, and cephalosporins. Fever and eosinophilia may also be associated with drug reactions, but often these signs are not present. Drug-induced neutropenia can be severe, but discontinuation of the sensitizing drug is sufficient for recovery, which is usually seen within 5–7 days and is complete by 10 days. Readministration of the sensitizing drug should be avoided, because abrupt neutropenia will often result. For this reason, diagnostic challenge should be avoided.

Autoimmune neutropenias caused by circulating antineutrophil antibodies are another form of acquired neutropenia that results in increased destruction of neutrophils. Acquired neutropenia may also be seen with viral infections, including acute infection with HIV. Acquired neutropenia may be cyclic in nature, occurring at intervals of several weeks. Acquired cyclic or stable neutropenia may be associated with an expansion of large granular lymphocytes (LGLs), which may be T cells, NK cells, or NK-like cells. Patients with large granular lymphocytosis may have moderate blood and bone marrow lymphocytosis, neutropenia, polyclonal hypergammaglobulinemia, splenomegaly, rheumatoid arthritis, and absence of lymphadenopathy. Such patients may have a chronic and relatively stable course. Recurrent bacterial infections are frequent. Benign and malignant forms of this syndrome occur. In some patients, a spontaneous regression has occurred even after 11 years, suggesting an immunoregulatory defect as the basis for at least one form of the disorder. Glucocorticoids, cyclosporine, methotrexate, and monoclonals are commonly used to manage these cytopenias.

**Heredity Neutropenias** Hereditary neutropenias are rare and may manifest in early childhood as a profound constant neutropenia or agranulocytosis. Congenital forms of neutropenia include Kostmann's syndrome (neutrophil count <100/ $\mu$ L), which is often fatal and due to mutations in the antiapoptosis gene *HAX-1*; severe chronic neutropenia (neutrophil count of 300–1500/ $\mu$ L) due to mutations in neutrophil elastase (*ELANE*); hereditary cyclic neutropenia, or, more appropriately, cyclic hematopoiesis, also due to mutations in neutrophil elastase (*ELANE*); the cartilage-hair hypoplasia syndrome due to mutations in the mitochondrial RNA-processing endoribonuclease *RMRP*; Shwachman-Diamond syndrome associated with pancreatic insufficiency due to mutations in the Shwachman-Bodian-Diamond syndrome gene *SBDS*; the WHIM (warts, hypogammaglobulinemia, infections, myelokathexis [retention of WBCs in the marrow]) syndrome, characterized by neutrophil hypersegmentation and bone marrow myeloid arrest due to mutations in the chemokine receptor *CXCR4*; and neutropenias associated with other immune defects, such as GATA2 deficiency, X-linked agammaglobulinemia, Wiskott-Aldrich syndrome, and CD40 ligand deficiency. Mutations in the G-CSF receptor can develop in severe congenital neutropenia and are linked to the development of leukemia. Absence of both myeloid and lymphoid cells is seen in reticular dysgenesis, due to mutations in the nuclear genome-encoded mitochondrial enzyme adenylate kinase-2 (*AK2*).

Maternal factors can be associated with neutropenia in the newborn. Transplacental transfer of IgG directed against antigens on fetal neutrophils can result in peripheral destruction. Drugs (e.g., thiazides) ingested during pregnancy can cause neutropenia in the newborn by either depressed production or peripheral destruction.

In Felty's syndrome—the triad of rheumatoid arthritis, splenomegaly, and neutropenia (Chap. 358)—spleen-produced antibodies can shorten neutrophil life span, while large granular lymphocytes can attack marrow neutrophil precursors. Splenectomy may increase the neutrophil count in Felty's syndrome and lower serum neutrophil-binding IgG. Some Felty's syndrome patients also have autoantibodies to G-CSF, while others have increased numbers of LGLs. Splenomegaly with peripheral trapping and destruction of neutrophils is also seen in lysosomal storage diseases and commonly in portal hypertension.

TABLE 64-1 Causes of Neutropenia

#### Decreased Production

Drug-induced—alkylating agents (nitrogen mustard, busulfan, chlorambucil, cyclophosphamide); antimetabolites (methotrexate, 6-mercaptopurine, 5-flucytosine); noncytotoxic agents (antibiotics [chloramphenicol, penicillins, sulfonamides], phenothiazines, tranquilizers [neuroleptics], anticonvulsants [carbamazepine], antipsychotics [clozapine], certain diuretics, anti-inflammatory agents, antithyroid drugs, many others)

Hematologic diseases—idiopathic, cyclic neutropenia, Chédiak-Higashi syndrome, aplastic anemia, infantile genetic disorders (see text)

Tumor invasion, myelofibrosis

Nutritional deficiency—vitamin B<sub>12</sub>, folate (especially alcoholics)

Infection—tuberculosis, typhoid fever, brucellosis, tularemia, measles, infectious mononucleosis, malaria, viral hepatitis, leishmaniasis, AIDS

#### Peripheral Destruction

Antineutrophil antibodies and/or splenic or lung trapping

Autoimmune disorders—Felty's syndrome, rheumatoid arthritis, lupus erythematosus

Drugs as haptens—aminopyrine,  $\alpha$ -methyl-dopa, phenylbutazone, mercurial diuretics, some phenothiazines

Granulomatosis with polyangiitis (Wegener's)

#### Peripheral Pooling (Transient Neutropenia)

Overwhelming bacterial infection (acute endotoxemia)

Hemodialysis

Cardiopulmonary bypass

TABLE 64-2 Causes of Neutrophilia

Increased Production	
Idiopathic	
Drug-induced—glucocorticoids, G-CSF	
Infection—bacterial, fungal, sometimes viral	
Inflammation—thermal injury, tissue necrosis, myocardial and pulmonary infarction, hypersensitivity states, collagen vascular diseases	
Myeloproliferative diseases—myelocytic leukemia, myeloid metaplasia, polycythemia vera	
Increased Marrow Release	
Glucocorticoids	
Acute infection (endotoxin)	
Inflammation—thermal injury	
Decreased or Defective Margination	
Drugs—epinephrine, glucocorticoids, nonsteroidal anti-inflammatory agents	
Stress, excitement, vigorous exercise	
Leukocyte adhesion deficiency type 1 (CD18); leukocyte adhesion deficiency type 2 (selectin ligand, CD15s); leukocyte adhesion deficiency type 3 ( <i>FERMT3</i> )	
Miscellaneous	
Metabolic disorders—ketoacidosis, acute renal failure, eclampsia, acute poisoning	
Drugs—lithium	
Other—metastatic carcinoma, acute hemorrhage or hemolysis	

Abbreviation: G-CSF, granulocyte colony-stimulating factor.

**Neutrophilia** Neutrophilia results from increased neutrophil production, increased marrow release, or defective margination (Table 64-2). The most important acute cause of neutrophilia is infection. Neutrophilia from acute infection represents both increased production and increased marrow release. Increased production is also associated with chronic inflammation and certain myeloproliferative diseases. Increased marrow release and mobilization of the marginated leukocyte pool are induced by glucocorticoids. Release of epinephrine, as with vigorous exercise, excitement, or stress, will demarginate neutrophils in the spleen and lungs and double the neutrophil count in minutes. Cigarette smoking can elevate neutrophil counts above the normal range. Leukocytosis with cell counts of 10,000–25,000/ $\mu$ L occurs in response to infection and other forms of acute inflammation and results from both release of the marginated pool and mobilization of marrow reserves. Persistent neutrophilia with cell counts of  $\geq$ 30,000–50,000/ $\mu$ L is called a *leukemoid reaction*, a term often used to distinguish this degree of neutrophilia from leukemia. In a leukemoid reaction, the circulating neutrophils are usually mature and not clonally derived.

**Abnormal Neutrophil Function** Inherited and acquired abnormalities of phagocyte function are listed in Table 64-3. The resulting diseases are best considered in terms of the functional defects of adherence, chemotaxis, and microbicidal activity. The distinguishing features of the important inherited disorders of phagocyte function are shown in Table 64-4.

**DISORDERS OF ADHESION** Three main types of leukocyte adhesion deficiency (LAD) have been described. All are autosomal recessive and result in the inability of neutrophils to exit the circulation to sites of infection, leading to leukocytosis and increased susceptibility to infection (Fig. 64-9). Patients with LAD 1 have mutations in *CD18*, the common component of the integrins LFA-1, Mac-1, and p150,95, leading to a defect in tight adhesion between neutrophils and the endothelium. The heterodimer formed by *CD18/CD11b* (Mac-1) is also the receptor for the complement-derived opsonin C3bi (CR3). The *CD18* gene is located on distal chromosome 21q. The severity of the defect determines the severity of clinical disease. Complete lack of expression of the leukocyte integrins results in a severe phenotype in which inflammatory stimuli do not increase the expression of leukocyte integrins on neutrophils or activated T and B cells. Neutrophils (and monocytes) from patients with LAD 1 adhere poorly to endothelial cells and protein-coated surfaces and exhibit defective spreading, aggregation, and chemotaxis. The inability of neutrophils to exit the vasculature to the tissue deprives the tissue macrophage of its expected neutrophil ingestion, leading to macrophage production of IL-23, which induces T-cell production of IL-17, a potent proinflammatory cytokine. These processes conspire to drive inflammation in LAD 1. Patients with LAD 1 have recurrent bacterial infections involving the skin, oral and genital mucosa, and respiratory and intestinal tracts; persistent leukocytosis (resting neutrophil counts of 15,000–20,000/ $\mu$ L) because cells do not marginate; and, in severe cases, a history of delayed separation of the umbilical stump. Infections, especially of the skin, may become necrotic with progressively enlarging borders, slow healing, and development of dysplastic scars. The most common bacteria are *Staphylococcus aureus* and enteric gram-negative bacteria. LAD 2 is caused by an abnormality of fucosylation of SLe<sup>x</sup> (*CD15s*), the ligand on neutrophils that interacts with selectins on endothelial cells and is responsible for neutrophil rolling along the endothelium. Infection susceptibility in LAD 2 appears to be less severe than in LAD 1. LAD 2 is also known as *congenital disorder of glycosylation IIc* (*CDGIIc*) due to mutation in a GDP-fucose transporter (*SLC35C1*). LAD 3 is characterized by infection susceptibility, leukocytosis, and petechial hemorrhage due to impaired integrin activation caused by mutations in the gene *FERMT3*.

**DISORDERS OF NEUTROPHIL GRANULES** The most common neutrophil defect is myeloperoxidase deficiency, a primary granule defect inherited as an autosomal recessive trait; the incidence is 1 in 2000 persons. Isolated myeloperoxidase deficiency is not associated with

TABLE 64-3 Types of Granulocyte and Monocyte Disorders

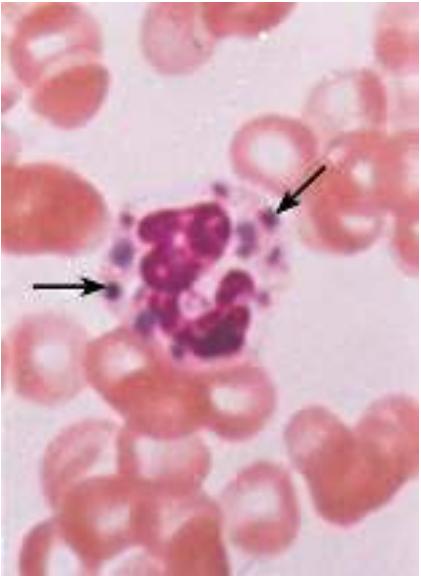
FUNCTION	CAUSE OF INDICATED DYSFUNCTION		
	DRUG-INDUCED	ACQUIRED	INHERITED
Adherence-aggregation	Aspirin, colchicine, alcohol, glucocorticoids, ibuprofen, piroxicam	Neonatal state, hemodialysis	Leukocyte adhesion deficiency types 1, 2, and 3
Deformability		Leukemia, neonatal state, diabetes mellitus, immature neutrophils	
Chemokinesis-chemotaxis	Glucocorticoids (high dose), auranofin, colchicine (weak effect), phenylbutazone, naproxen, indomethacin, interleukin 2	Thermal injury, malignancy, malnutrition, periodontal disease, neonatal state, systemic lupus erythematosus, rheumatoid arthritis, diabetes mellitus, sepsis, influenza virus infection, herpes simplex virus infection, acrodermatitis enteropathica, AIDS	Chédiak-Higashi syndrome, neutrophil-specific granule deficiency, hyper IgE-recurrent infection (Job's) syndrome (in some patients), Down's syndrome, $\alpha$ -mannosidase deficiency, leukocyte adhesion deficiencies, Wiskott-Aldrich syndrome
Microbicidal activity	Colchicine, cyclophosphamide, glucocorticoids (high dose), TNF- $\alpha$ -blocking antibodies	Leukemia, aplastic anemia, certain neutropenias, tuftsin deficiency, thermal injury, sepsis, neonatal state, diabetes mellitus, malnutrition, AIDS	Chédiak-Higashi syndrome, neutrophil-specific granule deficiency, chronic granulomatous disease, defects in IFN $\gamma$ /IL-12 axis

Abbreviations: IFN $\gamma$ , interferon  $\gamma$ ; IL, interleukin; TNF- $\alpha$ , tumor necrosis factor alpha.

TABLE 64-4 Inherited Disorders of Phagocyte Function: Differential Features

CLINICAL MANIFESTATIONS	CELLULAR OR MOLECULAR DEFECTS	DIAGNOSIS	
<b>Chronic Granulomatous Disease (70% X-Linked, 30% Autosomal Recessive)</b>	Severe infections of skin, ears, lungs, liver, and bone with catalase-positive microorganisms such as <i>Staphylococcus aureus</i> , <i>Burkholderia cepacia</i> complex, <i>Aspergillus</i> spp., <i>Chromobacterium violaceum</i> ; often hard to culture organism; excessive inflammation with granulomas, frequent lymph node suppuration; granulomas can obstruct GI or GU tracts; gingivitis, aphthous ulcers, seborrheic dermatitis	No respiratory burst due to the lack of one of five NADPH oxidase subunits in neutrophils, monocytes, and eosinophils	DHR or NBT test; no superoxide and H <sub>2</sub> O <sub>2</sub> production by neutrophils; immunoblot for NADPH oxidase components; genetic detection
<b>Chédiak-Higashi Syndrome (Autosomal Recessive)</b>	Recurrent pyogenic infections, especially with <i>S. aureus</i> ; many patients get lymphoma-like illness during adolescence; periodontal disease; partial oculocutaneous albinism, nystagmus, progressive peripheral neuropathy, cognitive impairment in some patients	Reduced chemotaxis and phagolysosome fusion, increased respiratory burst activity, defective egress from marrow, abnormal skin window; defect in <i>CHS1</i>	Giant primary granules in neutrophils and other granule-bearing cells (Wright's stain); genetic detection
<b>Specific Granule Deficiency (Autosomal Recessive and Dominant)</b>	Recurrent infections of skin, ears, and sinopulmonary tract; delayed wound healing; decreased inflammation; bleeding diathesis	Abnormal chemotaxis, impaired respiratory burst and bacterial killing, failure to upregulate chemotactic and adhesion receptors with stimulation, defect in transcription of granule proteins; defect in <i>CEBPE</i> or <i>SMARCD2</i>	Lack of secondary (specific) granules in neutrophils (Wright's stain), no neutrophil-specific granule contents (i.e., lactoferrin), no defensins, platelet α granule abnormality; genetic detection
<b>Myeloperoxidase Deficiency (Autosomal Recessive)</b>	Clinically normal except in patients with underlying disease such as diabetes mellitus; then candidiasis or other fungal infections	No myeloperoxidase due to pre- and posttranslational defects in myeloperoxidase deficiency	No peroxidase in neutrophils; genetic detection
<b>Leukocyte Adhesion Deficiency</b>	<p>Type 1: Delayed separation of umbilical cord, sustained neutrophilia, recurrent infections of skin and mucosa, gingivitis, periodontal disease</p> <p>Type 2: Cognitive impairment, short stature, Bombay (hh) blood phenotype, recurrent infections, neutrophilia</p> <p>Type 3: Petechial hemorrhage, recurrent infections</p>	<p>Impaired phagocyte adherence, aggregation, spreading, chemotaxis, phagocytosis of C3bi-coated particles; defective production of CD18 subunit common to leukocyte integrins</p> <p>Impaired phagocyte rolling along endothelium; due to defects in fucose transporter</p> <p>Impaired signaling for integrin activation resulting in impaired adhesion due to mutation in <i>FERMT3</i></p>	<p>Reduced phagocyte surface expression of the CD18-containing integrins with monoclonal antibodies against LFA-1 (CD18/CD11a), Mac-1 or CR3 (CD18/CD11b), p150,95 (CD18/CD11c); genetic detection</p> <p>Reduced phagocyte surface expression of Sialyl-Lewis<sup>x</sup>, with monoclonal antibodies against CD15s; genetic detection</p> <p>Reduced signaling for adhesion through integrins; genetic detection</p>
<b>Phagocyte Activation Defects (X-Linked and Autosomal Recessive)</b>	<p>NEMO deficiency: mild hypohidrotic ectodermal dysplasia; broad-based immune defect: pyogenic and encapsulated bacteria, viruses, <i>Pneumocystis</i>, mycobacteria; X-linked</p> <p>IRAK4 and MyD88 deficiency: susceptibility to pyogenic bacteria such as staphylococci, streptococci, clostridia; resistant to <i>Candida</i>; autosomal recessive</p>	<p>Impaired phagocyte activation by IL-1, IL-18, TLR, CD40L, TNF-α leading to problems with inflammation and antibody production</p> <p>Impaired phagocyte activation by endotoxin through TLR and other pathways; TNF-α signaling preserved</p>	<p>Poor in vitro response to endotoxin; impaired NF-κB activation; genetic detection</p> <p>Poor in vitro response to endotoxin; lack of NF-κB activation by endotoxin; genetic detection</p>
<b>Hyper IgE-Recurrent Infection Syndrome (Autosomal Dominant) (Job's Syndrome)</b>	Eczematoid or pruritic dermatitis, "cold" skin abscesses, recurrent pneumonias with <i>S. aureus</i> with bronchopleural fistulae and cyst formation, mild eosinophilia, mucocutaneous candidiasis, characteristic facies, restrictive lung disease, scoliosis, delayed primary dental deciduation	Reduced chemotaxis in some patients, reduced memory T and B cells; mutation in <i>STAT3</i>	Somatic and immune features involving lungs, skeleton, and immune system; serum IgE>2000 IU/mL; genetic testing
<b>DOCK8 deficiency (autosomal recessive)</b>	Severe eczema, atopic dermatitis, cutaneous abscesses, HSV, HPV, and molluscum infections, severe allergies, cancer	Impaired T-cell proliferation to mitogens; mutation in <i>DOCK8</i>	Severe allergies, viral infections, high IgE, eosinophilia, low IgM, progressive lymphopenia, genetic detection
<b>Mycobacterial Susceptibility (Autosomal Dominant and Recessive Forms)</b>	Severe extrapulmonary or disseminated infections with bacille Calmette-Guérin (BCG), nontuberculous mycobacteria, salmonella, histoplasmosis, coccidioidomycosis, poor granuloma formation	Inability to kill intracellular organisms due to low IFN-γ production or response; mutations in IFN-γ receptors, IL-12 receptors, IL-12 p40, <i>STAT1</i> , <i>NEMO</i> , <i>ISG15</i> , <i>GATA2</i>	Abnormally low or very high levels of IFN-γ receptor 1; functional assays of cytokine production and response; genetic detection
<b>GATA2 Deficiency (Autosomal Dominant)</b>	Persistent or disseminated warts, disseminated mycobacterial disease, low monocytes, NK cells, B cells; hypoplastic myelodysplasia, leukemia, cytogenetic abnormalities, pulmonary alveolar proteinosis	Impaired macrophage activity, cytopenias; mutations in <i>GATA2</i>	Profound circulating monocytopenia, NK and B-cell cytopenias; genetic detection

**Abbreviations:** C/EBP $\gamma$ , CCAAT/enhancer binding protein- $\gamma$ ; DHR, dihydrorhodamine (oxidation test); DOCK8, dedicator of cytokinesis 8; GI, gastrointestinal; GU, genitourinary; HPV, human papillomavirus; HSV, herpes simplex virus; IFN, interferon; IL, interleukin; IRAK4, IL-1 receptor-associated kinase 4; LFA-1, leukocyte function-associated antigen 1; MyD88, myeloid differentiation primary response gene 88; NADPH, nicotinamide-adenine dinucleotide phosphate; NBT, nitroblue tetrazolium (dye test); NEMO, NF-κB essential modulator; NF-κB, nuclear factor-κB; NK, natural killer; STAT1-3, signal transducer and activator of transcription 1-3; TLR, Toll-like receptor; TNF, tumor necrosis factor.



**FIGURE 64-10** Chédiak-Higashi syndrome. The granulocytes contain huge cytoplasmic granules formed from aggregation and fusion of azurophilic and specific granules. Large abnormal granules are found in other granule-containing cells throughout the body.

clinically compromised defenses, presumably because other defense systems such as hydrogen peroxide generation are amplified. Microbicidal activity of neutrophils is delayed but not absent. Myeloperoxidase deficiency may make other acquired host defense defects more serious, and patients with myeloperoxidase deficiency and diabetes are more susceptible to *Candida* infections. An acquired form of myeloperoxidase deficiency occurs in myelomonocytic leukemia and acute myeloid leukemia.

Chédiak-Higashi syndrome (CHS) is a rare disease with autosomal recessive inheritance due to defects in the lysosomal transport protein LYST, encoded by the gene *CHS1* at 1q42. This protein is required for normal packaging and disbursement of granules. Neutrophils (and all cells containing lysosomes) from patients with CHS characteristically have large granules (Fig. 64-10), making it a systemic disease. Patients with CHS have nystagmus, partial oculocutaneous albinism, and an increased number of infections resulting from many bacterial agents. Some CHS patients develop an “accelerated phase” in childhood with a hemophagocytic syndrome and an aggressive lymphoma requiring bone marrow transplantation. CHS neutrophils and monocytes have impaired chemotaxis and abnormal rates of microbial killing due to slow rates of fusion of the lysosomal granules with phagosomes. NK cell function is also impaired. CHS patients may develop a severe disabling peripheral neuropathy in adulthood.

Specific granule deficiency is a rare autosomal recessive disease in which the production of secondary granules and their contents, as well as the primary granule component defensins, is defective. The defect in killing leads to severe bacterial infections. One type of specific granule deficiency is due to a mutation in the CCAAT/enhancer binding protein- $\epsilon$ , a regulator of expression of granule components. A dominant mutation in *C/EBP- $\epsilon$*  has also been described. Another form is caused by mutations in *SMARCD2*.

**CHRONIC GRANULOMATOUS DISEASE** Chronic granulomatous disease (CGD) is a group of disorders of granulocyte and monocyte oxidative metabolism due to a defect in the enzyme NADPH oxidase also called NOX2. Although CGD is rare, with an incidence of 1 in 200,000 individuals, it is an important model of defective neutrophil oxidative metabolism. In about two-thirds of patients, CGD is inherited as an X-linked recessive trait; the remainder inherit their disease in autosomal recessive patterns. Mutations in the genes for the six proteins that allow assembly at the plasma membrane of NOX2 account

for all patients with CGD. Two proteins (a 91-kDa protein, abnormal in X-linked CGD, and a 22-kDa protein, absent in one form of autosomal recessive CGD) form the heterodimer cytochrome b-558 in the plasma membrane. The protein essential for reactive oxidant signaling (EROS) is encoded by *CYBC1*, which is required to transport the 91- and 22-kDa proteins to the endoplasmic reticulum. Three other proteins (40, 47, and 67 kDa, abnormal in the other autosomal recessive forms of CGD) are cytoplasmic in origin and interact with the cytochrome after cell activation to form the NADPH oxidase, required for hydrogen peroxide production. Leukocytes from patients with CGD have severely diminished hydrogen peroxide production. The genes involved in each of the defects have been cloned and sequenced and the chromosome locations identified. Patients with CGD characteristically have increased numbers of infections due to catalase-positive microorganisms (organisms that destroy their own hydrogen peroxide) such as *S. aureus*, *Serratia marsescens*, *Burkholderia cepacia* complex, *Nocardia* and *Aspergillus* species. When patients with CGD become infected, they often have extensive inflammatory reactions, and suppuration is common despite the administration of appropriate antibiotics. Aphthous ulcers and chronic inflammation of the nares are often present. Granulomas are frequent and can obstruct the gastrointestinal or genitourinary tracts. The excessive inflammation is due to failure to downregulate inflammation, reflecting a failure to inhibit the synthesis of, degradation of, or response to ILs or chemoattractants, leading to persistent myeloid reaction. Impaired killing of intracellular microorganisms by macrophages may lead to persistent cell-mediated immune activation and granuloma formation. Autoimmune complications such as immune thrombocytopenic purpura and juvenile idiopathic arthritis are also increased in CGD. In addition, for unexplained reasons, discoid lupus is more common in X-linked carriers. Late complications, including nodular regenerative hyperplasia and portal hypertension, are increasingly recognized in adolescent and adult patients with CGD. Interestingly, patients with CGD have been reported to be protected from atherosclerosis, suggesting an important role for NADPH oxidase (NOX2) in the pathogenesis of this inflammatory disease of arteries.

**DISORDERS OF PHAGOCYTE ACTIVATION** Phagocytes depend on cell-surface stimulation to induce signals that evoke multiple levels of the inflammatory response, including cytokine synthesis, chemotaxis, and antigen presentation. Mutations affecting the major pathway that signals through NF- $\kappa$ B have been noted in patients with a variety of infection susceptibility syndromes. If the defects are at a very late stage of signal transduction, in the protein critical for NF- $\kappa$ B activation known as the NF- $\kappa$ B essential modulator (NEMO), then affected males develop ectodermal dysplasia and severe immune deficiency with susceptibility to bacteria, fungi, mycobacteria, and viruses. If the defects in NF- $\kappa$ B activation are closer to the cell-surface receptors, in the proteins transducing Toll-like receptor signals, IL-1 receptor-associated kinase 4 (IRAK4), and myeloid differentiation primary response gene 88 (MyD88), then children have a marked susceptibility to pyogenic infections early in life but develop resistance to infection later.

## MONONUCLEAR PHAGOCYTES

The mononuclear phagocyte system is composed of monoblasts, promonocytes, and monocytes, in addition to the structurally diverse tissue macrophages that make up what was previously referred to as the reticuloendothelial system. Macrophages are long-lived phagocytic cells capable of many of the functions of neutrophils. They are also secretory cells that participate in many immunologic and inflammatory processes distinct from neutrophils. Monocytes leave the circulation by diapedesis more slowly than neutrophils and have a half-life in the blood of 12–24 h.

Many tissue macrophages (“big eaters”) arise even before hematopoiesis and take up residence in tissues. In addition, there are macrophages derived from monocytes, which may have specialized functions suited for specific anatomic locations. Macrophages are particularly abundant in capillary walls of the lung, spleen, liver, and bone marrow, where they function to remove microorganisms and other noxious elements from the blood. Alveolar macrophages, liver Kupffer cells,

splenic macrophages, peritoneal macrophages, bone marrow macrophages, lymphatic macrophages, brain microglial cells, and dendritic macrophages all have specialized functions. Macrophage-secreted products include lysozyme, neutral proteases, acid hydrolases, arginase, complement components, enzyme inhibitors (plasmin,  $\alpha_2$ -macroglobulin), binding proteins (transferrin, fibronectin, transcobalamin II), nucleosides, and cytokines (TNF- $\alpha$ ; IL-1, 8, 12, 18). IL-1 (Chaps. 18 and 349) has many functions, including initiating fever in the hypothalamus, mobilizing leukocytes from the bone marrow, and activating lymphocytes and neutrophils. TNF- $\alpha$  is a pyrogen that duplicates many of the actions of IL-1 and plays an important role in the pathogenesis of gram-negative shock (Chap. 304). TNF- $\alpha$  stimulates production of hydrogen peroxide and related toxic oxygen species by macrophages and neutrophils. In addition, TNF- $\alpha$  induces catabolic changes that contribute to the profound wasting (cachexia) associated with many chronic diseases.

Other macrophage-secreted products include reactive oxygen and nitrogen metabolites, bioactive lipids (arachidonic acid metabolites and platelet-activating factors), chemokines, CSFs, and factors stimulating fibroblast and vessel proliferation. Macrophages help regulate the replication of lymphocytes and participate in the killing of tumors, viruses, and certain bacteria (*Mycobacterium tuberculosis* and *Listeria monocytogenes*). Macrophages are key effector cells in the elimination of intracellular microorganisms. Their ability to fuse to form giant cells that coalesce into granulomas in response to some inflammatory stimuli is important in the elimination of intracellular microbes and is under the control of IFN- $\gamma$ . Nitric oxide induced by IFN- $\gamma$  may be an important effector against intracellular parasites, including tuberculosis and *Leishmania*.

Macrophages play an important role in the immune response (Chap. 349). They process and present antigen to lymphocytes and secrete cytokines that modulate and direct lymphocyte development and function. Macrophages participate in autoimmune phenomena by removing immune complexes and other substances from the circulation. Polymorphisms in macrophage receptors for immunoglobulin (Fc $\gamma$ RII) determine susceptibility to some infections and autoimmune diseases. In wound healing, they dispose of senescent cells, and they also contribute to atheroma development. Macrophage elastase mediates development of emphysema from cigarette smoking.

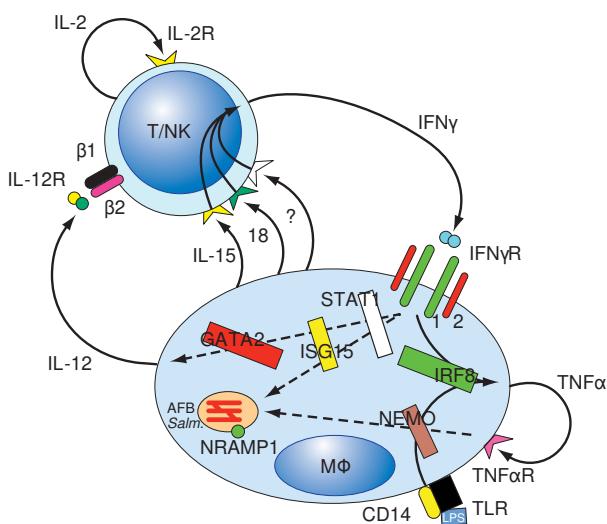
## ■ DISORDERS OF THE MONONUCLEAR PHAGOCYTE SYSTEM

Many disorders of neutrophils extend to mononuclear phagocytes. Monocytosis is associated with tuberculosis, brucellosis, subacute bacterial endocarditis, Rocky Mountain spotted fever, malaria, and visceral leishmaniasis (kala azar). Monocytosis also occurs with malignancies, leukemias, myeloproliferative syndromes, hemolytic anemias, chronic idiopathic neutropenias, and granulomatous diseases such as sarcoidosis, regional enteritis, and some collagen vascular diseases. Patients with LAD, hyperimmunoglobulin E-recurrent infection (Job's) syndrome, CHS, and CGD all have defects in the mononuclear phagocyte system.

Monocyte cytokine production or response is impaired in some patients with disseminated nontuberculous mycobacterial infection who are not infected with HIV. Genetic defects in the pathways regulated by IFN- $\gamma$  and IL-12 lead to impaired killing of intracellular bacteria, mycobacteria, salmonellae, and certain viruses (Fig. 64-11).

Certain viral infections impair mononuclear phagocyte function. For example, influenza virus infection causes abnormal monocyte chemotaxis. Mononuclear phagocytes can be infected by HIV using CCR5, the chemokine receptor that acts as a co-receptor with CD4 for HIV. T lymphocytes produce IFN- $\gamma$ , which induces FcR expression and phagocytosis and stimulates hydrogen peroxide production by mononuclear phagocytes and neutrophils. In certain diseases, such as AIDS, IFN- $\gamma$  production may be deficient, whereas in other diseases, such as T-cell lymphomas, excessive release of IFN- $\gamma$  may be associated with erythrophagocytosis by splenic macrophages.

Autoinflammatory diseases are characterized by abnormal cytokine regulation, leading to excess inflammation in the absence of infection. These diseases can mimic infectious or immunodeficient syndromes.



**FIGURE 64-11** Lymphocyte-macrophage interactions underlying resistance to mycobacteria and other intracellular pathogens such as *Salmonella*, *Histoplasma*, and *Coccidioides*. Mycobacteria (and others) infect macrophages, leading to the production of IL-12, which activates T or NK cells through its receptor, leading to production of IL-2 and IFN- $\gamma$ . IFN- $\gamma$  acts through its receptor on macrophages to upregulate TNF- $\gamma$  and IL-12 and kill intracellular pathogens. Other critical interacting molecules include signal transducer and activator of transcription 1 (STAT1), interferon regulatory factor 8 (IRF8), GATA2, and ISG15. Mutant forms of the cytokines and receptors shown in bold type have been found in severe cases of nontuberculous mycobacterial infection, salmonellosis, and other intracellular pathogens. AFB, acid-fast bacilli; IFN, interferon; IL, interleukin; NEMO, nuclear factor- $\kappa$ B essential modulator; NK, natural killer; TLR, Toll-like receptor; TNF, tumor necrosis factor.

Gain-of-function mutations in the TNF- $\alpha$  receptor cause TNF- $\alpha$  receptor-associated periodic syndrome (TRAPS), which is characterized by recurrent fever in the absence of infection, due to persistent stimulation of the TNF- $\alpha$  receptor (Chap. 369). Diseases with abnormal IL-1 regulation leading to fever include familial Mediterranean fever due to mutations in PYRIN. Mutations in cold-induced autoinflammatory syndrome 1 (CIASI) lead to neonatal-onset multisystem autoinflammatory disease, familial cold urticaria, and Muckle-Wells syndrome. The syndrome of pyoderma gangrenosum, acne, and sterile pyogenic arthritis (PAPA syndrome) is caused by mutations in PSTPIP1. In contrast to these syndromes of overexpression of proinflammatory cytokines, blockade of TNF- $\alpha$  by the antagonists infliximab, adalimumab, certolizumab, golimumab, or etanercept has been associated with severe infections due to tuberculosis, nontuberculous mycobacteria, and fungi (Chap. 369).

Moncytopenia occurs with acute infections, with stress, and after treatment with glucocorticoids. Drugs that suppress neutrophil production in the bone marrow can cause moncytopenia. Persistent severe circulating moncytopenia is seen in GATA2 deficiency, even though macrophages are found at the sites of inflammation. Moncytopenia also occurs in aplastic anemia, hairy cell leukemia, acute myeloid leukemia, and as a direct result of myelotoxic drugs.

## EOSINOPHILS

Eosinophils and neutrophils share similar morphology, many lysosomal constituents, phagocytic capacity, and oxidative metabolism. Eosinophils express a specific chemoattractant receptor and respond to a specific chemokine, eotaxin, but little is known about their required role. Eosinophils are much longer lived than neutrophils, and unlike neutrophils, tissue eosinophils can recirculate. During most infections, eosinophils appear unimportant. However, in invasive helminthic infections, such as hookworm, schistosomiasis, strongyloidiasis, toxocariasis, trichinosis, filariasis, echinococcosis, and cysticercosis, the eosinophil plays a central role in host defense. Eosinophils are associated

with bronchial asthma, cutaneous allergic reactions, and other hypersensitivity states.

The distinctive feature of the red-staining (Wright's stain) eosinophil granule is its crystalline core consisting of an arginine-rich protein (major basic protein) with histaminase activity, important in host defense against parasites. Eosinophil granules also contain a unique eosinophil peroxidase that catalyzes the oxidation of many substances by hydrogen peroxide and may facilitate killing of microorganisms.

Eosinophil peroxidase, in the presence of hydrogen peroxide and halide, initiates mast cell secretion in vitro and thereby promotes inflammation. Eosinophils contain cationic proteins, some of which bind to heparin and reduce its anticoagulant activity. Eosinophil-derived neurotoxin and eosinophil cationic protein are ribonucleases that can kill respiratory syncytial virus. Eosinophil cytoplasm contains Charcot-Leyden crystal protein, a hexagonal bipyramidal crystal first observed in a patient with leukemia and then in sputum of patients with asthma; this protein is lysophospholipase and may function to detoxify certain lysophospholipids.

Several factors enhance the eosinophil's function in host defense. T cell-derived factors enhance the ability of eosinophils to kill parasites. Mast cell-derived eosinophil chemotactic factor of anaphylaxis (ECFa) increases the number of eosinophil complement receptors and enhances eosinophil killing of parasites. Eosinophil CSFs (e.g., IL-5) produced by macrophages increase eosinophil production in the bone marrow and activate eosinophils to kill parasites.

## ■ EOSINOPHILIA

Eosinophilia is the presence of >500 eosinophils per  $\mu\text{L}$  of blood and is common in many settings besides parasite infection. Significant tissue eosinophilia can occur without an elevated blood count. A common cause of eosinophilia is allergic reaction to drugs (iodides, aspirin, sulfonamides, nitrofurantoin, penicillins, and cephalosporins). Allergies such as hay fever, asthma, eczema, serum sickness, allergic vasculitis, and pemphigus are associated with eosinophilia. Eosinophilia also occurs in collagen vascular diseases (e.g., rheumatoid arthritis, eosinophilic fasciitis, allergic angiitis, and periarteritis nodosa) and malignancies (e.g., Hodgkin's disease; mycosis fungoïdes; chronic myeloid leukemia; and cancer of the lung, stomach, pancreas, ovary, or uterus), as well as in STAT3-deficient Job's syndrome, DOCK8 deficiency (see below), and CGD. Eosinophilia is commonly present in helminthic infections. IL-5 is the dominant eosinophil growth factor. Therapeutic administration of the cytokines IL-2 or GM-CSF frequently leads to transient eosinophilia. The most dramatic hypereosinophilic syndromes are Loeffler's syndrome, tropical pulmonary eosinophilia, Loeffler's endocarditis, eosinophilic leukemia, and idiopathic hyper-eosinophilic syndrome (50,000–100,000/ $\mu\text{L}$ ). IL-5 is the dominant eosinophil growth factor and can be specifically inhibited with the monoclonal antibody mepolizumab.

The idiopathic hypereosinophilic syndromes are a heterogeneous group of disorders with the common feature of prolonged eosinophilia of unknown cause and organ system dysfunction, including the heart, central nervous system, kidneys, lungs, gastrointestinal tract, and skin. The bone marrow is involved in all affected individuals, but the most severe complications involve the heart and central nervous system. Clinical manifestations and organ dysfunction are highly variable. Eosinophils are found in the involved tissues and likely cause tissue damage by local deposition of toxic eosinophil proteins such as eosinophil cationic protein and major basic protein. In the heart, the pathologic changes lead to thrombosis, endocardial fibrosis, and restrictive endomyocardopathy. The damage to tissues in other organ systems is similar. Some cases are due to mutations involving the platelet-derived growth factor receptor, and these are extremely sensitive to the tyrosine kinase inhibitor imatinib. Glucocorticoids, hydroxyurea, and IFN- $\alpha$  each have been used successfully, as have therapeutic antibodies against IL-5. Cardiovascular complications are managed aggressively.

The *eosinophilia-myalgia syndrome* is a multisystem disease, with prominent cutaneous, hematologic, and visceral manifestations, that frequently evolves into a chronic course and can occasionally be fatal. The syndrome is characterized by eosinophilia (eosinophil count

>1000/ $\mu\text{L}$ ) and generalized disabling myalgias without other recognized causes. Eosinophilic fasciitis, pneumonitis, and myocarditis; neuropathy culminating in respiratory failure; and encephalopathy may occur. The disease is caused by ingesting contaminants in L-tryptophan-containing products. Eosinophils, lymphocytes, macrophages, and fibroblasts accumulate in the affected tissues, but their role in pathogenesis is unclear. Activation of eosinophils and fibroblasts and the deposition of eosinophil-derived toxic proteins in affected tissues may contribute. IL-5 and transforming growth factor  $\beta$  have been implicated as potential mediators. Treatment is withdrawal of products containing L-tryptophan and the administration of glucocorticoids. Most patients recover fully, remain stable, or show slow recovery, but the disease can be fatal in up to 5% of patients.

**Eosinophilic neoplasms are discussed in Chap. 110.**

## ■ EOSINOPENIA

Eosinopenia occurs with stress, such as acute bacterial infection, and after treatment with glucocorticoids. The mechanism of eosinopenia of acute bacterial infection is unknown but is independent of endogenous glucocorticoids, because it occurs in animals after total adrenalectomy. There is no known adverse effect of eosinopenia.

## HYPERIMMUNOGLOBULIN E RECURRENT INFECTION SYNDROME

The hyperimmunoglobulin E-recurrent infection syndrome, or Job's syndrome, is a rare multisystem disease in which the immune and somatic systems are affected, including neutrophils, monocytes, T cells, B cells, and osteoclasts. Autosomal *dominant* inhibitory mutations in signal transducer and activator of transcription 3 (STAT3) lead to inhibition of normal STAT signaling with broad and profound effects. Patients have characteristic facies with broad nose, kyphoscoliosis, and eczema. The primary teeth erupt normally but do not deciduate, often requiring extraction. Patients develop recurrent sinopulmonary and cutaneous infections that tend to be much less inflamed than appropriate for the degree of infection and have been referred to as "cold abscesses." Characteristically, pneumonias cavitate, leading to pneumatoceles. Coronary artery aneurysms are common, as are cerebral demyelinated plaques that accumulate with age. Importantly, IL-17-producing T cells, which are thought responsible for protection against extracellular and mucosal infections, are profoundly reduced in Job's syndrome. Despite very high IgE levels, these patients have only mildly elevated levels of allergy. An important syndrome with clinical overlap with the dominant negative STAT3 deficiency is due to autosomal recessive defects in dedicator of cytokinesis 8 (DOCK8). In DOCK8 deficiency, IgE elevation is joined to severe allergy, viral susceptibility, and increased rates of cancer. Autosomal dominant *gain-of-function* mutations in STAT3 lead to a disease characterized by onset in childhood of lymphadenopathy, autoimmune cytopenias, multiorgan autoimmunity, infections, and interstitial lung disease.

## LABORATORY DIAGNOSIS AND MANAGEMENT

Initial studies of WBC and differential are essential, and careful examination of neutrophils on peripheral blood smears can diagnose Chediak-Higashi syndrome and suggest other neutrophil granule abnormalities such as specific granule deficiency. Often a bone marrow examination and serologies may be followed by either gene panel or whole exome sequencing in the cases of suspected genetic defects. Functionally, assessment of bone marrow reserves (steroid challenge test), marginated circulating pool of cells (epinephrine challenge test), and marginating ability (endotoxin challenge test) (Fig. 64-8) are also doable. In vivo assessment of inflammation is possible with a Rebuck skin window test or an in vivo skin blister assay, which measures the ability of leukocytes and inflammatory mediators to accumulate locally in the skin. In vitro tests of phagocyte aggregation, adherence, chemotaxis, phagocytosis, degranulation, and microbial activity (for *S. aureus*) may help pinpoint cellular or humoral lesions. Deficiencies of oxidative metabolism are detected with either the nitroblue tetrazolium (NBT) dye test or the dihydrorhodamine (DHR) oxidation test. These

tests are based on the ability of products of oxidative metabolism to alter the oxidation states of reporter molecules so that they can be detected microscopically (NBT) or by flow cytometry (DHR). Qualitative studies of superoxide and hydrogen peroxide production may further define neutrophil oxidative function.

Patients with leukopenias or leukocyte dysfunction often have delayed inflammatory responses. Therefore, clinical manifestations may be minimal despite overwhelming infection, and unusual infections must always be suspected. Early signs of infection demand prompt, aggressive culturing for microorganisms, use of antibiotics, and drainage of abscesses. Prolonged courses of antibiotics are often required. In patients with CGD, prophylactic antibiotics (trimethoprim-sulfamethoxazole) and antifungals (itraconazole) markedly diminish the frequency of life-threatening infections. Glucocorticoids may relieve gastrointestinal or genitourinary tract obstruction by granulomas in patients with CGD. Although TNF- $\alpha$ -blocking agents may markedly relieve inflammatory bowel symptoms, extreme caution must be exercised in their use in CGD inflammatory bowel disease, because it profoundly increases these patients' already heightened susceptibility to infection. Recombinant human IFN- $\gamma$ , which nonspecifically stimulates phagocytic cell function, reduces the frequency of infections in patients with CGD by 70% and reduces the severity of infection. This effect of IFN- $\gamma$  in CGD is additive to the effect of prophylactic antibiotics. The recommended dose is 50  $\mu\text{g}/\text{m}^2$  subcutaneously three times weekly. IFN- $\gamma$  has also been used successfully in the treatment of leprosy, nontuberculous mycobacteria, and visceral leishmaniasis.

Rigorous oral hygiene reduces but does not eliminate the discomfort of gingivitis, periodontal disease, and aphthous ulcers; chlorhexidine mouthwash and tooth brushing with a hydrogen peroxide–sodium bicarbonate paste also helps many patients. Oral antifungal agents (fluconazole, itraconazole, voriconazole, posaconazole) have reduced mucocutaneous candidiasis in patients with Job's syndrome. Androgens, glucocorticoids, lithium, and immunosuppressive therapy have been used to restore myelopoiesis in patients with neutropenia due to impaired production. Recombinant G-CSF is useful in the management of certain forms of neutropenia due to depressed neutrophil production, including those related to cancer chemotherapy. Patients with chronic neutropenia with evidence of a good bone marrow reserve need not receive prophylactic antibiotics. Patients with chronic or cyclic neutrophil counts <500/ $\mu\text{L}$  may benefit from prophylactic antibiotics and G-CSF during periods of neutropenia. Oral trimethoprim-sulfamethoxazole (160/800 mg) twice daily can prevent infection. Increased numbers of fungal infections are not seen in patients with CGD on this regimen. Oral quinolones such as levofloxacin and ciprofloxacin are alternatives.

In the setting of cytotoxic chemotherapy with severe, persistent lymphocyte dysfunction, trimethoprim-sulfamethoxazole prevents *Pneumocystis jiroveci* pneumonia. These patients, and patients with phagocytic cell dysfunction, should avoid heavy exposure to airborne soil, dust, or decaying matter (mulch, manure), which are often rich in *Nocardia* and the spores of *Aspergillus* and other fungi. Restriction of activities or social contact has no proven role in reducing risk of infection for phagocyte defects.

Although aggressive medical care for many patients with phagocytic disorders can allow them to go for years without a life-threatening infection, there may still be delayed effects of prolonged antimicrobials and other inflammatory complications. Cure of most congenital phagocyte defects is possible by bone marrow transplantation, and rates of success are improving (Chap. 114). The identification of specific gene defects in patients with LAD 1, CGD, and other immunodeficiencies has led to gene therapy trials in a number of genetic white cell disorders.

## FURTHER READING

- B S et al: To NET or not to NET: Current opinions and state of the science regarding the formation of neutrophil extracellular traps. *Cell Death Differ* 26:395, 2019.
- B A et al: Human inborn errors of immunity: 2019 update of the IUIS phenotypical classification. *J Clin Immunol* 40:66, 2020.

- D MC: Inflammatory consequences of inherited disorders affecting neutrophil function. *Blood* 133:2130, 2019.
- K AD et al: Contributions of eosinophils to human health and disease. *Annu Rev Pathol* 15:179, 2020.
- K DB: Diagnostic testing for chronic granulomatous disease. *Methods Mol Biol* 1982:543, 2019.
- O S et al: Genetic susceptibility to fungal infection in children. *Curr Opin Pediatr* 32:780, 2020.
- P M, K P: More friend than foe: the emerging role of neutrophils in tissue repair. *J Clin Invest* 129:2629, 2019.
- T SG et al: Human inborn errors of immunity: 2019 Update on the classification from the International Union of Immunological Societies Expert Committee. *J Clin Immunol* 40:24, 2020.
- W UI, H SM: Host susceptibility to non-tuberculous mycobacterial infections. *Lancet Infect Dis* 15:968, 2015.

## 65

## Bleeding and Thrombosis

Barbara A. Konkle



The human hemostatic system provides a natural balance between procoagulant and anticoagulant forces. The procoagulant forces include platelet adhesion and aggregation and fibrin clot formation; anticoagulant forces include the natural inhibitors of coagulation and fibrinolysis. Under normal circumstances, hemostasis is regulated to promote blood flow; however, it is also prepared to clot blood rapidly to arrest blood flow and prevent exsanguination. After bleeding is successfully halted, the system remodels the damaged vessel to restore normal blood flow. The major components of the hemostatic system, which function in concert, are (1) platelets and other formed elements of blood, such as monocytes and red cells; (2) plasma proteins (the coagulation and fibrinolytic factors and inhibitors); and (3) the vessel wall.

## STEPS OF NORMAL HEMOSTASIS

### PLATELET PLUG FORMATION

On vascular injury, platelets adhere to the site of injury, usually the denuded vascular intimal surface. Platelet adhesion is mediated primarily by von Willebrand factor (VWF), a large multimeric protein present in both plasma and the extracellular matrix of the subendothelial vessel wall, which serves as the primary "molecular glue," providing sufficient strength to withstand the high levels of shear stress that would tend to detach them with the flow of blood. Platelet adhesion is also facilitated by direct binding to subendothelial collagen through specific platelet membrane collagen receptors.

Platelet adhesion results in subsequent platelet activation and aggregation. This process is enhanced and amplified by humoral mediators in plasma (e.g., epinephrine, thrombin); mediators released from activated platelets (e.g., adenosine diphosphate, serotonin); and vessel wall extracellular matrix constituents that come in contact with adherent platelets (e.g., collagen, VWF). Activated platelets undergo the release reaction, during which they secrete contents that further promote aggregation and inhibit the naturally anticoagulant endothelial cell factors. During platelet aggregation (platelet-platelet interaction), additional platelets are recruited from the circulation to the site of vascular injury, leading to the formation of an occlusive platelet thrombus. The platelet plug is anchored and stabilized by the developing fibrin mesh.

The platelet glycoprotein (Gp) IIb/IIIa ( $\alpha_{IIb}\beta_3$ ) complex is the most abundant receptor on the platelet surface. Platelet activation converts the normally inactive Gp IIb/IIIa receptor into an active receptor, enabling binding to fibrinogen and VWF. Because the surface of each platelet has about 50,000 Gp IIb/IIIa-binding sites, numerous activated

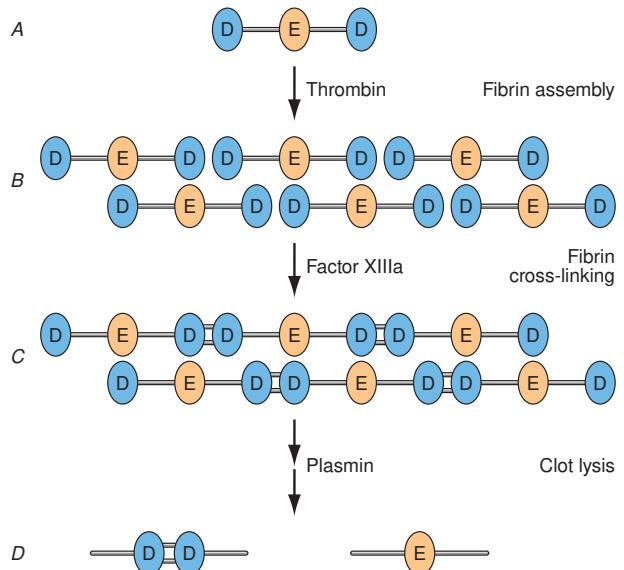
platelets recruited to the site of vascular injury can rapidly form an occlusive aggregate by means of a dense network of intercellular fibrinogen bridges.

## FIBRIN CLOT FORMATION

Plasma coagulation proteins (*clotting factors*) normally circulate in plasma in their inactive forms. The sequence of coagulation protein reactions that culminate in the formation of fibrin was originally described as a *waterfall* or a *cascade*. Two pathways of blood coagulation have been described in the past: the so-called extrinsic, or tissue factor, pathway and the so-called intrinsic, or contact activation, pathway. We now know that coagulation is normally initiated through tissue factor (TF) exposure and activation through the classic *extrinsic pathway* but with critically important amplification through elements of the classic *intrinsic pathway*, as illustrated in Fig. 65-1. These reactions take place on phospholipid surfaces, usually the activated platelet surface. Coagulation testing in the laboratory can reflect other influences due to the artificial nature of the in vitro systems used (see below).

The immediate trigger for coagulation is vascular damage that exposes blood to TF that is constitutively expressed on the surfaces of subendothelial cellular components of the vessel wall, such as smooth muscle cells and fibroblasts. TF is also present in circulating microparticles, presumably shed from cells including monocytes and platelets. TF binds the serine protease factor VIIa; the complex activates factor X to factor Xa. Alternatively, the complex can indirectly activate factor X by initially converting factor IX to factor IXa, which then activates factor X. The participation of factor XI in hemostasis is not dependent on its activation by factor XIIa but rather on its positive feedback activation by thrombin. Thus, factor XIIa functions in the propagation and amplification, rather than in the initiation, of the coagulation cascade. The role of factor XIIa in activation of factor XI is not fully elucidated, but studies suggest it may be a mechanism to promote thrombosis.

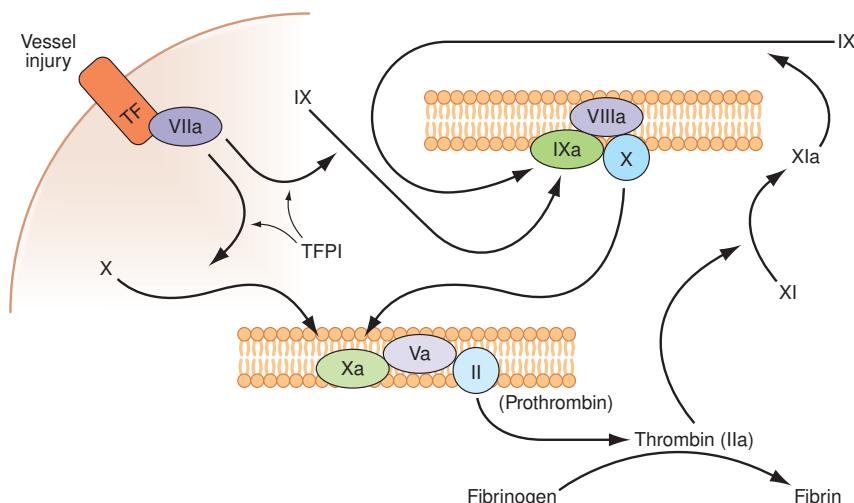
Factor Xa can be formed through the actions of either the TF/factor VIIa complex or factor IXa (with factor VIIIa as a cofactor) and converts prothrombin to thrombin, the pivotal protease of the coagulation system. The essential cofactor for this reaction is factor Va. Like the homologous factor VIIIa, factor Va is produced by thrombin-induced limited proteolysis of factor V. Thrombin is a multifunctional enzyme that converts soluble plasma fibrinogen to an insoluble fibrin



**FIGURE 65-2** Fibrin formation and dissolution. (A) Fibrinogen is a trinodular structure consisting of two D domains and one E domain. Thrombin activation results in an ordered lateral assembly of protofibrils (B) with noncovalent associations. Factor XIIIa cross-links the D domains on adjacent molecules (C). Fibrin and fibrinogen (not shown) lysis by plasmin occurs at discrete sites and results in intermediary fibrin(ogen) degradation products (not shown). D-Dimers are the product of complete lysis of fibrin (D), maintaining the cross-linked D domains.

matrix. Fibrin polymerization involves an orderly process of intermolecular associations (Fig. 65-2). Thrombin also activates factor XIII (fibrin-stabilizing factor) to factor XIIIa, which covalently cross-links and thereby stabilizes the fibrin clot.

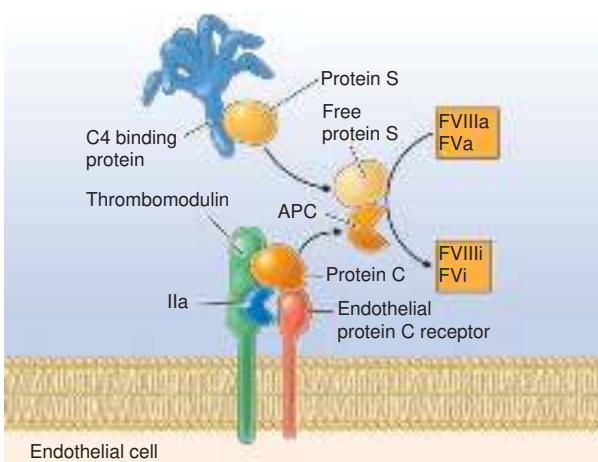
The assembly of the clotting factors on activated cell membrane surfaces greatly accelerates their reaction rates and also serves to localize blood clotting to sites of vascular injury. The critical cell membrane components, acidic phospholipids, are not normally exposed on resting cell membrane surfaces. However, when platelets, monocytes, and endothelial cells are activated by vascular injury or inflammatory stimuli, the procoagulant head groups of the membrane anionic phospholipids become translocated to the surfaces of these cells or released as part of microparticles, making them available to support and promote the plasma coagulation reactions.



**FIGURE 65-1** Coagulation is initiated by tissue factor (TF) exposure, which, with factor (F) VIIa, activates FIX and FX, which in turn, with FVIII and FV as cofactors, respectively, results in thrombin formation and subsequent conversion of fibrinogen to fibrin. Thrombin activates FXI, FVIII, and FV, amplifying the coagulation signal. Once the TF/FVIIa/FXa complex is formed, tissue factor pathway inhibitor (TFPI) inhibits the TF/FVIIa pathway, making coagulation dependent on the amplification loop through FIX/FVIII. Coagulation requires calcium (not shown) and takes place on phospholipid surfaces, usually the activated platelet membrane.

## ANTITHROMBOTIC MECHANISMS

Several physiologic antithrombotic mechanisms act in concert to prevent clotting under normal circumstances. These mechanisms operate to preserve blood fluidity and to limit blood clotting to specific focal sites of vascular injury. Endothelial cells have many antithrombotic effects. They produce prostacyclin, nitric oxide, and ectoADPase/CD39, which act to inhibit platelet binding, secretion, and aggregation. Endothelial cells produce anticoagulant factors including heparan proteoglycans, TF pathway inhibitor, and thrombomodulin. They also activate fibrinolytic mechanisms through the production of tissue plasminogen activator, urokinase, plasminogen activator inhibitors, and annexin-2.



**FIGURE 65-3** The activated protein C pathway in regulation of thrombosis. Thrombin generation results in protein C activation through interaction with thrombomodulin and protein C bound to the endothelial protein C receptor (EPCR). Activated protein C (APC) with free protein S converts activated factors (F) VIII and V to inactive forms, thus in turn decreasing thrombin generation. C4BP, C4 binding protein; EC, endothelial cell; F, factor; IIa, thrombin; PC, protein C; PS, protein S; TM, thrombomodulin.

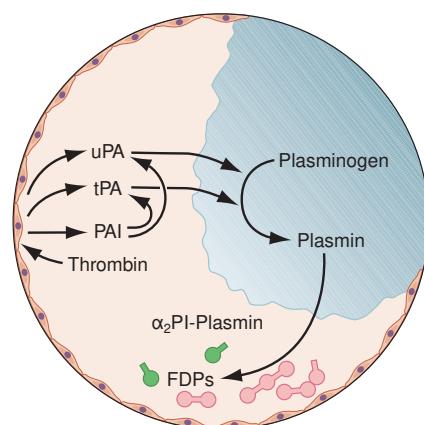
Antithrombin is the major plasma protease inhibitor of thrombin and the other clotting factors in coagulation. Antithrombin neutralizes thrombin and other activated coagulation factors by forming a complex between the active site of the enzyme and the reactive center of antithrombin. The rate of formation of these inactivating complexes increases by a factor of several thousand in the presence of heparin. Antithrombin inactivation of thrombin and other activated clotting factors occurs physiologically on vascular surfaces, where glycosaminoglycans, including heparan sulfates, are present to catalyze these reactions. Inherited quantitative or qualitative deficiencies of antithrombin lead to a lifelong predisposition to venous thromboembolism.

Protein C is a plasma glycoprotein that becomes an anticoagulant when it is activated by thrombin. The thrombin-induced activation of protein C occurs physiologically on thrombomodulin, a transmembrane proteoglycan-binding site for thrombin on endothelial cell surfaces. The binding of protein C to its receptor on endothelial cells places it in proximity to the thrombin-thrombomodulin complex, thereby enhancing its activation efficiency. (See Fig. 65-3.) Activated protein C acts as an anticoagulant by cleaving and inactivating activated factors V and VIII. This reaction is accelerated by a cofactor, protein S, which, like protein C, is a glycoprotein that undergoes vitamin K-dependent posttranslational modification. Quantitative or qualitative deficiencies of protein C or protein S, or resistance to the action of activated protein C by a specific variant at its target cleavage site in factor Va (factor V Leiden), lead to hypercoagulable states.

Tissue factor pathway inhibitor (TFPI) is a plasma protease inhibitor that regulates the TF-induced extrinsic pathway of coagulation. TFPI inhibits the TF/factor VIIa/factor Xa complex, essentially turning off the TF/factor VIIa initiation of coagulation, which then becomes dependent on the “amplification loop” via factor XI and factor VIII activation by thrombin. TFPI is bound to lipoprotein and can also be released by heparin from endothelial cells, where it is bound to glycosaminoglycans, and from platelets. The heparin-mediated release of TFPI may play a role in the anticoagulant effects of unfractionated and low-molecular-weight heparins.

### THE FIBRINOLYTIC SYSTEM

Any thrombin that escapes the inhibitory effects of the physiologic anticoagulant systems is available to convert fibrinogen to fibrin. In response, the endogenous fibrinolytic system is then activated to



**FIGURE 65-4** A schematic diagram of the fibrinolytic system. Tissue plasminogen activator (tPA) is released from endothelial cells, binds the fibrin clot, and activates plasminogen to plasmin. Release of plasminogen activator inhibitors (PAI-1 and PAI-2) inhibits tPA and urokinase (uPA). Excess fibrin is degraded by plasmin to distinct degradation products [FDPs (d-dimers)]. Any free plasmin is complexed with  $\alpha_2$ -antiplasmin ( $\alpha_2$ PI). PAI, plasminogen activator inhibitor; uPA, urokinase-type plasminogen activator.

dispose of intravascular fibrin and thereby maintain or reestablish the patency of the circulation. Just as thrombin is the key protease enzyme of the coagulation system, plasmin is the major protease enzyme of the fibrinolytic system, acting to digest fibrin to fibrin degradation products. The general scheme of fibrinolysis and its control is shown in Fig. 65-4.

The plasminogen activators, tissue type plasminogen activator (tPA) and the urokinase-type plasminogen activator (uPA), cleave the Arg560-Val561 bond of plasminogen to generate the active enzyme plasmin. The lysine-binding sites of plasmin (and plasminogen) permit it to bind to fibrin, so that physiologic fibrinolysis is “fibrin specific.” Both plasminogen (through its lysine-binding sites) and tPA possess specific affinity for fibrin and thereby bind selectively to clots. The assembly of a ternary complex, consisting of fibrin, plasminogen, and tPA, promotes the localized interaction between plasminogen and tPA and greatly accelerates the rate of plasminogen activation to plasmin. Moreover, partial degradation of fibrin by plasmin exposes new plasminogen and tPA-binding sites in carboxy-terminus lysine residues of fibrin fragments to enhance these reactions further. This creates a highly efficient mechanism to generate plasmin focally on the fibrin clot, which then becomes plasmin’s substrate for digestion to fibrin degradation products.

Plasmin cleaves fibrin at distinct sites of the fibrin molecule, leading to the generation of characteristic fibrin fragments during the process of fibrinolysis (Fig. 65-2). The sites of plasmin cleavage of fibrin are the same as those in fibrinogen. However, when plasmin acts on covalently cross-linked fibrin, -dimers are released; hence, -dimers can be measured in plasma as a relatively specific test of fibrin (rather than fibrinogen) degradation. -Dimer assays can be used as sensitive markers of blood clot formation and have been validated for clinical use to exclude the diagnosis of deep venous thrombosis (DVT) and pulmonary embolism in selected populations. -Dimer levels increase with age. A higher cut-off value to rule out venous thromboembolism (VTE) in the elderly has been proposed but is controversial.

Physiologic regulation of fibrinolysis occurs primarily at three levels: (1) plasminogen activator inhibitors (PAIs), specifically PAI-1 and PAI-2, inhibit the physiologic plasminogen activators; (2) the thrombin-activatable fibrinolysis inhibitor (TAFI) limits fibrinolysis; and (3)  $\alpha_2$ -antiplasmin inhibits plasmin. PAI-1 is the primary inhibitor of tPA and uPA in plasma. TAFI cleaves the N-terminal lysine residues of fibrin, which aid in localization of plasmin activity.  $\alpha_2$ -Antiplasmin is the main inhibitor of plasmin in human plasma, inactivating any nonfibrin clot-associated plasmin.

## APPROACH TO THE PATIENT

### Bleeding and Thrombosis

#### CLINICAL PRESENTATION

Disorders of hemostasis may be either inherited or acquired. A detailed personal and family history is key in determining the chronicity of symptoms and the likelihood of the disorder being inherited, as well as providing clues to underlying conditions that have contributed to the bleeding or thrombotic state. In addition, the history can give clues as to the etiology by determining (1) the bleeding (mucosal and/or joint) or thrombosis (arterial and/or venous) site and (2) whether an underlying bleeding or clotting tendency was enhanced by another medical condition or the introduction of medications or dietary supplements.

**History of Bleeding** A history of bleeding is the most important predictor of bleeding risk. In evaluating a patient for a bleeding disorder, a history of at-risk situations, including the response to past surgeries, should be assessed. Does the patient have a history of spontaneous or trauma/surgery-induced bleeding? Spontaneous hemarthroses are a hallmark of moderate and severe factor VIII and IX deficiency and, in rare circumstances, of other clotting factor deficiencies. Mucosal bleeding symptoms are more suggestive of underlying platelet disorders or von Willebrand disease (VWD), termed *disorders of primary hemostasis or platelet plug formation*. Disorders affecting primary hemostasis are shown in Table 65-1.

A bleeding score has been validated as a tool to predict patients more likely to have type 1 VWD (International Society on Thrombosis and Haemostasis Bleeding Assessment Tool [[www.isth.org/resource/resmgr/ssc/isth-ssc\\_bleeding\\_assessment.pdf](http://www.isth.org/resource/resmgr/ssc/isth-ssc_bleeding_assessment.pdf)]), and a self-administered form has been validated. This is the most useful tool in excluding the diagnosis of a bleeding disorder, thus avoiding unnecessary testing, and is recommended by 2021 guidelines for screening for VWD in primary care. Bleeding symptoms that are more common in patients with bleeding disorders include prolonged bleeding with surgery, dental procedures and extractions, and/or trauma; heavy menstrual bleeding or postpartum hemorrhage; and large bruises (often described with lumps).

Easy bruising and heavy menstrual bleeding are common complaints in patients with and without bleeding disorders. Easy bruising can also be a sign of medical conditions in which there is no

identifiable coagulopathy; instead, the conditions are caused by an abnormality of blood vessels or their supporting connective tissues. In Ehlers-Danlos syndrome, there may be posttraumatic bleeding and a history of joint hyperextensibility. Cushing's syndrome, chronic steroid use, and aging result in changes in skin and subcutaneous tissue, and subcutaneous bleeding occurs in response to minor trauma. The latter has been termed *senile purpura*.

Epistaxis is a common symptom, particularly in children and in dry climates, and may not reflect an underlying bleeding disorder. However, it is the most common symptom in hereditary hemorrhagic telangiectasia and in boys with VWD. Clues that epistaxis is a symptom of an underlying bleeding disorder include lack of seasonal variation and bleeding that requires medical evaluation or treatment, including cauterization. Bleeding with eruption of primary teeth is seen in children with more severe bleeding disorders, such as moderate and severe hemophilia. It is uncommon in children with mild bleeding disorders. Patients with disorders of primary hemostasis (platelet adhesion) may have increased bleeding after dental cleanings and other procedures that involve gum manipulation.

**Heavy menstrual bleeding** is defined quantitatively as a loss of >80 mL of blood per cycle, based on the quantity of blood loss required to produce iron-deficiency anemia. A complaint of heavy menses is subjective and has a poor correlation with excessive blood loss. Predictors of heavy menstrual bleeding include bleeding resulting in iron-deficiency anemia or a need for blood transfusion, passage of clots >1 inch in diameter, and changing a pad or tampon more than hourly. Heavy menstrual bleeding is a common symptom in women with underlying bleeding disorders and is reported in the majority of women with VWD, factor XI deficiency, platelet function disorders, and hemophilia, including genetic carriers with borderline-normal factor levels. Women with underlying bleeding disorders are more likely to have other bleeding symptoms, including bleeding after dental extractions and postoperative and postpartum bleeding, and are much more likely to have heavy menstrual bleeding beginning at menarche than women with heavy menstrual bleeding due to other causes. Heavy menstrual bleeding may result in iron deficiency and is documented to have significant adverse effects on quality of life.

Postpartum hemorrhage is a common symptom in women with underlying bleeding disorders. In women with type 1 VWD or hemophilia A in whom levels of VWF and factor VIII usually normalize during pregnancy, postpartum hemorrhage may be delayed. Women with a history of postpartum hemorrhage may have a higher risk of recurrence with subsequent pregnancies. Women with underlying bleeding disorders are at risk for other reproductive tract bleeding, including rupture of ovarian cysts with intraabdominal hemorrhage.

Tonsillectomy is a major hemostatic challenge, because intact hemostatic mechanisms are essential to prevent excessive bleeding from the tonsillar bed. Bleeding may occur early after surgery or after approximately 7 days postoperatively, with loss of the eschar at the operative site. Similar delayed bleeding is seen after colonic polyp resection. Gastrointestinal (GI) bleeding and hematuria are usually due to underlying pathology, and procedures to identify and treat the bleeding site should be undertaken, even in patients with known bleeding disorders. VWD, particularly types 2 and 3, is associated with angiomyolysis of the bowel and GI bleeding.

Hemarthroses and spontaneous muscle hematomas are characteristic of moderate or severe congenital factor VIII or IX deficiency. They can also be seen in moderate and severe deficiencies of fibrinogen, prothrombin, and factors V, VII, and X. Spontaneous hemarthroses occur rarely in other bleeding disorders except for severe VWD, with associated factor VIII levels <5%. Muscle and soft tissue bleeds are also common in acquired factor VIII deficiency. Bleeding into a joint results in severe pain and swelling, as well as loss of function, but is rarely associated with discoloration from bruising around the joint. Life-threatening sites of bleeding

TABLE 65-1 Primary Hemostatic (Platelet Plug) Disorders

#### Defects of Platelet Adhesion

von Willebrand disease

Bernard-Soulier syndrome (absence or dysfunction of platelet Gp Ib-IX-V)

#### Defects of Platelet Aggregation

Glanzmann's thrombasthenia (absence or dysfunction of platelet glycoprotein [Gp] IIb/IIIa)

Afibrinogenemia

#### Defects of Platelet Secretion

Decreased cyclooxygenase activity

Drug-induced (aspirin, nonsteroidal anti-inflammatory agents, thienopyridines)

Inherited

Granule storage pool defects

Inherited

Acquired

Nonspecific inherited secretory defects

Nonspecific drug effects

Uremia

Platelet coating (e.g., paraprotein, penicillin)

#### Defect of Platelet Coagulant Activity

Scott's syndrome

include bleeding into the oropharynx, where bleeding can obstruct the airway, into the central nervous system, and into the retroperitoneum. Central nervous system bleeding is the major cause of bleeding-related deaths in patients with severe congenital factor deficiencies.

#### *Prohemorrhagic Effects of Medications and Dietary Supplements*

Aspirin and other nonsteroidal anti-inflammatory drugs (NSAIDs) that inhibit cyclooxygenase 1 impair primary hemostasis and may exacerbate bleeding from another cause or even unmask a previously occult mild bleeding disorder such as VWD. All NSAIDs, however, can precipitate GI bleeding, which may be more severe in patients with underlying bleeding disorders. The aspirin effect on platelet function lasts for the life of the platelet; however, in individuals with typical platelet turnover, the functional defect reverts to near-normal within 2–3 days after the last dose. The effect of other NSAIDs is shorter, as the inhibitor effect is reversed when the drug is removed. Inhibitors of the ADP P2Y<sub>12</sub> receptor (clopidogrel, prasugrel, and ticagrelor) inhibit ADP-mediated platelet aggregation and, like NSAIDs, can precipitate or exacerbate bleeding symptoms. The risk of bleeding with these drugs is higher than with NSAIDs.

Many herbal supplements can impair hemostatic function (Table 65-2). Some are more convincingly associated with a bleeding risk than others. Fish oil or concentrated omega-3 fatty acid supplements impair platelet function. They alter platelet biochemistry to produce more PGI<sub>3</sub>, a more potent platelet inhibitor than prostacyclin (PGI<sub>2</sub>), and more thromboxane A<sub>3</sub>, a less potent platelet activator than thromboxane A<sub>2</sub>. In fact, diets naturally rich in omega-3 fatty acids can result in a prolonged bleeding time and abnormal platelet aggregation studies, but the actual associated bleeding risk is unclear. Vitamin E appears to inhibit protein kinase C-mediated platelet aggregation and nitric oxide production. In patients with unexplained bruising or bleeding, it is prudent to review any new medications or supplements and discontinue those that may be associated with bleeding.

**Underlying Systemic Diseases That Cause or Exacerbate a Bleeding Tendency** Acquired bleeding disorders are commonly secondary to, or associated with, systemic disease. The clinical evaluation of a patient with a bleeding tendency must therefore include a thorough assessment for evidence of underlying disease. Bruising or mucosal bleeding may be the presenting complaint in

TABLE 65-2 Herbal Supplements Associated with Increased Bleeding

#### Herbs with Potential Antiplatelet Activity

- Ginkgo (*Ginkgo biloba L.*)
- Garlic (*Allium sativum*)
- Bilberry (*Vaccinium myrtillus*)
- Ginger (*Gingiber officinale*)
- Dong quai (*Angelica sinensis*)
- Feverfew (*Tanacetum parthenium*)
- Asian ginseng (*Panax ginseng*)
- American ginseng (*Panax quinquefolius*)
- Siberian ginseng/eleuthero (*Eleutherococcus senticosus*)
- Turmeric (*Circuma longa*)
- Meadowsweet (*Filipendula ulmaria*)
- Willow (*Salix spp.*)

#### Coumarin-Containing Herbs

- Motherwort (*Leonurus cardiaca*)
- Chamomile (*Matricaria recutita, Chamaemelum mobile*)
- Horse chestnut (*Aesculus hippocastanum*)
- Red clover (*Trifolium pratense*)
- Fenugreek (*Trigonella foenum-graecum*)

liver disease, severe renal impairment, hypothyroidism, paraproteinemias or amyloidosis, and conditions causing bone marrow failure. All coagulation factors are synthesized in the liver, and hepatic failure results in combined factor deficiencies. This is often compounded by thrombocytopenia and portal hypertension. Coagulation factors II, VII, IX, and X and proteins C, S, and Z are dependent on vitamin K for posttranslational modification. Although vitamin K is required in both procoagulant and anticoagulant processes, the phenotype of vitamin K deficiency or the warfarin effect on coagulation is bleeding.

The normal blood platelet count is 150,000–450,000/ $\mu$ L. Thrombocytopenia results from decreased production, increased destruction, and/or sequestration. Although the bleeding risk varies somewhat by the reason for the thrombocytopenia, bleeding rarely occurs in isolated thrombocytopenia at counts >50,000/ $\mu$ L and usually not until <10,000–20,000/ $\mu$ L. Coexisting coagulopathies, as is seen in liver failure or disseminated coagulation; infection; platelet-inhibitory drugs; and underlying medical conditions can all increase the risk of bleeding in the thrombocytopenic patient. Most procedures can be performed in patients with a platelet count of 50,000/ $\mu$ L or greater.

#### HISTORY OF THROMBOSIS

The risk of thrombosis, like that of bleeding, is influenced by both genetic and environmental factors. The major risk factor for arterial thrombosis is atherosclerosis, whereas for venous thrombosis, the risk factors are immobility, surgery, underlying medical conditions such as malignancy, medications such as hormonal therapy, obesity, and genetic predispositions. Factors that increase risks for venous and for both venous and arterial thromboses are shown in Table 65-3.

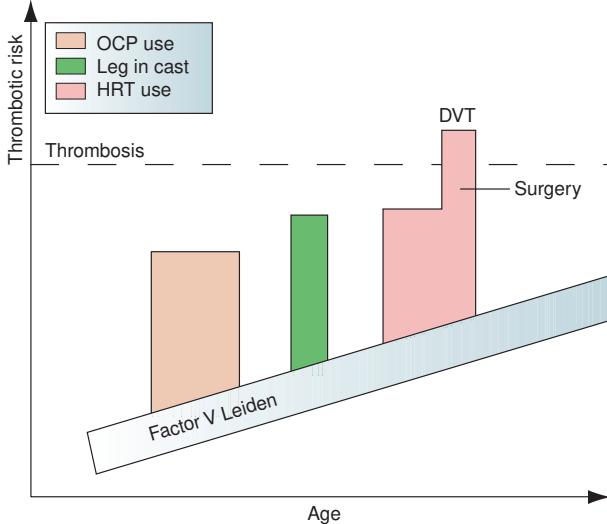
The most important point in a history related to venous thrombosis is determining whether the thrombotic event was idiopathic (meaning there was no clear precipitating factor) or was a precipitated event. In patients without underlying malignancy, having an idiopathic event is the strongest predictor of recurrence of VTE. In patients who have a vague history of thrombosis, a history of being treated with warfarin or other anticoagulants suggests a past DVT. Age is an important risk factor for venous thrombosis—the risk of DVT increases per decade, with an approximate incidence of 1/100,000 per year in early childhood to 1/200 per year among octogenarians. Family history is helpful in determining if there is a

TABLE 65-3 Some Risk Factors for Thrombosis

VENOUS	VENOUS AND ARTERIAL
Inherited	Inherited
Factor V Leiden	Homocystinuria
Prothrombin G20210A	Dysfibrinogenemia
Antithrombin deficiency	Acquired
Protein C deficiency	Malignancy
Protein S deficiency	Antiphospholipid antibody syndrome
Acquired	Hormonal therapy
Age	Polycythemia vera
Previous thrombosis	Essential thrombocythemia
Immobilization	Paroxysmal nocturnal hemoglobinuria
Major surgery	Thrombotic thrombocytopenic purpura
Pregnancy and puerperium	Heparin-induced thrombocytopenia
Hospitalization	Disseminated intravascular coagulation
Obesity	Unknown <sup>a</sup>
Infection	Elevated factor II, VIII, IX, XI
Smoking	Elevated TAFI levels
	Low levels of TFPI

<sup>a</sup>Unknown whether risk is inherited or acquired.

Abbreviations: APC, activated protein C; TAFI, thrombin-activatable fibrinolysis inhibitor; TFPI, tissue factor pathway inhibitor.



**FIGURE 65-5** Thrombotic risk over time. Shown schematically is an individual's thrombotic risk over time. An underlying factor V Leiden variant provides a "theoretically" constant increased risk. The thrombotic risk increases with age and, intermittently, with oral contraceptive (OCP) or hormone replacement therapy (HRT) use; other events, like major surgery or illness, will increase the risk further. At some point, the cumulative risk may increase to the threshold for thrombosis and result in deep venous thrombosis (DVT). Note: The magnitude and duration of risk portrayed in the figure are meant for example only and may not precisely reflect the relative risk determined by clinical study. (Sources: From BA Konkle, A Schafer, in DP Zipes et al [eds]: Braunwald's Heart Disease, 7th ed. Philadelphia, Saunders, 2005; from FR Rosendaal: Venous thrombosis: A multicausal disease. *Lancet* 353:1167, 1999.)

genetic predisposition and how strong that predisposition appears to be. A genetic thrombophilia that confers a relatively small increased risk, such as being a heterozygote for the prothrombin G20210A or factor V Leiden mutation, is a minor determinant of risk in an elderly individual undergoing a high-risk surgical procedure. As illustrated in Fig. 65-5, a thrombotic event usually has more than one contributing factor. Predisposing factors must be carefully assessed to determine the risk of recurrent thrombosis and, with consideration of the patient's bleeding risk, determine the length of anticoagulation. Testing for inherited thrombophilias in adults should be limited to instances where results would change clinical care. Such instances are rare.

#### LABORATORY EVALUATION

Careful history taking and clinical examination are essential components in the assessment of bleeding and thrombotic risk. The use of laboratory tests of coagulation complements, but cannot substitute for, clinical assessment. No test exists that provides a global assessment of hemostasis. The bleeding time has been used to assess bleeding risk; however, it does not predict bleeding risk with surgery, and it is not recommended for this indication. The PFA-100, an instrument that measures platelet-dependent coagulation under flow conditions, is more sensitive and specific for VWD than the bleeding time; however, it is not sensitive enough to rule out mild bleeding disorders. PFA-100 closure times are prolonged in patients with some, but not all, inherited platelet disorders. Also, its utility in predicting bleeding risk has not been determined. Thromboelastography can be useful in guiding intraoperative transfusion and is being explored in other settings, but is not broadly applicable for the diagnosis of disorders of hemostasis and thrombosis.

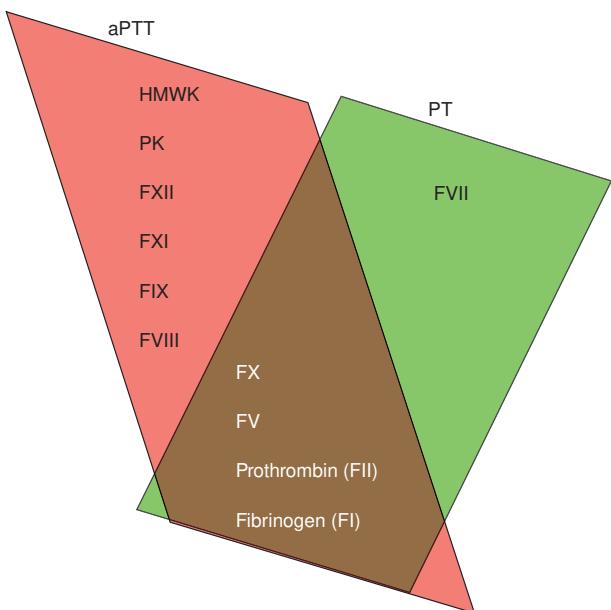
For routine preoperative and preprocedure testing, an abnormal prothrombin time (PT) may detect liver disease or vitamin K deficiency that had not been previously appreciated. Studies have not confirmed the usefulness of an activated partial thromboplastin time (aPTT) in preoperative evaluations in patients with a negative

bleeding history. The primary use of coagulation testing should be to confirm the presence and type of bleeding disorder in a patient with a suspicious clinical history.

Because of the nature of coagulation assays, proper sample acquisition and handling is critical to obtaining valid results. In patients with abnormal coagulation assays who have no bleeding history, repeat studies with attention to these factors frequently results in normal values. Most coagulation assays are performed in sodium citrate anticoagulated plasma that is recalcified for the assay. Because the anticoagulant is in liquid solution and needs to be added to blood in proportion to the plasma volume, incorrectly filled or inadequately mixed blood collection tubes will give erroneous results. These vacutainer tubes should be filled to >90% of the recommended fill, which is usually denoted by a line on the tube. An elevated hematocrit (>55%) can result in a false value due to a decreased plasma-to-anticoagulant ratio.

**Screening Assays** The most commonly used screening tests are the PT, aPTT, and platelet count. The PT assesses the factors I (fibrinogen), II (prothrombin), V, VII, and X (Fig. 65-6). The PT measures the time for clot formation of the citrated plasma after recalcification and addition of thromboplastin, a mixture of TF and phospholipids. The sensitivity of the assay varies by the source of thromboplastin. The relationship between defects in secondary hemostasis (fibrin formation) and coagulation test abnormalities is shown in Table 65-4. To adjust for this variability, the overall sensitivity of different thromboplastins to reduction of the vitamin K-dependent clotting factors II, VII, IX, and X in anticoagulation patients is expressed as the International Sensitivity Index (ISI). The international normalized ratio (INR) is determined based on the formula:  $INR = (\frac{PT_{patient}}{PT_{normal\ mean}})^{ISI}$ .

The INR was developed to assess stable anticoagulation due to reduction of vitamin K-dependent coagulation factors; it is commonly used in the evaluation of patients with liver disease. Although it does allow comparison between laboratories, reagent sensitivity as used to determine the ISI is not the same in liver disease as with warfarin anticoagulation. In addition, progressive liver failure is associated with variable changes in coagulation factors; the degree of prolongation of either the PT or the INR only roughly



**FIGURE 65-6** Coagulation factor activity tested in the activated partial thromboplastin time (aPTT) in red and prothrombin time (PT) in green, or both. F, factor; HMWK, high-molecular-weight kininogen; PK, prekallikrein.

TABLE 65-4 Hemostatic Disorders and Coagulation Test Abnormalities	
<b>Prolonged Activated Partial Thromboplastin Time (aPTT)</b>	
No clinical bleeding—↓ factor XII, high-molecular-weight kininogen, prekallikrein	
Variable, but usually mild, bleeding—↓ factor XI, mild ↓ factor VIII and factor IX	
Frequent, severe bleeding—severe deficiencies of factors VIII and IX	
Heparin and direct thrombin inhibitors	
<b>Prolonged Prothrombin Time (PT)</b>	
Factor VII deficiency	
Vitamin K deficiency—early	
Warfarin anticoagulation	
Direct Xa inhibitors (rivaroxaban, edoxaban, apixaban—note PT may be normal)	
<b>Prolonged aPTT and PT</b>	
Factor II, V, X, or fibrinogen deficiency	
Vitamin K deficiency—late	
Direct thrombin inhibitors	
<b>Prolonged Thrombin Time</b>	
Heparin or heparin-like inhibitors	
Direct thrombin inhibitors (e.g., dabigatran, argatroban, bivalirudin)	
Mild or no bleeding—dysfibrinogenemia	
Frequent, severe bleeding—afibrinogenemia	
<b>Prolonged PT and/or aPTT Not Corrected with Mixing with Normal Plasma</b>	
Bleeding—specific factor inhibitor	
No symptoms, or clotting and/or pregnancy loss—lupus anticoagulant	
Disseminated intravascular coagulation	
Heparin or direct thrombin inhibitor	
<b>Abnormal Clot Solubility</b>	
Factor XIII deficiency	
Inhibitors or defective cross-linking	
<b>Rapid Clot Lysis</b>	
Deficiency of $\alpha_2$ -antiplasmin or plasminogen activator inhibitor 1	
Treatment with fibrinolytic therapy	

predicts the bleeding risk. Thrombin generation has been shown to be normal in many patients with mild to moderate liver dysfunction. Because the PT only measures one aspect of hemostasis affected by liver dysfunction, we likely overestimate the bleeding risk of a mildly elevated INR in this setting. PT reagents have variable sensitivity to the direct Xa inhibitors, and the PT is usually normal in patients on apixaban.

The aPTT assesses the intrinsic and common coagulation pathways; factors XI, IX, VIII, X, V, and II; fibrinogen; prekallikrein; high-molecular-weight kininogen; and factor XII (Fig. 65-6). The aPTT reagent contains phospholipids derived from either animal or vegetable sources that function as a platelet substitute in the coagulation pathways and includes an activator of the intrinsic coagulation system, such as nonparticulate ellagic acid or the particulate activators kaolin, celite, or micronized silica.

The phospholipid composition of aPTT reagents varies, which influences the sensitivity of individual reagents to clotting factor deficiencies and to inhibitors such as heparin and lupus anticoagulants. Thus, aPTT results will vary from one laboratory to another, and the normal range in the laboratory where the testing occurs should be used in the interpretation. Local laboratories can relate their aPTT values to the therapeutic heparin anticoagulation by correlating aPTT values with direct measurements of heparin activity (anti-Xa or protamine titration assays) in samples from heparinized patients, although correlation between these assays is

often poor. The aPTT reagent will vary in sensitivity to individual factor deficiencies and usually becomes prolonged with individual factor deficiencies of 30–50%.

**Mixing Studies** Mixing studies are used to evaluate a prolonged aPTT or, less commonly PT, to distinguish between a factor deficiency and an inhibitor. In this assay, normal plasma and patient plasma are mixed in a 1:1 ratio, and the aPTT or PT is determined immediately and after incubation at 37°C for varying times, typically 30, 60, and/or 120 min. With isolated factor deficiencies, the aPTT will correct with mixing and stay corrected with incubation. With aPTT prolongation due to a lupus anticoagulant, the mixing and incubation will show no correction. In acquired neutralizing factor antibodies, notably an acquired factor VIII inhibitor, the initial assay may or may not correct immediately after mixing but will prolong or remain prolonged with incubation at 37°C. Failure to correct with mixing can also be due to the presence of other inhibitors or interfering substances such as heparin, fibrin split products, and paraproteins.

**Specific Factor Assays** Decisions to proceed with specific clotting factor assays will be influenced by the clinical situation and the results of coagulation screening tests. Precise diagnosis and effective management of inherited and acquired coagulation deficiencies necessitate quantitation of the relevant factors. When bleeding is severe, specific assays are urgently required to guide appropriate therapy. Individual factor assays are usually performed as modifications of the mixing study, where the patient's plasma is mixed with plasma deficient in the factor being studied. This will correct all factor deficiencies to >50%, thus making prolongation of clot formation due to a factor deficiency dependent on the factor missing from the added plasma.

**Testing for Antiphospholipid Antibodies** Antibodies to phospholipids (cardiolipin) or phospholipid-binding proteins ( $\beta_2$ -microglobulin and others) are detected by enzyme-linked immunosorbent assay (ELISA). When these antibodies interfere with phospholipid-dependent coagulation tests, they are termed *lupus anticoagulants*. The aPTT has variability sensitivity to lupus anticoagulants, depending in part on the aPTT reagents used. An assay using a sensitive reagent has been termed an *LA-aPTT*. The dilute Russell viper venom test (dRVVT) is a modification of a standard test with the phospholipid reagent decreased, thus increasing the sensitivity to antibodies that interfere with the phospholipid component. These tests, however, are not specific for lupus anticoagulants, because factor deficiencies or other inhibitors will also result in prolongation. Documentation of a lupus anticoagulant requires not only prolongation of a phospholipid-dependent coagulation test but also lack of correction when mixed with normal plasma and correction with the addition of activated platelet membranes or certain phospholipids (e.g., hexagonal phase).

**Other Coagulation Tests** The thrombin time and the reptilase time measure fibrinogen conversion to fibrin and are prolonged when the fibrinogen level is low (usually <80–100 mg/dL) or qualitatively abnormal, as seen in inherited or acquired dysfibrinogenemias, or when fibrin/fibrinogen degradation products interfere. The thrombin time, but not the reptilase time, is prolonged in the presence of heparin. The thrombin time is markedly prolonged in the presence of the direct thrombin inhibitor, dabigatran; a dilute thrombin time can be used to assess drug activity. Measurement of anti-factor Xa plasma inhibitory activity is a test frequently used to assess low-molecular-weight heparin (LMWH) levels, as a direct measurement of unfractionated heparin (UFH) activity, or to assess activity of the direct Xa inhibitors rivaroxaban, apixaban, and edoxaban. Drug in the patient sample inhibits the enzymatic conversion of an Xa-specific chromogenic substrate to colored product by factor Xa. Standard curves are created using multiple concentrations of the specific drug and are used to calculate the concentration of anti-Xa activity in the patient plasma.

**Laboratory Testing for Thrombophilia** Laboratory assays to detect thrombophilic states include molecular diagnostics and immunologic and functional assays. These assays vary in their sensitivity and specificity for the condition being tested. Furthermore, acute thrombosis, acute illnesses, inflammatory conditions, pregnancy, and medications affect levels of many coagulation factors and their inhibitors. Antithrombin is decreased by heparin and in the setting of acute thrombosis. Protein C and S levels may be increased in the setting of acute thrombosis and are decreased by warfarin. Antiphospholipid antibodies are frequently transiently positive in acute illness. Testing for genetic thrombophilias should, in general, only be performed when there is a strong family history of thrombosis and results would affect clinical decision-making.

Because thrombophilia evaluations are usually performed to assess the need to extend anticoagulation, testing, if indicated, should be performed in a steady state, remote from the acute event. Functional assays, but not genetic assays, will be affected by anticoagulants including warfarin (for vitamin K-dependent proteins) and thrombin and Xa inhibitors and cannot be interpreted in patients on those drugs. In most instances, when discontinuation of anticoagulation is being considered, drugs can be stopped after the initial 3–6 months of treatment, and testing can be performed at least 3 weeks later.

**Measures of Platelet Function** The bleeding time was used in the past to assess bleeding risk; however, it has not been found to predict bleeding risk with surgery, and it is not recommended for use for this indication. The PFA-100 and similar instruments that measure platelet-dependent coagulation under flow conditions are generally more sensitive and specific for platelet disorders and VWD than the bleeding time; however, data are insufficient to support their use to predict bleeding risk or monitor response to therapy, and they will be normal in some patients with platelet disorders or mild VWD. When they are used in the evaluation of a patient with bleeding symptoms, abnormal results require specific testing, such as VWF assays and/or platelet aggregation studies. Because all of these “screening” assays may miss patients with mild bleeding disorders, further studies are needed to define their role in hemostasis testing.

For classic platelet aggregometry, various agonists are added to the patient’s platelet-rich plasma or whole blood, and platelet aggregation is measured. Tests of platelet secretion in response to agonists can also be measured. These remain the gold standard for diagnosis of platelet function disorders. However, they are affected by many factors, including numerous medications, and the association between minor defects in these assays and bleeding risk is not clearly established.

## FURTHER READING

- C JC, H KA: Fibrinolysis and the control of blood coagulation. *Blood Rev* 29:17, 2015.
- C JM: Thrombophilia testing and venous thrombosis. *N Engl J Med* 377:12, 2017.
- C JM: Testing and monitoring direct oral anticoagulants. *Blood* 132:2009, 2018.
- D AJ et al: Prognostic factors for VTE and bleeding in hospitalized medical patients: A systematic review and meta-analysis. *Blood* 135:1788, 2020.
- D KMJ et al: Guidance from the Scientific and Standardization Committee for lupus anticoagulant/antiphospholipid antibodies of the International Society on Thrombosis and Haemostasis Update of the guidelines for lupus anticoagulant detection and interpretation. *J Thromb Haemost* 18:2828, 2020.
- E C, S M: An illustrated review of bleeding assessment tools and common coagulation tests. *Res Pract Thromb Haemost* 4:761, 2020.
- J PD et al: ASH ISTH NHF WFH 2021 guidelines on the diagnosis of von Willebrand disease. *Blood Adv* 5:280, 2021.

- K RM et al: Platelet transfusion: A clinical practice guideline from the AABB. *Ann Intern Med* 162:205, 2020.
- M I et al: Guidelines on the laboratory aspect of assays used in haemostasis and thrombosis. *Int J Lab Hem* 35:1, 2013.
- M J, B KA: Managing thromboembolic risk in patients with hereditary and acquired thrombophilias. *Blood* 135:344, 2020.
- W BL et al: The laboratory approach to inherited and acquired coagulation factor deficiencies. *Clin Lab Med* 29:229, 2009.
- Y JW et al: Endothelial cell control of thrombosis. *BMC Cardiovasc Disord* 15:130, 2015.

66

## Enlargement of Lymph Nodes and Spleen

Dan L. Longo



This chapter is intended to serve as a guide to the evaluation of patients who present with enlargement of the lymph nodes (*lymphadenopathy*) or the spleen (*splenomegaly*). Lymphadenopathy is a rather common clinical finding in primary care settings, whereas palpable splenomegaly is less so.

### LYMPHADENOPATHY

Lymphadenopathy may be an incidental finding in patients being examined for various reasons, or it may be a presenting sign or symptom of the patient’s illness. The physician must eventually decide whether the lymphadenopathy is a normal finding or one that requires further study, up to and including biopsy. Soft, flat, submandibular nodes (<1 cm) are often palpable in healthy children and young adults; healthy adults may have palpable inguinal nodes of up to 2 cm, which are considered normal. Further evaluation of these normal nodes is not warranted. In contrast, if the physician believes the node(s) to be abnormal, then pursuit of a more precise diagnosis is needed.

### APPROACH TO THE PATIENT

#### Lymphadenopathy

Lymphadenopathy may be a primary or secondary manifestation of numerous disorders, as shown in Table 66-1. Many of these disorders are infrequent causes of lymphadenopathy. In primary care practice, more than two-thirds of patients with lymphadenopathy have nonspecific causes or upper respiratory illnesses (viral or bacterial) and <1% have a malignancy. In one study, 84% of patients referred for evaluation of lymphadenopathy had a “benign” diagnosis. The remaining 16% had a malignancy (lymphoma or metastatic adenocarcinoma). Of the patients with benign lymphadenopathy, 63% had a nonspecific or reactive etiology (no causative agent found), and the remainder had a specific cause demonstrated, most commonly infectious mononucleosis, toxoplasmosis, or tuberculosis. Thus, the vast majority of patients with lymphadenopathy will have a nonspecific etiology requiring few diagnostic tests.

#### CLINICAL ASSESSMENT

The physician will be aided in the pursuit of an explanation for the lymphadenopathy by a careful medical history, physical examination, selected laboratory tests, and perhaps an excisional lymph node biopsy.

The *medical history* should reveal the setting in which lymphadenopathy is occurring. Symptoms such as sore throat, cough, fever, night sweats, fatigue, weight loss, or pain in the nodes should be

TABLE 66-1 Diseases Associated with Lymphadenopathy

1. Infectious diseases
  - a. Viral—*infectious mononucleosis syndromes (EBV, CMV)*, *infectious hepatitis*, *herpes simplex*, *herpesvirus-6*, *varicella-zoster virus*, *rubella*, *measles*, *adenovirus*, *HIV*, *epidemic keratoconjunctivitis*, *vaccinia*, *herpesvirus-8*
  - b. Bacterial—*streptococci*, *staphylococci*, *cat-scratch disease*, *brucellosis*, *tularemia*, *plague*, *chancroid*, *melioidosis*, *glanders*, *tuberculosis*, *atypical mycobacterial infection*, *primary and secondary syphilis*, *diphtheria*, *leprosy*, *bartonella*
  - c. Fungal—*histoplasmosis*, *coccidioidomycosis*, *paracoccidioidomycosis*
  - d. Chlamydial—*lymphogranuloma venereum*, *trachoma*
  - e. Parasitic—*toxoplasmosis*, *leishmaniasis*, *trypanosomiasis*, *filariasis*
  - f. Rickettsial—*scrub typhus*, *rickettsialpox*, *Q fever*
2. Immunologic diseases
  - a. *Rheumatoid arthritis*
  - b. *Juvenile rheumatoid arthritis*
  - c. *Mixed connective tissue disease*
  - d. *Systemic lupus erythematosus*
  - e. *Dermatomyositis*
  - f. *Sjögren's syndrome*
  - g. *Serum sickness*
  - h. *Drug hypersensitivity*—*diphenylhydantoin*, *hydralazine*, *allopurinol*, *primidone*, *gold*, *carbamazepine*, etc.
  - i. *Angioimmunoblastic lymphadenopathy*
  - j. *Primary biliary cirrhosis*
  - k. *Graft-vs-host disease*
  - l. *Silicone-associated*
  - m. *Autoimmune lymphoproliferative syndrome*
  - n. *IgG4-related disease*
  - o. *Immune reconstitution inflammatory syndrome (IRIS)*
3. Malignant diseases
  - a. *Hematologic*—*Hodgkin's disease*, *non-Hodgkin's lymphomas*, *acute or chronic lymphocytic leukemia*, *hairy cell leukemia*, *malignant histiocytosis*, *amyloidosis*
  - b. *Metastatic*—from numerous primary sites
4. Lipid storage diseases—*Gaucher's*, *Niemann-Pick*, *Fabry*, *Tangier*
5. Endocrine diseases—*hyperthyroidism*
6. Other disorders
  - a. *Castleman's disease* (*giant lymph node hyperplasia*)
  - b. *Sarcoidosis*
  - c. *Dermatopathic lymphadenitis*
  - d. *Lymphomatoid granulomatosis*
  - e. *Histiocytic necrotizing lymphadenitis (Kikuchi's disease)*
  - f. *Sinus histiocytosis with massive lymphadenopathy (Rosai-Dorfman disease)*
  - g. *Mucocutaneous lymph node syndrome (Kawasaki's disease)*
  - h. *Histiocytosis X*
    - i. *Familial Mediterranean fever*
    - j. *Severe hypertriglyceridemia*
    - k. *Vascular transformation of sinuses*
    - l. *Inflammatory pseudotumor of lymph node*
    - m. *Congestive heart failure*

*Abbreviations:* CMV, cytomegalovirus; EBV, Epstein-Barr virus.

sought. The patient's age, sex, occupation, exposure to pets, sexual behavior, and use of drugs such as diphenylhydantoin are other important historic points. For example, children and young adults usually have benign (i.e., nonmalignant) disorders that account for the observed lymphadenopathy such as viral or bacterial upper respiratory infections; infectious mononucleosis; toxoplasmosis; and, in some countries, tuberculosis. In contrast, after age 50, the incidence of malignant disorders increases and that of benign disorders decreases.

The *physical examination* can provide useful clues such as the extent of lymphadenopathy (localized or generalized), size of nodes, texture, presence or absence of nodal tenderness, signs of inflammation over the node, skin lesions, and splenomegaly. A thorough ear, nose, and throat (ENT) examination is indicated in adult patients with cervical adenopathy and a history of tobacco use. Localized or regional adenopathy implies involvement of a single anatomic area. Generalized adenopathy has been defined as involvement of three or more noncontiguous lymph node areas. Many of the causes of lymphadenopathy (Table 66-1) can produce localized or generalized adenopathy, so this distinction is of limited utility in the differential diagnosis. Nevertheless, generalized lymphadenopathy is frequently associated with nonmalignant disorders such as infectious mononucleosis (Epstein-Barr virus [EBV] or cytomegalovirus [CMV]), toxoplasmosis, AIDS, other viral infections, systemic lupus erythematosus (SLE), and mixed connective tissue disease. Acute and chronic lymphocytic leukemias and malignant lymphomas also produce generalized adenopathy in adults.

The site of localized or regional adenopathy may provide a useful clue about the cause. Occipital adenopathy often reflects an infection of the scalp, and preauricular adenopathy accompanies conjunctival infections and cat-scratch disease. The most frequent site of regional adenopathy is the neck, and most of the causes are benign—upper respiratory infections, oral and dental lesions, infectious mononucleosis, or other viral illnesses. The chief malignant causes include metastatic cancer from head and neck, breast, lung, and thyroid primaries. Enlargement of supraclavicular and scalene nodes is always abnormal. Because these nodes drain regions of the lung and retroperitoneal space, they can reflect lymphomas, other cancers, or infectious processes arising in these areas. Virchow's node is an enlarged left supraclavicular node infiltrated with metastatic cancer from a gastrointestinal primary. Metastases to supraclavicular nodes also occur from lung, breast, testis, or ovarian cancers. Tuberculosis, sarcoidosis, and toxoplasmosis are nonneoplastic causes of supraclavicular adenopathy. Axillary adenopathy is usually due to injuries or localized infections of the ipsilateral upper extremity. Malignant causes include melanoma or lymphoma and, in women, breast cancer. Inguinal lymphadenopathy is usually secondary to infections or trauma of the lower extremities and may accompany sexually transmitted diseases such as lymphogranuloma venereum, primary syphilis, genital herpes, or chancroid. These nodes may also be involved by lymphomas and metastatic cancer from primary lesions of the rectum, genitalia, or lower extremities (melanoma).

The size and texture of the lymph node(s) and the presence of pain are useful parameters in evaluating a patient with lymphadenopathy. Nodes  $<1.0 \text{ cm}^2$  in area ( $1.0 \text{ cm} \times 1.0 \text{ cm}$  or less) are almost always secondary to benign, nonspecific reactive causes. In one retrospective analysis of younger patients (9–25 years) who had a lymph node biopsy, a maximum diameter of  $>2 \text{ cm}$  served as one discriminant for predicting that the biopsy would reveal malignant or granulomatous disease. Another study showed that a lymph node size of  $2.25 \text{ cm}^2$  ( $1.5 \text{ cm} \times 1.5 \text{ cm}$ ) was the best size limit for distinguishing malignant or granulomatous lymphadenopathy from other causes of lymphadenopathy. Patients with node(s)  $\leq 1.0 \text{ cm}^2$  should be observed after excluding infectious mononucleosis and/or toxoplasmosis unless there are symptoms and signs of an underlying systemic illness.

The texture of lymph nodes may be described as soft, firm, rubbery, hard, discrete, matted, tender, movable, or fixed. Tenderness is found when the capsule is stretched during rapid enlargement, usually secondary to an inflammatory process. Some malignant diseases such as acute leukemia may produce rapid enlargement and pain in the nodes. Nodes involved by lymphoma tend to be large, discrete, symmetric, rubbery, firm, mobile, and nontender. Nodes containing metastatic cancer are often hard, nontender, and nonmovable because of fixation to surrounding tissues. The coexistence of splenomegaly in the patient with lymphadenopathy implies a systemic illness such

as infectious mononucleosis, lymphoma, acute or chronic leukemia, SLE, sarcoidosis, toxoplasmosis, cat-scratch disease, or other less common hematologic disorders. The patient's story should provide helpful clues about the underlying systemic illness.

Nonsuperficial presentations (thoracic or abdominal) of adenopathy are usually detected as the result of a symptom-directed diagnostic workup. Thoracic adenopathy may be detected by routine chest radiography or during the workup for superficial adenopathy. It may also be found because the patient complains of a cough or wheezing from airway compression; hoarseness from recurrent laryngeal nerve involvement; dysphagia from esophageal compression; or swelling of the neck, face, or arms secondary to compression of the superior vena cava or subclavian vein. The differential diagnosis of mediastinal and hilar adenopathy includes primary lung disorders and systemic illnesses that characteristically involve mediastinal or hilar nodes. In the young, mediastinal adenopathy is associated with infectious mononucleosis and sarcoidosis. In endemic regions, histoplasmosis can cause unilateral paratracheal lymph node involvement that mimics lymphoma. Tuberculosis can also cause unilateral adenopathy. In older patients, the differential diagnosis includes primary lung cancer (especially among smokers), lymphomas, metastatic carcinoma (usually lung), tuberculosis, fungal infection, and sarcoidosis.

Enlarged intraabdominal or retroperitoneal nodes are usually malignant. Although tuberculosis may present as mesenteric lymphadenitis, these masses usually contain lymphomas or, in young men, germ cell tumors.

#### LABORATORY INVESTIGATION

The laboratory investigation of patients with lymphadenopathy must be tailored to elucidate the etiology suspected from the patient's history and physical findings. One study from a family practice clinic evaluated 249 younger patients with "enlarged lymph nodes, not infected" or "lymphadenitis." No laboratory studies were obtained in 51%. When studies were performed, the most common were a complete blood count (CBC) (33%), throat culture (16%), chest x-ray (12%), or monospot test (10%). Only eight patients (3%) had a node biopsy, and half of those were normal or reactive. The CBC can provide useful data for the diagnosis of acute or chronic leukemias, EBV or CMV mononucleosis, lymphoma with a leukemic component, pyogenic infections, or immune cytopenias in illnesses such as SLE. Serologic studies may demonstrate antibodies specific to components of EBV, CMV, HIV, and other viruses; *Toxoplasma gondii*; *Brucella*; etc. If SLE is suspected, antinuclear and anti-DNA antibody studies are warranted.

The chest x-ray is usually negative, but the presence of a pulmonary infiltrate or mediastinal lymphadenopathy would suggest tuberculosis, histoplasmosis, sarcoidosis, lymphoma, primary lung cancer, or metastatic cancer and demands further investigation.

A variety of imaging techniques (CT, MRI, ultrasound, color Doppler ultrasonography) have been employed to differentiate benign from malignant lymph nodes, especially in patients with head and neck cancer. CT and MRI are comparably accurate (65–90%) in the diagnosis of metastases to cervical lymph nodes. Ultrasonography has been used to determine the long (L) axis, short (S) axis, and a ratio of long to short axis in cervical nodes. An L/S ratio of <2.0 has a sensitivity and a specificity of 95% for distinguishing benign and malignant nodes in patients with head and neck cancer. This ratio has greater specificity and sensitivity than palpation or measurement of either the long or the short axis alone.

The indications for lymph node biopsy are imprecise, yet it is a valuable diagnostic tool. The decision to biopsy may be made early in a patient's evaluation or delayed for up to 2 weeks. Prompt biopsy should occur if the patient's history and physical findings suggest a malignancy; examples include a solitary, hard, nontender cervical node in an older patient who is a chronic user of tobacco; supraclavicular adenopathy; and solitary or generalized adenopathy that is firm, movable, and suggestive of lymphoma. If a primary head

and neck cancer is suspected as the basis of a solitary, hard cervical node, then a careful ENT examination should be performed. Any mucosal lesion that is suspicious for a primary neoplastic process should be biopsied first. If no mucosal lesion is detected, an excisional biopsy of the largest node should be performed. Fine-needle aspiration should not be performed as the first diagnostic procedure. Most diagnoses require more tissue than such aspiration can provide, and it often delays a definitive diagnosis. Fine-needle aspiration should be reserved for thyroid nodules and for confirmation of relapse in patients whose primary diagnosis is known. If the primary physician is uncertain about whether to proceed to biopsy, consultation with a hematologist or medical oncologist should be helpful. In primary care practices, <5% of lymphadenopathy patients will require a biopsy. That percentage will be considerably larger in referral practices, i.e., hematology, oncology, or ENT.

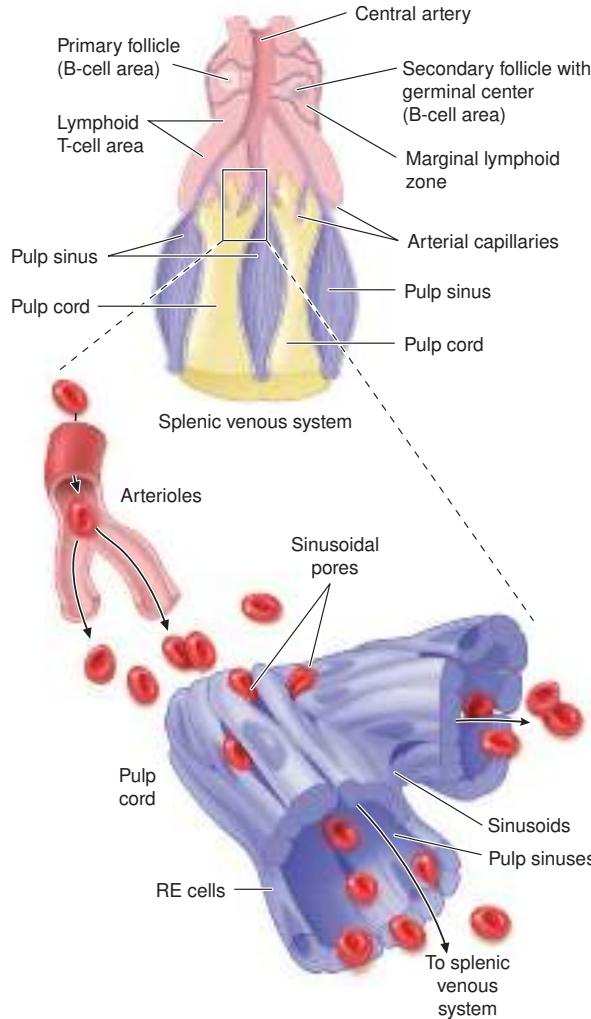
Two groups have reported algorithms that they claim will identify more precisely those lymphadenopathy patients who should have a biopsy. Both reports were retrospective analyses in referral practices. The first study involved patients 9–25 years of age who had a node biopsy performed. Three variables were identified that predicted those young patients with peripheral lymphadenopathy who should undergo biopsy; lymph node size >2 cm in diameter and abnormal chest x-ray had positive predictive values, whereas recent ENT symptoms had negative predictive values. The second study evaluated 220 lymphadenopathy patients in a hematology unit and identified five variables (lymph node size, location [supraclavicular or nonsupraclavicular], age [>40 years or <40 years], texture [nonhard or hard], and tenderness) that were used in a mathematical model to identify those patients requiring a biopsy. Positive predictive value was found for age >40 years, supraclavicular location, node size >2.25 cm<sup>2</sup>, hard texture, and lack of pain or tenderness. Negative predictive value was evident for age <40 years, node size <1.0 cm<sup>2</sup>, nonhard texture, and tender or painful nodes. Ninety-one percent of those who required biopsy were correctly classified by this model. Because both of these studies were retrospective analyses and one was limited to young patients, it is not known how useful these models would be if applied prospectively in a primary care setting.

Most lymphadenopathy patients do not require a biopsy, and at least half require no laboratory studies. If the patient's history and physical findings point to a benign cause for lymphadenopathy, careful follow-up at a 2- to 4-week interval can be employed. The patient should be instructed to return for reevaluation if there is an increase in the size of the nodes. Antibiotics are not indicated for lymphadenopathy unless strong evidence of a bacterial infection is present. Glucocorticoids should not be used to treat lymphadenopathy because their lympholytic effect obscures some diagnoses (lymphoma, leukemia, Castleman's disease) and they contribute to delayed healing or activation of underlying infections. An exception to this statement is the life-threatening pharyngeal obstruction by enlarged lymphoid tissue in Waldeyer's ring that is occasionally seen in infectious mononucleosis.

## SPLENOMEGLY

### ■ STRUCTURE AND FUNCTION OF THE SPLEEN

The spleen is a reticuloendothelial organ that has its embryologic origin in the dorsal mesogastrium at about 5 weeks' gestation. It arises in a series of hillocks, migrates to its normal adult location in the left upper quadrant (LUQ), and is attached to the stomach via the gastrosplenic ligament and to the kidney via the lienorenal ligament. When the hillocks fail to unify into a single tissue mass, accessory spleens may develop in around 20% of persons. The function of the spleen has been elusive. Galen believed it was the source of "black bile" or melancholia, and the word *hypochondria* (literally, beneath the ribs) and the idiom "to vent one's spleen" attest to the beliefs that the spleen had an important influence on the psyche and emotions. In humans, its normal physiologic roles seem to be the following:



**FIGURE 66-1** Schematic spleen structure. The spleen comprises many units of red and white pulp centered around small branches of the splenic artery, called *central arteries*. White pulp is lymphoid in nature and contains B-cell follicles, a marginal zone around the follicles, and T-cell-rich areas sheathing arterioles. The red pulp areas include pulp sinuses and pulp cords. The cords are dead ends. In order to regain access to the circulation, red blood cells must traverse tiny openings in the sinusoidal lining. Stiff, damaged, or old red cells cannot enter the sinuses. RE, reticuloendothelial. (Bottom portion of figure reproduced with permission from RS Hillman, KA Ault: *Hematology in Clinical Practice*, 4th ed. New York, McGraw-Hill, 2005.)

- Maintenance of quality control over erythrocytes in the red pulp by removal of senescent and defective red blood cells. The spleen accomplishes this function through a unique organization of its parenchyma and vasculature (Fig. 66-1).
- Synthesis of antibodies in the white pulp.
- The removal of antibody-coated bacteria and antibody-coated blood cells from the circulation.

An increase in these normal functions may result in splenomegaly. The spleen is composed of *red pulp* and *white pulp*, which are Malpighi's terms for the red blood-filled sinuses and reticuloendothelial cell-lined cords and the white lymphoid follicles arrayed within the red pulp matrix. The spleen is in the portal circulation. The reason for this is unknown but may relate to the fact that lower blood pressure allows less rapid flow and minimizes damage to normal erythrocytes. Blood flows into the spleen at a rate of about 150 mL/min through the splenic artery, which ultimately ramifies into central arterioles. Some blood goes from the arterioles to capillaries and then to splenic veins

and out of the spleen, but the majority of blood from central arterioles flows into the macrophage-lined sinuses and cords. The blood entering the sinuses reenters the circulation through the splenic venules, but the blood entering the cords is subjected to an inspection of sorts. To return to the circulation, the blood cells in the cords must squeeze through slits in the cord lining to enter the sinuses that lead to the venules. Old and damaged erythrocytes are less deformable and are retained in the cords, where they are destroyed and their components recycled. Red cell-inclusion bodies such as parasites (Chaps. 224, 225, and A2), nuclear residua (Howell-Jolly bodies, see Fig. 63-6), or denatured hemoglobin (Heinz bodies) are pinched off in the process of passing through the slits, a process called *pitting*. The culling of dead and damaged cells and the pitting of cells with inclusions appear to occur without significant delay because the blood transit time through the spleen is only slightly slower than in other organs.

The spleen is also capable of assisting the host in adapting to its hostile environment. It has at least three adaptive functions: (1) clearance of bacteria and particulates from the blood, (2) the generation of immune responses to certain pathogens, and (3) the generation of cellular components of the blood under circumstances in which the marrow is unable to meet the needs (i.e., extramedullary hematopoiesis). The latter adaptation is a recapitulation of the blood-forming function the spleen plays during gestation. In some animals, the spleen also serves a role in the vascular adaptation to stress because it stores red blood cells (often hemoconcentrated to higher hematocrits than normal) under normal circumstances and contracts under the influence of  $\beta$ -adrenergic stimulation to provide the animal with an autotransfusion and improved oxygen-carrying capacity. However, the normal human spleen does not sequester or store red blood cells and does not contract in response to sympathetic stimuli. The normal human spleen contains approximately one-third of the total body platelets and a significant number of marginated neutrophils. These sequestered cells are available when needed to respond to bleeding or infection.

## APPROACH TO THE PATIENT

### Splenomegaly

#### CLINICAL ASSESSMENT

The most common *symptoms* produced by diseases involving the spleen are pain and a heavy sensation in the LUQ. Massive splenomegaly may cause early satiety. Pain may result from acute swelling of the spleen with stretching of the capsule, infarction, or inflammation of the capsule. For many years, it was believed that splenic infarction was clinically silent, which, at times, is true. However, Soma Weiss, in his classic 1942 report of the self-observations by a Harvard medical student on the clinical course of subacute bacterial endocarditis, documented that severe LUQ and pleuritic chest pain may accompany thromboembolic occlusion of splenic blood flow. Vascular occlusion, with infarction and pain, is commonly seen in children with sickle cell crises. Rupture of the spleen, from either trauma or infiltrative disease that breaks the capsule, may result in intraperitoneal bleeding, shock, and death. The rupture itself may be painless.

A palpable spleen is the major *physical sign* produced by diseases affecting the spleen and suggests enlargement of the organ. The normal spleen weighs <250 g, decreases in size with age, normally lies entirely within the rib cage, has a maximum cephalocaudal diameter of 13 cm by ultrasonography or maximum length of 12 cm and/or width of 7 cm by radionuclide scan, and is usually not palpable. However, a palpable spleen was found in 3% of 2200 asymptomatic, male, freshman college students. Follow-up at 3 years revealed that 30% of those students still had a palpable spleen without any increase in disease prevalence. Ten-year follow-up found no evidence for lymphoid malignancies. Furthermore, in some tropical countries (e.g., New Guinea), the incidence of splenomegaly may reach 60%. Thus, the presence of a palpable spleen does not always equate with presence of disease. Even when disease is present,

splenomegaly may not reflect the primary disease but rather a reaction to it. For example, in patients with Hodgkin's disease, only two-thirds of the palpable spleens show involvement by the cancer.

Physical examination of the spleen uses primarily the techniques of palpation and percussion. Inspection may reveal fullness in the LUQ that descends on inspiration, a finding associated with a massively enlarged spleen. Auscultation may reveal a venous hum or friction rub.

*Palpation* can be accomplished by bimanual palpation, ballottement, and palpation from above (Middleton maneuver). For bimanual palpation, which is at least as reliable as the other techniques, the patient is supine with flexed knees. The examiner's left hand is placed on the lower rib cage and pulls the skin toward the costal margin, allowing the fingertips of the right hand to feel the tip of the spleen as it descends while the patient inspires slowly, smoothly, and deeply. Palpation is begun with the right hand in the left lower quadrant with gradual movement toward the left costal margin, thereby identifying the lower edge of a massively enlarged spleen. When the spleen tip is felt, the finding is recorded as centimeters below the left costal margin at some arbitrary point, i.e., 10–15 cm, from the midpoint of the umbilicus or the xiphisternal junction. This allows other examiners to compare findings or the initial examiner to determine changes in size over time. Bimanual palpation in the right lateral decubitus position adds nothing to the supine examination.

*Percussion* for splenic dullness is accomplished with any of three techniques described by Nixon, Castell, or Barkun:

1. *Nixon's method*: The patient is placed on the right side so that the spleen lies above the colon and stomach. Percussion begins at the lower level of pulmonary resonance in the posterior axillary line and proceeds diagonally along a perpendicular line toward the lower midanterior costal margin. The upper border of dullness is normally 6–8 cm above the costal margin. Dullness >8 cm in an adult is presumed to indicate splenic enlargement.
2. *Castell's method*: With the patient supine, percussion in the lowest intercostal space in the anterior axillary line (8th or 9th) produces a resonant note if the spleen is normal in size. This is true during expiration or full inspiration. A dull percussion note on full inspiration suggests splenomegaly.
3. *Percussion of Traube's semilunar space*: The borders of Traube's space are the sixth rib superiorly, the left midaxillary line laterally, and the left costal margin inferiorly. The patient is supine with the left arm slightly abducted. During normal breathing, this space is percussed from medial to lateral margins, yielding a normal resonant sound. A dull percussion note suggests splenomegaly.

Studies comparing methods of percussion and palpation with a standard of ultrasonography or scintigraphy have revealed sensitivity of 56–71% for palpation and 59–82% for percussion. Reproducibility among examiners is better for palpation than percussion. Both techniques are less reliable in obese patients or patients who have just eaten. Thus, the physical examination techniques of palpation and percussion are imprecise at best. It has been suggested that the examiner perform percussion first and, if positive, proceed to palpation; if the spleen is palpable, then one can be reasonably confident that splenomegaly exists. However, not all LUQ masses are enlarged spleens; gastric or colon tumors and pancreatic or renal cysts or tumors can mimic splenomegaly.

The presence of an enlarged spleen can be more precisely determined, if necessary, by liver-spleen radionuclide scan, CT, MRI, or ultrasonography. The latter technique is the current procedure of choice for routine assessment of spleen size (normal = a maximum cephalocaudad diameter of 13 cm) because it has high sensitivity and specificity and is safe, noninvasive, quick, mobile, and less costly. Equipment advances allow ultrasonography to be performed at the bedside with excellent sensitivity and specificity. Nuclear medicine scans are accurate, sensitive, and reliable but are costly,

require greater time to generate data, and use immobile equipment. They have the advantage of demonstrating accessory splenic tissue. CT and MRI provide accurate determination of spleen size, but the equipment is immobile and the procedures are expensive. MRI appears to offer no advantage over CT. Changes in spleen structure such as mass lesions, infarcts, inhomogeneous infiltrates, and cysts are more readily assessed by CT, MRI, or ultrasonography. None of these techniques is very reliable in the detection of patchy infiltration (e.g., Hodgkin's disease).

#### DIFFERENTIAL DIAGNOSIS

Many of the diseases associated with splenomegaly are listed in Table 66-2. They are grouped according to the presumed basic mechanisms responsible for organ enlargement:

1. Hyperplasia or hypertrophy related to a particular splenic function such as reticuloendothelial hyperplasia (work hypertrophy) in diseases such as hereditary spherocytosis or thalassemia syndromes that require removal of large numbers of defective red blood cells; immune hyperplasia in response to systemic infection (infectious mononucleosis, subacute bacterial endocarditis) or to immunologic diseases (immune thrombocytopenia, SLE, Felty's syndrome).
2. Passive congestion due to decreased blood flow from the spleen in conditions that produce portal hypertension (cirrhosis, Budd-Chiari syndrome, congestive heart failure).
3. Infiltrative diseases of the spleen (lymphomas, metastatic cancer, amyloidosis, Gaucher's disease, myeloproliferative disorders with extramedullary hematopoiesis).

The differential diagnostic possibilities are much fewer when the spleen is "massively enlarged" or palpable >8 cm below the left costal margin or its drained weight is  $\geq 1000$  g (Table 66-3). The vast majority of such patients will have non-Hodgkin's lymphoma, chronic lymphocytic leukemia, hairy cell leukemia, chronic myeloid leukemia, myelofibrosis with myeloid metaplasia, or polycythemia vera.

#### LABORATORY ASSESSMENT

The major laboratory abnormalities accompanying splenomegaly are determined by the underlying systemic illness. Erythrocyte counts may be normal, decreased (thalassemia major syndromes, SLE, cirrhosis with portal hypertension), or increased (polycythemia vera). Granulocyte counts may be normal, decreased (Felty's syndrome, congestive splenomegaly, leukemias), or increased (infections or inflammatory disease, myeloproliferative disorders). Similarly, the platelet count may be normal, decreased when there is enhanced sequestration or destruction of platelets in an enlarged spleen (congestive splenomegaly, Gaucher's disease, immune thrombocytopenia), or increased in the myeloproliferative disorders such as polycythemia vera.

The CBC may reveal cytopenia of one or more blood cell types, which should suggest *hypersplenism*. This condition is characterized by splenomegaly, cytopenia(s), normal or hyperplastic bone marrow, and a response to splenectomy. The latter characteristic is less precise because reversal of cytopenia, particularly granulocytopenia, is sometimes not sustained after splenectomy. The cytopenias result from increased destruction of the cellular elements secondary to reduced flow of blood through enlarged and congested cords (congestive splenomegaly) or to immune-mediated mechanisms. In hypersplenism, various cell types usually have normal morphology on the peripheral blood smear, although the red cells may be spherocytic due to loss of surface area during their longer transit through the enlarged spleen. The increased marrow production of red cells should be reflected as an increased reticulocyte production index, although the value may be less than expected due to increased sequestration of reticulocytes in the spleen.

The need for additional laboratory studies is dictated by the differential diagnosis of the underlying illness of which splenomegaly is a manifestation.

TABLE 66-2 Diseases Associated with Splenomegaly Grouped by Pathogenic Mechanism

## Enlargement Due to Increased Demand for Splenic Function

Reticuloendothelial system hyperplasia (for removal of defective erythrocytes)	
Spherocytosis	Leishmaniasis
Early sickle cell anemia	Trypanosomiasis
Ovalocytosis	Ehrlichiosis
Thalassemia major	Disordered immunoregulation
Hemoglobinopathies	Hemophagocytic lymphohistiocytosis (HLH)
Paroxysmal nocturnal hemoglobinuria	Rheumatoid arthritis (Felty's syndrome)
Pernicious anemia	Systemic lupus erythematosus
Immune hyperplasia	Collagen vascular diseases
Response to infection (viral, bacterial, fungal, parasitic)	Serum sickness
Infectious mononucleosis	Immune hemolytic anemias
AIDS	Immune thrombocytopenias
Viral hepatitis	Immune neutropenias
Cytomegalovirus	Drug reactions
Subacute bacterial endocarditis	Angioimmunoblastic lymphadenopathy
Bacterial septicemia	Sarcoidosis
Congenital syphilis	Thyrotoxicosis (benign lymphoid hypertrophy)
Splenic abscess	Interleukin 2 therapy
Tuberculosis	Extramedullary hematopoiesis
Histoplasmosis	Myelofibrosis
Malaria	Marrow damage by toxins, radiation, strontium
	Marrow infiltration by tumors, leukemias, Gaucher's disease

## Enlargement Due to Abnormal Splenic or Portal Blood Flow

Gerrhosis	Splenic artery aneurysm
Hepatic vein obstruction	Hepatic schistosomiasis
Portal vein obstruction, intrahepatic or extrahepatic	Congestive heart failure
Cavernous transformation of the portal vein	Hepatic echinococcosis
Splenic vein obstruction	Portal hypertension (any cause including the above): "Banti's disease"

## Infiltration of the Spleen

Intracellular or extracellular depositions	Hodgkin's disease
Amyloidosis	Myeloproliferative syndromes (e.g., polycythemia vera, essential thrombocythosis)
Gaucher's disease	Angiosarcomas
Niemann-Pick disease	Metastatic tumors (melanoma is most common)
Tangier disease	Eosinophilic granuloma
Hurler's syndrome and other mucopolysaccharidoses	Histiocytosis X
Hyperlipidemias	Hamartomas
Benign and malignant cellular infiltrations	Hemangiomas, fibromas, lymphangiomas
Leukemias (acute, chronic, lymphoid, myeloid, monocytic)	Splenic cysts
Lymphomas	

## Unknown Etiology

Idiopathic splenomegaly	Iron-deficiency anemia
Berylliosis	

## SPLENECTOMY

Splenectomy is infrequently performed for diagnostic purposes, especially in the absence of clinical illness or other diagnostic tests that suggest underlying disease. More often, splenectomy is performed for symptom control in patients with massive splenomegaly, for disease

control in patients with traumatic splenic rupture, or for correction of cytopenias in patients with hypersplenism or immune-mediated destruction of one or more cellular blood elements. Splenectomy is necessary for staging of patients with Hodgkin's disease only in those with clinical stage I or II disease in whom radiation therapy alone is contemplated as the treatment. Noninvasive staging of the spleen in Hodgkin's disease is not a sufficiently reliable basis for treatment decisions because one-third of normal-sized spleens will be involved with Hodgkin's disease and one-third of enlarged spleens will be tumor-free. The widespread use of systemic therapy to treat all stages of Hodgkin's disease has made staging laparotomy with splenectomy unnecessary. Although splenectomy in chronic myeloid leukemia (CML) does not affect the natural history of disease, removal of the massive spleen usually makes patients significantly more comfortable and simplifies their management by significantly reducing transfusion requirements.

TABLE 66-3 Diseases Associated with Massive Splenomegaly<sup>a</sup>

Chronic myeloid leukemia	Gaucher's disease
Lymphomas	Chronic lymphocytic leukemia
Hairy cell leukemia	Sarcoidosis
Myelofibrosis with myeloid metaplasia	Autoimmune hemolytic anemia
Polycythemia vera	Diffuse splenic hemangiomatosis

<sup>a</sup>The spleen extends >8 cm below left costal margin and/or weighs >1000 g.

The improvements in therapy of CML have reduced the need for splenectomy for symptom control. Splenectomy is an effective secondary or tertiary treatment for two chronic B-cell leukemias, hairy cell leukemia and prolymphocytic leukemia, and for the very rare splenic mantle cell or marginal zone lymphoma. Splenectomy in these diseases may be associated with significant tumor regression in bone marrow and other sites of disease. Similar regressions of systemic disease have been noted after splenic irradiation in some types of lymphoid tumors, especially chronic lymphocytic leukemia and prolymphocytic leukemia. This has been termed the *abscopal effect*. Such systemic tumor responses to local therapy directed at the spleen suggest that some hormone or growth factor produced by the spleen may affect tumor cell proliferation, but this conjecture is not yet substantiated. A common therapeutic indication for splenectomy is traumatic or iatrogenic splenic rupture. In a fraction of patients with splenic rupture, peritoneal seeding of splenic fragments can lead to *splenosis*—the presence of multiple rests of spleen tissue not connected to the portal circulation. This ectopic spleen tissue may cause pain or gastrointestinal obstruction, as in endometriosis. A large number of hematologic, immunologic, and congestive causes of splenomegaly can lead to destruction of one or more cellular blood elements. In the majority of such cases, splenectomy can correct the cytopenias, particularly anemia and thrombocytopenia. In a large series of patients seen in two tertiary care centers, the indication for splenectomy was diagnostic in 10% of patients, therapeutic in 44%, staging for Hodgkin's disease in 20%, and incidental to another procedure in 26%. Perhaps the only contraindication to splenectomy is the presence of marrow failure, in which the enlarged spleen is the only source of hematopoietic tissue.

Often the splenectomy is done by laparoscopy, which is associated with shorter hospital stays and faster recovery than the open procedure; however, concern has emerged that the laparoscopic approach is associated with a higher risk of postoperative portal venous system thrombosis and Budd-Chiari syndrome.

The absence of the spleen has minimal long-term effects on the hematologic profile. In the immediate postsplenectomy period, leukocytosis (up to 25,000/ $\mu$ L) and thrombocytosis (up to  $1 \times 10^6/\mu$ L) may develop, but within 2–3 weeks, blood cell counts and survival of each cell lineage are usually normal. The chronic manifestations of splenectomy are marked variation in size and shape of erythrocytes (anisocytosis, poikilocytosis) and the presence of Howell-Jolly bodies (nuclear remnants), Heinz bodies (denatured hemoglobin), basophilic stippling, and an occasional nucleated erythrocyte in the peripheral blood. When such erythrocyte abnormalities appear in a patient whose spleen has not been removed, one should suspect splenic infiltration by tumor that has interfered with its normal culling and pitting function.

The most serious consequence of splenectomy is increased susceptibility to bacterial infections, particularly those with capsules such as *Streptococcus pneumoniae*, *Haemophilus influenzae*, and some gram-negative enteric organisms. Patients aged <20 years are particularly susceptible to overwhelming sepsis with *S. pneumoniae*, and the overall actuarial risk of sepsis in patients who have had their spleens removed is about 7% in 10 years. The case-fatality rate for pneumococcal sepsis in splenectomized patients is 50–80%. About 25% of patients without spleens will develop a serious infection at some time in their life. The frequency is highest within the first 3 years after splenectomy. About 15% of the infections are polymicrobial, and lung, skin, and blood are the most common sites. No increased risk of viral infection has been noted in patients who have no spleen. The susceptibility to bacterial infections relates to the inability to remove opsonized bacteria from the bloodstream and a defect in making antibodies to T-cell-independent antigens such as the polysaccharide components of bacterial capsules. Pneumococcal vaccine should be administered to all patients 2 weeks before elective splenectomy. The Advisory Committee on Immunization Practices recommends that these patients receive

repeat vaccination 5 years after splenectomy. Efficacy has not been proven for this group, and the recommendation discounts the possibility that administration of the vaccine may actually lower the titer of specific pneumococcal antibodies. A more effective pneumococcal conjugate vaccine that involves T cells in the response is now available (PCV13). The vaccine to *Neisseria meningitidis* should also be given to patients in whom elective splenectomy is planned. Although efficacy data for *Haemophilus influenzae* type b vaccine are not available for older children or adults, it may be given to patients who have had a splenectomy.

Splenectomized patients should be educated to consider any unexplained fever as a medical emergency. Prompt medical attention with evaluation and treatment of suspected bacteremia may be lifesaving. Routine chemoprophylaxis with oral penicillin can result in the emergence of drug-resistant strains and is not recommended.

In addition to an increased susceptibility to bacterial infections, splenectomized patients are also more susceptible to the parasitic disease babesiosis. The splenectomized patient should avoid areas where the parasite *Babesia* is endemic (e.g., Cape Cod, MA).

Surgical removal of the spleen is an obvious cause of hyposplenism. Patients with sickle cell disease often suffer from autosplenectomy as a result of splenic destruction by the numerous infarcts associated with sickle cell crises during childhood. Indeed, the presence of a palpable spleen in a patient with sickle cell disease after age 5 suggests a coexisting hemoglobinopathy, e.g., thalassemia or hemoglobin C. In addition, patients who receive splenic irradiation for a neoplastic or autoimmune disease are also functionally hyposplenic. The term *hyposplenism* is preferred to *asplenia* in referring to the physiologic consequences of splenectomy because asplenia is a rare, specific, and fatal congenital abnormality in which there is a failure of the left side of the coelomic cavity (which includes the splenic anlagen) to develop normally. Infants with asplenia have no spleens, but that is the least of their problems. The right side of the developing embryo is duplicated on the left so there is liver where the spleen should be, there are two right lungs, and the heart comprises two right atria and two right ventricles.

## A

*Patrick H. Henry, MD, friend and mentor now deceased, contributed significantly to the chapter in past editions, and much of his work remains in this chapter.*

## ■ FURTHER READING

- B AN et al: The bedside assessment of splenic enlargement. *Am J Med* 91:512, 1991.
- C T et al: Comparing physical examination with sonographic versions of the same examination techniques for splenomegaly. *J Ultrasound Med* 37:1621, 2018.
- F: Tumors of the spleen. *Int J Surg Pathol* 18:136S, 2010.
- G E et al: Management of splenic and pancreatic trauma. *J Visc Surg* 153(suppl 4):45, 2016.
- G SA et al: Does this patient have splenomegaly? *JAMA* 270:2218, 1993.
- K DK et al: Advisory committee on immunization practices recommended immunization schedule for adults aged 19 years or older—United States, 2017. *MMWR* 66:136, 2017.
- K MD et al: The spleen as a diagnostic specimen: A review of ten years' experience at two tertiary care institutions. *Cancer* 91:2001, 2001.
- M I OR, E FG J : Palpable spleens: Ten-year follow-up. *Ann Intern Med* 90:130, 1979.
- P GA et al: Clinical approach to lymphadenopathy. *Semin Oncol* 20:570, 1993.
- W HA J : Lymphadenopathy in a family practice: A descriptive study of 240 cases. *J Fam Pract* 20:449, 1985.



Drugs are the cornerstone of modern therapeutics. Nevertheless, it is well recognized among health care providers and the lay community that the outcome of drug therapy varies widely among individuals. While this variability has been perceived as an unpredictable, and therefore inevitable, accompaniment of drug therapy, this is not the case.

Drugs interact with specific target molecules to produce their beneficial and adverse effects. The chain of events between administration of a drug and production of these effects in the body can be divided into two components, both of which contribute to variability in drug actions. The first component comprises the processes that determine drug delivery to, and removal from, molecular targets. The resulting description of the relationship between drug concentration and time is termed *pharmacokinetics*. The second component of variability in drug action comprises the processes that determine variability in drug actions independent of variability in drug delivery to effector drug sites. This description of the relationship between drug concentration and effect is termed *pharmacodynamics*. As discussed further below, pharmacodynamic variability can arise as a result of variability in function of the target molecule itself or of variability in the broad biologic context in which the drug-target interaction occurs to achieve drug effects. The principles described below were developed by studying small drug molecules but are equally useful in describing the effects of very large molecules, such as the therapeutic antibodies increasingly applied to autoimmune diseases and cancer.

Two important goals of clinical pharmacology are (1) to provide a description of conditions under which drug actions vary among human subjects; and (2) to determine mechanisms underlying this variability, with the goal of improving therapy with available drugs as well as pointing to mechanisms whose targeting by new drugs may be effective in the treatment of human disease. The drug development process is briefly described at the end of this chapter.

The first steps in the discipline of clinical pharmacology were empirical descriptions of the influence of disease on drug actions and of individuals or families with unusual sensitivities to adverse drug reactions (ADRs). These important descriptive findings are now being replaced by an understanding of the molecular mechanisms underlying variability in drug actions. Importantly, it is often the personal interaction of the patient with the physician or other health care provider that first identifies unusual variability in drug actions; maintained alertness to unusual drug responses continues to be a key component of improving drug safety.

One useful unifying framework is to consider that the effects of disease, drug coadministration, or familial factors in modulating drug action reflect variability in expression or function of specific genes whose products determine pharmacokinetics and pharmacodynamics. This idea forms the basis for pharmacogenomic science; a few examples are cited in this chapter, and further details are addressed in Chap. 68.

## ■ GLOBAL CONSIDERATIONS

It is true across all cultures and diseases that factors such as compliance, genetic variants affecting pharmacokinetics or pharmacodynamics (which themselves vary by ancestry), and drug interactions contribute to drug responses. Cost issues or cultural factors may determine the likelihood that specific drugs, drug combinations, or over-the-counter (OTC) remedies are prescribed. The broad principles of clinical pharmacology enunciated here can be used to analyze the mechanisms underlying successful or unsuccessful therapy with any drug.

## ■ INDICATIONS FOR DRUG THERAPY: RISK VERSUS BENEFIT

It is self-evident that the benefits of drug therapy should outweigh the risks. Benefits fall into broad categories: alleviation of symptoms, prevention of disease progression or complications, and prolonged life. However, establishing the balance between risk and benefit for an individual patient is not always simple. In addition to variability seen even within highly controlled drug trials, patients treated in clinical settings may display responses that were not observed in trials, sometimes due to comorbidities that were trial exclusion criteria. In addition, therapies that provide symptomatic benefits but shorten life may be entertained in patients with serious and highly symptomatic diseases such as heart failure or cancer. These considerations illustrate the continuing, highly personal nature of the relationship between the prescriber and the patient.

**Adverse Effects** Some adverse effects are so common and so readily associated with drug therapy that they are identified very early during clinical use of a drug. By contrast, serious ADRs may be sufficiently uncommon that they escape detection for many years after a drug begins to be widely used. The issue of how to identify rare but serious ADRs (that can profoundly affect the benefit-risk perception in an individual patient) has not been satisfactorily resolved. Potential approaches range from an increased understanding of the molecular and genetic basis of variability in drug actions to expanded postmarketing surveillance mechanisms. None of these have been completely effective, so practitioners must be continuously vigilant to the possibility that unusual symptoms may be related to specific drugs, or combinations of drugs, that their patients receive.

**Therapeutic Index** Beneficial and adverse reactions to drug therapy can be described by a series of dose-response relations (Fig. 67-1). Well-tolerated drugs demonstrate a wide margin, termed the *therapeutic ratio*, *therapeutic index*, or *therapeutic window*, between the doses required to produce a therapeutic effect and those producing toxicity. In cases where there is a similar relationship between plasma drug concentration and effects, monitoring plasma concentrations can be a highly effective aid in managing drug therapy by enabling concentrations to be maintained above the minimum required to produce an effect and below the concentration range likely to produce toxicity. Such monitoring has been widely used to guide therapy with specific agents, such as certain antiarrhythmics, anticonvulsants, and antibiotics. Many of the principles in clinical pharmacology and

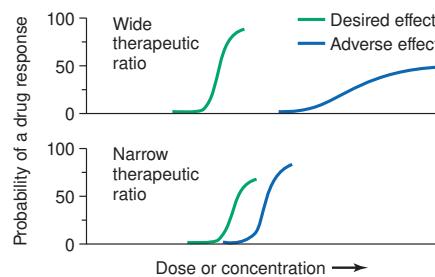


FIGURE 67-1 The concept of a therapeutic ratio. Each panel illustrates the relationship between increasing dose and cumulative probability of a desired or adverse drug effect. *Top*. A drug with a wide therapeutic ratio, that is, a wide separation of the two curves. *Bottom*. A drug with a narrow therapeutic ratio; here, the likelihood of adverse effects at therapeutic doses is increased because the curves are not well separated. Further, a steep dose-response curve for adverse effects is especially undesirable, as it implies that even small dosage increments may sharply increase the likelihood of toxicity. When there is a definable relationship between drug concentration (usually measured in plasma) and desirable and adverse effect curves, concentration may be substituted on the abscissa. Note that not all patients necessarily demonstrate a therapeutic response (or adverse effect) at any dose and that some effects (notably some adverse effects) may occur in a dose-independent fashion.

examples outlined below, which can be applied broadly to therapeutics, have been developed in these arenas.

## PRINCIPLES OF PHARMACOKINETICS

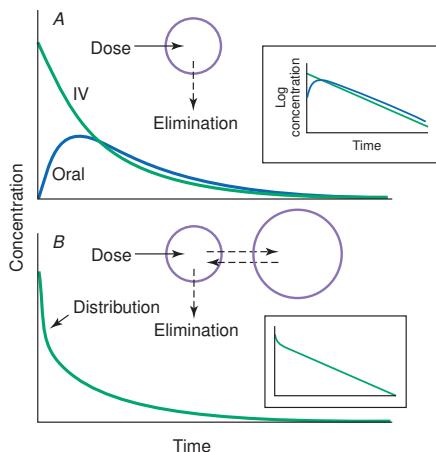
The processes of absorption, distribution, metabolism, and excretion—collectively termed *drug disposition*—determine the concentration of drug delivered to target effector molecules.

### ■ ABSORPTION AND BIOAVAILABILITY

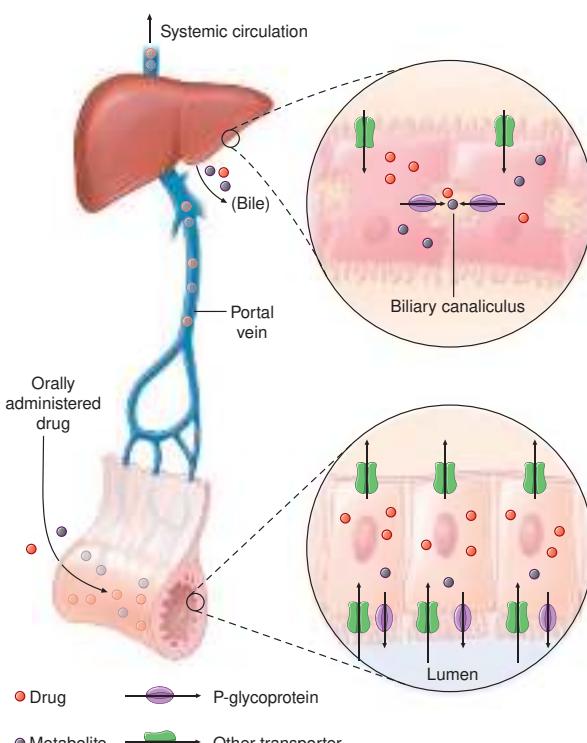
When a drug is administered orally, subcutaneously, intramuscularly, rectally, sublingually, or directly into desired sites of action, the amount of drug eventually entering the systemic circulation may be less than with the intravenous route (Fig. 67-2A). The fraction of drug available to the systemic circulation by other routes is termed *bioavailability*. Bioavailability may be <100% for two main reasons: (1) incomplete absorption, or (2) metabolism or elimination prior to entering the systemic circulation.

Compared to the same dose given intravenously, a nonintravenous dose will have a later and lower peak plasma concentration (Fig. 67-2). Drug absorption may be reduced because a drug is incompletely released from its dosage form, undergoes destruction at the site of administration, or has physicochemical properties such as insolubility that prevent complete absorption from its site of administration. Slow absorption rates are deliberately designed into “slow-release” or “sustained-release” drug formulations in order to minimize variation in plasma concentrations during the interval between doses. Therapeutic antibodies administered subcutaneously may take days to reach the systemic circulation.

**“First-Pass” Effect** When a drug is administered orally, it must traverse the intestinal epithelium, the portal venous system, and the liver prior to entering the systemic circulation (Fig. 67-3). Once a drug enters the enterocyte, it may undergo metabolism, be transported into the portal vein, or be excreted back into the intestinal lumen. Both excretion into the intestinal lumen and metabolism decrease bioavailability. Once a drug passes this enterocyte barrier, it may also be taken up into the hepatocyte, where bioavailability can be further limited by metabolism or excretion into the bile. This elimination in



**FIGURE 67-2** Idealized time-plasma concentration curves after a single dose of drug. **A.** The time course of drug concentration after an instantaneous intravenous (IV) bolus or an oral dose in the one-compartment model shown. The area under the time-concentration curve is clearly less with the oral drug than the IV drug, indicating incomplete bioavailability. Note that despite this incomplete bioavailability, concentration after the oral dose can be higher than after the IV dose at some time points. The inset shows that the decline of concentrations over time is linear on a log-linear plot, characteristic of first-order elimination, and that oral and IV drugs have the same elimination (parallel) time course. **B.** The decline of central compartment concentration when drug is distributed both to and from a peripheral compartment and eliminated from the central compartment. The rapid initial decline of concentration reflects not drug elimination but distribution.



**FIGURE 67-3** Mechanism of presystemic elimination. After drug enters the enterocyte, it can undergo metabolism, excretion into the intestinal lumen, or transport into the portal vein. Similarly, the hepatocyte may accomplish metabolism and biliary excretion prior to the entry of drug and metabolites to the systemic circulation. (Adapted by permission from DM Roden, in DP Zipes, J Jalife [eds]: *Cardiac Electrophysiology: From Cell to Bedside*, 4th ed. Philadelphia, Saunders, 2003. Copyright 2003 with permission from Elsevier.)

intestine and liver, which reduces the amount of drug delivered to the systemic circulation, is termed *presystemic elimination*, *presystemic extraction*, or *first-pass elimination*.

### ■ DRUG TRANSPORT

Drug movement across the membrane of any cell, including enterocytes and hepatocytes, is a combination of passive diffusion and active transport, mediated by specific drug uptake and efflux molecules. One widely studied drug transport molecule is the drug efflux pump P-glycoprotein, the product of the *ABCB1* (or *MDR1*) gene. P-glycoprotein is expressed on the apical aspect of the enterocyte and on the canalicular aspect of the hepatocyte (Fig. 67-3). In both locations, it serves as an efflux pump, limiting availability of drug to the systemic circulation. P-glycoprotein-mediated drug efflux from cerebral capillaries limits drug brain penetration and is an important component of the blood-brain barrier. Other transporters mediate uptake into cells of drugs and endogenous substrates such as vitamins or nutrients.

### ■ DRUG METABOLISM

Drug metabolism generates compounds that are usually more polar and, hence, more readily excreted than parent drug. Metabolism takes place predominantly in the liver but can occur at other sites such as kidney, intestinal epithelium, lung, and plasma. Phase I metabolism involves chemical modification, most often oxidation accomplished by members of the cytochrome P450 (CYP) monooxygenase superfamily. CYPs and other molecules that are especially important for drug metabolism are presented in Table 67-1, and each drug may be a substrate for one or more of these enzymes. Phase II metabolism involves conjugation of specific endogenous compounds to drugs or their metabolites. The enzymes that accomplish phase II reactions include glucuronyl-, acetyl-, sulfo-, and methyltransferases. Drug metabolites

TABLE 67-1 Molecular Pathways Mediating Drug Disposition

ENZYME	SUBSTRATES <sup>a</sup>	INHIBITORS <sup>a</sup>
CYP3A	Calcium channel blockers	Amiodarone
	Antiarrhythmics (lidocaine, quinidine, mexiletine)	Ketoconazole, itraconazole
	HMG-CoA reductase inhibitors ("statins"; see text)	Erythromycin, clarithromycin
	Cyclosporine, tacrolimus Indinavir, saquinavir, ritonavir	Ritonavir Gemfibrozil and other fibrates
CYP2D6 <sup>b</sup>	Timolol, metoprolol, carvedilol	Quinidine (even at ultra-low doses)
	Propafenone, flecainide	Tricyclic antidepressants
	Tricyclic antidepressants	Fluoxetine, paroxetine
	Fluoxetine, paroxetine	
CYP2C9 <sup>b</sup>	Warfarin	Amiodarone
	Phenytoin	Fluconazole
	Glipizide	Phenytoin
	Losartan	
CYP2C19 <sup>b</sup>	Omeprazole Mephenytoin Clopidogrel	Omeprazole
CYP2B6 <sup>b</sup>	Eflavirenz	
Thiopurine S-methyltransferase <sup>b</sup>	6-Mercaptopurine, azathioprine	
N-acetyltransferase <sup>b</sup>	Isoniazid Procainamide Hydralazine Some sulfonamides	
UGT1A1 <sup>b</sup>	Irinotecan	
Pseudocholinesterase <sup>b</sup>	Succinylcholine	
TRANSPORTER	SUBSTRATES <sup>a</sup>	INHIBITORS <sup>a</sup>
P-glycoprotein	Digoxin HIV protease inhibitors Many CYP3A substrates	Quinidine Amiodarone Verapamil Cyclosporine Itraconazole Erythromycin
SLCO1B1 <sup>b</sup>	Simvastatin and some other statins	

<sup>a</sup>Inhibitors affect the molecular pathway and thus may decrease substrate metabolism. <sup>b</sup>Clinically important genetic variants described; see Chap. 68.

Note: A listing of CYP substrates, inhibitors, and inducers is maintained at <https://drug-interactions.medicine.iu.edu/MainTable.aspx>.

may exert important pharmacologic activity, as discussed further below. Therapeutic antibodies are very slowly eliminated (allowing infrequent dosing, e.g., monthly injections), probably by lysosomal uptake and degradation.

**Clinical Implications of Altered Bioavailability** Some drugs undergo near-complete presystemic metabolism and thus cannot be administered orally. Nitroglycerin cannot be used orally because it is completely extracted prior to reaching the systemic circulation. The drug is, therefore, used by the sublingual, transdermal, or intravascular routes, which bypass presystemic metabolism.

Some drugs with very extensive presystemic metabolism can still be administered by the oral route, using much higher doses than those required intravenously. Thus, a typical intravenous dose of verapamil is 1–5 mg, compared to a usual single oral dose of 40–120 mg. Administration

of low-dose aspirin can result in exposure of cyclooxygenase in platelets in the portal vein to the drug, but systemic sparing because of first-pass aspirin deacetylation in the liver. This is an example of presystemic metabolism being exploited to therapeutic advantage.

## ■ PLASMA HALF LIFE

Most pharmacokinetic processes, such as elimination, are first-order; that is, the rate of the process depends on the amount of drug present. Elimination can occasionally be zero-order (fixed amount eliminated per unit time), and this can be clinically important (see "Principles of Dose Selection," later in this chapter). In the simplest pharmacokinetic model (Fig. 67-2A), a drug bolus (D) is administered instantaneously to a central compartment, from which drug elimination occurs as a first-order process. Occasionally, central and other compartments correspond to physiologic spaces (e.g., plasma volume), whereas in other cases, they are simply mathematical functions used to describe drug disposition. The first-order nature of drug elimination leads directly to the relationship describing drug concentration (C) at any time (t) following the bolus:

$$C = \frac{D}{V_c} \cdot e^{(-0.69t/t_{1/2})}$$

where  $V_c$  is the volume of the compartment into which drug is delivered and  $t_{1/2}$  is elimination half-life. As a consequence of this relationship, a plot of the logarithm of concentration versus time is a straight line (Fig. 67-2A, inset). Half-life is the time required for 50% of a first-order process to be completed. Thus, 50% of drug elimination is achieved after one drug-elimination half-life, 75% after two, 87.5% after three, etc. In practice, first-order processes such as elimination are near-complete after four to five half-lives.

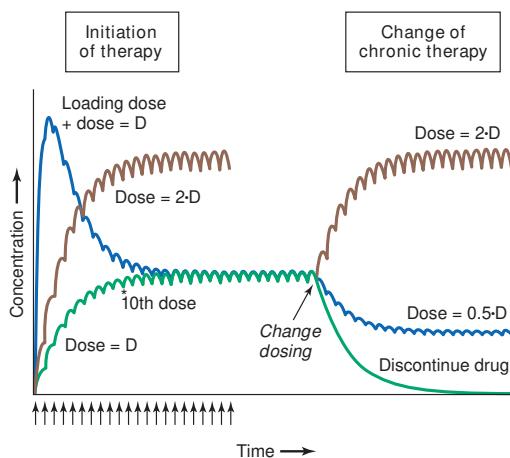
In some cases, drug is removed from the central compartment not only by elimination but also by distribution into peripheral compartments. In this case, the plot of plasma concentration versus time after a bolus may demonstrate two (or more) exponential components (Fig. 67-2B). In general, the initial rapid drop in drug concentration represents not elimination but drug distribution into and out of peripheral tissues (also first-order processes), while the slower component represents drug elimination; the initial precipitous decline is usually evident with administration by intravenous but not by other routes. Drug concentrations at peripheral sites are determined by a balance between drug distribution to and redistribution from those sites, as well as by elimination. Once distribution is near-complete (four to five distribution half-lives), plasma and tissue concentrations decline in parallel.

**Clinical Implications of Half-Life Measurements** The elimination half-life not only determines the time required for drug concentrations to fall to near-immeasurable levels after a single bolus, it is also the sole determinant of the time required for steady-state plasma concentrations to be achieved after any change in drug dosing (Fig. 67-4). This applies to the initiation of chronic drug therapy (whether by multiple oral doses or by continuous intravenous infusion), a change in chronic drug dose or dosing interval, or discontinuation of drug.

*Steady state* describes the situation during chronic drug administration when the amount of drug administered per unit time equals drug eliminated per unit time. With a continuous intravenous infusion, plasma concentrations at steady state are stable, while with chronic oral drug administration, plasma concentrations vary during the dosing interval, but the time-concentration profile between dosing intervals is stable (Fig. 67-4).

## ■ DRUG DISTRIBUTION

In a typical 70-kg human, plasma volume is 3 L, blood volume is 5.5 L, and extracellular water outside the vasculature is 20 L. The volume of distribution of drugs extensively bound to plasma proteins but not to tissue components approaches plasma volume; warfarin is an example. By contrast, for drugs highly bound to tissues, the volume of distribution can be far greater than any physiologic space. For example, the volume of distribution of digoxin and tricyclic antidepressants is hundreds



**FIGURE 67-4** Drug accumulation to steady state. In this simulation, drug was administered (arrows) at intervals = 50% of the elimination half-life. Steady state is achieved during initiation of therapy after 5 elimination half-lives, or 10 doses. A loading dose did not alter the eventual steady state achieved. A doubling of the dose resulted in a doubling of the steady state but the same time course of accumulation. Once steady state is achieved, a change in dose (increase, decrease, or drug discontinuation) results in a new steady state in 5 elimination half-lives. (Adapted by permission from DM Roden, in DP Zipes, J Jalife [eds]: *Cardiac Electrophysiology: From Cell to Bedside*, 4th ed. Philadelphia, Saunders, 2003. Copyright 2003 with permission from Elsevier.)

of liters, obviously exceeding total-body volume. Such drugs are not readily removed by dialysis, an important consideration in overdose.

**Clinical Implications of Drug Distribution** In some cases, pharmacologic effects require drug distribution to peripheral sites. In this instance, the time course of drug delivery to and removal from these sites determines the time course of drug effects; anesthetic uptake into the central nervous system (CNS) is an example.

**LOADING DOSES** For some drugs, the indication may be so urgent that administration of “loading” dosages is required to achieve rapid elevations of drug concentration and therapeutic effects earlier than with chronic maintenance therapy (Fig. 67-4). Nevertheless, the time required for a true steady state to be achieved is still determined only by the elimination half-life.

**RATE OF INTRAVENOUS DRUG ADMINISTRATION** Although the simulations in Fig. 67-2 use a single intravenous bolus, this is usually inappropriate in practice because side effects related to transiently very high concentrations can result. Rather, drugs are more usually administered orally or as a slower intravenous infusion. Some drugs are so predictably lethal when infused too rapidly that special precautions should be taken to prevent accidental boluses. For example, solutions of potassium for intravenous administration >20 mEq/L should be avoided in all but the most exceptional and carefully monitored circumstances. This minimizes the possibility of cardiac arrest due to accidental increases in infusion rates of more concentrated solutions.

Transiently high drug concentrations after rapid intravenous administration can occasionally be used to advantage. The use of midazolam for intravenous sedation, for example, depends upon its rapid uptake by the brain during the distribution phase to produce sedation quickly, with subsequent egress from the brain during the redistribution of the drug as equilibrium is achieved.

Similarly, adenosine must be administered as a rapid bolus in the treatment of reentrant supraventricular tachycardias (Chap. 246) to prevent elimination by very rapid ( $t_{1/2}$  of seconds) uptake into erythrocytes and endothelial cells before the drug can reach its clinical site of action, the atrioventricular node.

**Clinical Implications of Altered Protein Binding** Many drugs circulate in the plasma partly bound to plasma proteins. Since only unbound (free) drug can distribute to sites of pharmacologic action,

drug response is related to the free rather than the total circulating plasma drug concentration. In chronic kidney or liver disease, protein binding may be decreased and thus drug actions increased. In some situations (myocardial infarction, infection, surgery), acute phase reactants transiently increase binding of some drugs and thus decrease efficacy. These changes assume the greatest clinical importance for drugs that are highly protein-bound since even a small change in protein binding can result in large changes in free drug; for example, a decrease in binding from 99 to 98% doubles the free drug concentration from 1 to 2%. For some drugs (e.g., phenytoin), monitoring free rather than total drug concentrations can be useful.

## ■ DRUG ELIMINATION

Drug elimination reduces the amount of drug in the body over time. An important approach to quantifying this reduction is to consider that drug concentrations at the beginning and end of a time period are unchanged, and that a specific volume of the body has been “cleared” of the drug during that time period. This defines clearance as volume/time. Clearance includes both drug metabolism and excretion.

**Clinical Implications of Altered Clearance** While elimination half-life determines the time required to achieve steady-state plasma concentration ( $C_{ss}$ ), the magnitude of that steady state is determined by clearance ( $Cl$ ) and dose alone. For a drug administered as an intravenous infusion, this relationship is:

$$C_{ss} = \text{dosing rate}/Cl \quad \text{or} \quad \text{dosing rate} = Cl \cdot C_{ss}$$

When a drug is administered orally, the average plasma concentration within a dosing interval ( $C_{avg,ss}$ ) replaces  $C_{ss}$ , and the dosage (dose per unit time) must be increased if bioavailability ( $F$ ) is <100%:

$$\text{Dose}/\text{time} = Cl \cdot C_{avg,ss}/F$$

Genetic variants, drug interactions, or diseases that reduce the activity of drug-metabolizing enzymes or excretory mechanisms lead to decreased clearance and, hence, a requirement for a downward dose adjustment to avoid toxicity. Conversely, some drug interactions and genetic variants increase the function of drug elimination pathways, and hence, increased drug dosage is necessary to maintain a therapeutic effect.

## ■ ACTIVE DRUG METABOLITES

Metabolites may produce effects similar to, overlapping with, or distinct from those of the parent drug. Accumulation of the major metabolite of procainamide, *N*-acetylprocainamide (NAPA), likely accounts for marked QT prolongation and torsades de pointes ventricular tachycardia (Chap. 252) during therapy with procainamide. Neurotoxicity during therapy with the opioid analgesic meperidine is likely due to accumulation of normeperidine, especially in renal disease.

Prodrugs are inactive compounds that require metabolism to generate active metabolites that mediate the drug effects. Examples include many angiotensin-converting enzyme (ACE) inhibitors, the angiotensin receptor blocker losartan, the antineoplastic irinotecan, the antiestrogen tamoxifen, the analgesic codeine (whose active metabolite morphine probably underlies the opioid effect during codeine administration), and the antiplatelet drug clopidogrel. Drug metabolism has also been implicated in bioactivation of procarcinogens and in the generation of reactive metabolites that mediate certain ADRs (e.g., acetaminophen hepatotoxicity, discussed below).

## ■ THE CONCEPT OF HIGH RISK PHARMACOKINETICS

When plasma concentrations of active drug depend exclusively on a single metabolic pathway, any condition that inhibits that pathway (be it disease related, genetic, or due to a drug interaction) can lead to dramatic changes in drug concentrations and marked variability in drug action. Two mechanisms can generate highly variable drug concentrations and effects through such “high-risk pharmacokinetics.” First, variability in bioactivation of a prodrug can lead to striking variability in drug action; examples include decreased CYP2D6 activity, which prevents analgesia

by codeine, and decreased CYP2C19 activity, which reduces the antiplatelet effects of clopidogrel. The second setting is drug elimination that relies on a single pathway. In this case, inhibition of the elimination pathway by genetic variants or by administration of inhibiting drugs leads to marked elevation of drug concentration and, for drugs with a narrow therapeutic window, an increased likelihood of dose-related toxicity. The active S-enantiomer of the anticoagulant warfarin is eliminated by CYP2C9, and co-administration of amiodarone or phenytoin, CYP2C9 inhibitors, may therefore increase the risk of bleeding unless the dose is decreased. When drugs undergo elimination by multiple-drug metabolizing or excretory pathways, absence of one pathway (due to a genetic variant or drug interaction) is much less likely to have a large impact on drug concentrations or drug actions.

## ■ PRINCIPLES OF PHARMACODYNAMICS

**Time Course of Drug Action** Pharmacokinetic parameters, such as half-life and clearance, explain drug concentrations over time, but understanding the action of a drug over time (pharmacodynamics) often requires an understanding of its precise mechanism of action. Drugs act through interactions with drug targets, often in specific tissues, and with a cascade of downstream consequences. For drugs used in the urgent treatment of acute symptoms, little or no delay is anticipated (or desired) between the administration of the drug, the drug-target interaction, and the development of a clinical effect. Examples of such acute situations include vascular thrombosis, shock, or status epilepticus.

For many conditions, however, the indication for therapy is less urgent, and a delay in the onset of action clinically acceptable. Delay can be due to pharmacokinetic mechanisms such as slow elimination (resulting in slow accumulation to steady state), slow uptake into the target tissue, or slow accumulation of active metabolites. A common pharmacodynamic explanation for such a delay is the biological mechanism of action. For example, the glucocorticoid prednisolone has a plasma half-life of about 60 min. The mechanism of action, however, involves binding of the glucocorticoid receptor, translocation to the cell nucleus, and alterations in gene transcription. These downstream effects alter immune function for a much longer time frame, as evidenced by the biological half-life of 24–36 h. Other examples include proton pump inhibitors, which irreversibly bind the hydrogen/potassium adenosine triphosphatase enzyme and thus affect acid secretion for the lifetime of that enzyme, and the irreversible antiplatelet drugs, which exert effects for the duration of the life of the platelet.

**Drug Effects May Be Disease Specific** A drug may produce no action or a different spectrum of actions in unaffected individuals compared to patients with underlying disease. Further, concomitant disease can complicate interpretation of response to drug therapy, especially ADRs. For example, high doses of anticonvulsants such as phenytoin may cause neurologic symptoms, which may be confused with the underlying neurologic disease. Similarly, increasing dyspnea in a patient with chronic lung disease receiving amiodarone therapy could be due to the drug, underlying disease, or an intercurrent cardiopulmonary problem. As a result, alternate antiarrhythmic therapies may be preferable in patients with chronic lung disease.

While drugs interact with specific molecular receptors, drug effects may vary over time, even if stable drug and metabolite concentrations are maintained. The drug-receptor interaction occurs in a complex biologic milieu that can vary to modulate the drug effect. For example, ion channel blockade by drugs, an important anticonvulsant and antiarrhythmic effect, is often modulated by membrane potential, itself a function of factors such as extracellular potassium or local ischemia. Receptors may be up- or downregulated by disease or by the drug itself. For example,  $\beta$ -adrenergic blockers upregulate  $\beta$ -receptor density during chronic therapy. While this effect does not usually result in resistance to the therapeutic effect of the drugs, it may produce severe agonist-mediated effects (such as hypertension or tachycardia) if the blocking drug is abruptly withdrawn.

As molecular mechanisms of disease become better defined, drugs targeting those mechanisms are being introduced into practice.

Antineoplastic agents targeting mutant kinases overexpressed in cancers (e.g., BRAF V600E in melanoma, hairy cell leukemia, and other malignancies) are revolutionizing cancer care. Ivacaftor was originally developed and marketed for patients with cystic fibrosis (CF) carrying the G551D mutation in the disease gene *CFTR* (Chap. 291). While the most common *CFTR* mutations causing CF generate normal chloride channels that are not correctly trafficked to the cell surface, G551D channels are trafficked normally but do not conduct chloride correctly, and ivacaftor corrects this “gating” defect. Following initial marketing for only G551D patients (5% of all CF patients), the U.S. Food and Drug Administration (FDA) approved ivacaftor for use in patients carrying other *CFTR* mutations that confer gating defects corrected by ivacaftor *in vitro*.

## ■ PRINCIPLES OF DOSE SELECTION

The desired goal of therapy with any drug is to maximize the likelihood of a beneficial effect while minimizing the risk of ADRs. Previous experience with the drug, in controlled clinical trials or in postmarketing use, defines the relationships between dose or plasma concentration and these dual effects (Fig. 67-1) and has important implications for initiation of drug therapy:

1. *The target drug effect should be defined when drug treatment is started.* With some drugs, the desired effect may be difficult to measure objectively, or the onset of efficacy can be delayed for weeks or months; drugs used in the treatment of cancer and psychiatric disease are examples. Sometimes a drug is used to treat a symptom, such as pain or palpitations, and here it is the patient who will report whether the selected dose is effective. In yet other settings, such as anticoagulation or hypertension, the desired response can be repeatedly and objectively assessed by simple clinical or laboratory tests.
2. *The nature of anticipated toxicity often dictates the starting dose.* If side effects are minor, it may be acceptable to start chronic therapy at a dose highly likely to achieve efficacy and down-titrate if side effects occur. However, this approach is rarely, if ever, justified if the anticipated toxicity is serious or life-threatening; in this circumstance, it is more appropriate to initiate therapy with the lowest dose that may produce a desired effect. In cancer chemotherapy, it is common practice to use maximally tolerated doses.
3. *The above considerations do not apply if these relationships between dose and effects cannot be defined.* This is especially relevant to some ADRs (discussed further below) whose development is not readily related to drug dose.
4. *If a drug dose does not achieve its desired effect, a dosage increase is justified only if toxicity is absent and the likelihood of serious toxicity is small.*

**Failure of Efficacy** Even assuming the diagnosis is correct and the correct drug and dose are prescribed, drugs may fail to be effective because 100% efficacy is not expected. A complete therapeutic response is often absent with antihypertensive or antidepressant drugs, and a major challenge in contemporary therapeutics is to identify patient-specific predictors of response to individual drugs. Other explanations for failure of efficacy include drug interactions, noncompliance, or unexpectedly low drug concentration due to administration of expired or degraded drug. These are situations in which measurement of plasma drug concentrations, if available, can be especially useful. Noncompliance is an especially frequent problem in the long-term treatment of diseases such as hypertension and epilepsy, occurring in  $\geq 25\%$  of patients in therapeutic environments in which no special effort is made to involve patients in the responsibility for their own health. Multidrug regimens with multiple doses per day are especially prone to noncompliance.

Monitoring response to therapy, by physiologic measures or by plasma concentration measurements, requires an understanding of the relationships between plasma concentration and anticipated effects. For example, measurement of QT interval is used during treatment with sotalol or dofetilide to avoid marked QT prolongation that can herald serious arrhythmias. In this setting, evaluating the

electrocardiogram at the time of anticipated peak plasma concentration and effect (e.g., 1–2 h postdose at steady state) is most appropriate. Maintained high vancomycin levels carry a risk of nephrotoxicity, so dosages should be adjusted on the basis of plasma concentrations measured at trough (predose). Similarly, for dose adjustment of other drugs (e.g., anticonvulsants), concentration should be measured at its lowest during the dosing interval, just prior to a dose at steady state (Fig. 67-4), to ensure a maintained therapeutic effect.

**Concentration of Drugs in Plasma as a Guide to Therapy**  
 Factors such as interactions with other drugs, disease-induced alterations in elimination and distribution, and genetic variation in drug disposition combine to yield a wide range of plasma levels in patients given the same dose. Hence, if a predictable relationship can be established between plasma drug concentration and beneficial or adverse drug effect, measurement of plasma levels can provide a valuable tool to guide selection of an optimal dose, especially when there is a narrow range between the plasma levels yielding therapeutic and adverse effects. Such therapeutic drug monitoring is commonly used with certain types of drugs including many anticonvulsants, antirejection agents, antiarrhythmics, and antibiotics. By contrast, if no such relationship can be established (e.g., if drug access to important sites of action outside plasma is highly variable), monitoring plasma concentration may not provide an accurate guide to therapy (Fig. 67-5).

The common situation of first-order elimination implies that average, maximum, and minimum steady-state concentrations are related linearly to the dosing rate. Accordingly, the maintenance dose may be adjusted on the basis of the ratio between the desired and measured concentrations *at steady state*; for example, if a doubling of the steady-state plasma concentration is desired, the dose should be doubled. This does not apply to drugs eliminated by zero-order kinetics (fixed amount per unit time), where small dosage increases will produce disproportionate increases in plasma concentration; examples include phenytoin and theophylline.

If an increase in dosage is needed, this is usually best achieved by increasing the drug dose and leaving the dosing interval constant

(e.g., by giving 200 mg every 8 h instead of 100 mg every 8 h). However, this approach is acceptable only if the resulting maximum concentration is not toxic and the trough value does not fall below the minimum effective concentration for an undesirable period of time. Alternatively, the steady state may be changed by altering the frequency of intermittent dosing but not the size of each dose. In this case, the magnitude of the fluctuations around the average steady-state level will change—the shorter the dosing interval, the smaller the difference between peak and trough levels.

## EFFECTS OF DISEASE ON DRUG CONCENTRATION AND RESPONSE

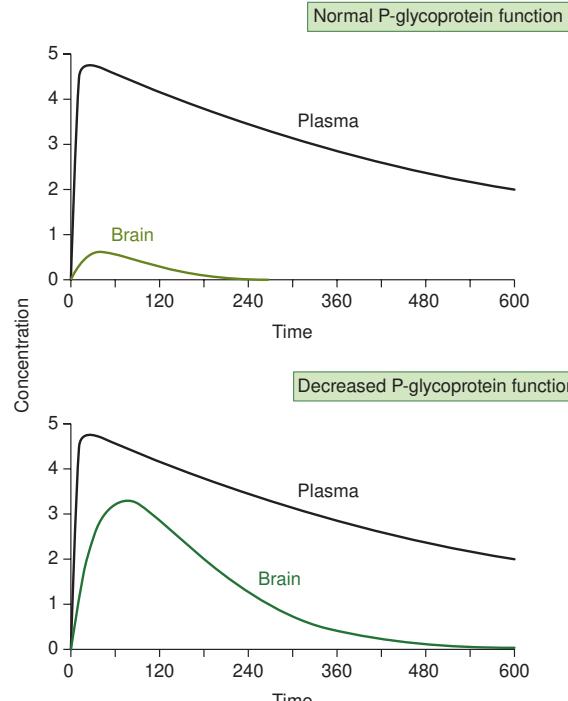
### ■ RENAL DISEASE

Renal excretion of parent drug and metabolites is generally accomplished by glomerular filtration and by specific drug transporters. If a drug or its metabolites are primarily excreted through the kidneys and increased drug levels are associated with ADRs (an example of “high-risk pharmacokinetics” described above), drug dosages must be reduced in patients with renal dysfunction to avoid toxicity. The antiarrhythmics dofetilide and sotalol undergo predominant renal excretion and carry a risk of QT prolongation and arrhythmias if doses are not reduced in renal disease. In end-stage renal disease, sotalol has been given as 40 mg after dialysis (every second day), compared to the usual daily dose, 80–120 mg every 12 h. At approved doses, the anticoagulant edoxaban appears to be somewhat more effective in subjects with mild renal dysfunction, possibly reflecting higher drug levels. The narcotic analgesic meperidine undergoes extensive hepatic metabolism, so that renal failure has little effect on its plasma concentration. However, its metabolite, normeperidine, does undergo renal excretion, accumulates in renal failure, and probably accounts for the signs of CNS excitation, such as irritability, twitching, and seizures, that appear when multiple doses of meperidine are administered to patients with renal disease. Protein binding of some drugs (e.g., phenytoin) may be altered in uremia, so measuring free drug concentration may be desirable.

In non-end-stage renal disease, changes in renal drug clearance are generally proportional to those in creatinine clearance, which may be measured directly or estimated from the serum creatinine. This estimate, coupled with the knowledge of how much drug is normally excreted renally versus nonrenally, allows an estimate of the dose adjustment required. In practice, most decisions involving dosing adjustment in patients with renal failure use published recommended adjustments in dosage or dosing interval based on the severity of renal dysfunction indicated by creatinine clearance. Any such modification of dose is a first approximation and should be followed by plasma concentration data (if available) and clinical observation to further optimize therapy for the individual patient.

### ■ LIVER DISEASE

Standard tests of liver function are not useful in adjusting doses in diseases like hepatitis or cirrhosis. First-pass metabolism may decrease, leading to increased oral bioavailability as a consequence of disrupted hepatocyte function, altered liver architecture, and portacaval shunts. The oral bioavailability for high first-pass drugs such as morphine, meperidine, midazolam, and nifedipine is almost doubled in patients with cirrhosis, compared to those with normal liver function. Therefore, the size of the oral dose of such drugs should be reduced in this setting.



**FIGURE 67-5** Drug concentrations in specific tissues may not always parallel those in plasma. For example, the efflux pump P-glycoprotein excludes drugs from the endothelium of capillaries in the brain and so constitutes a key element of the blood-brain barrier. Reduced P-glycoprotein function (e.g., due to drug interactions) can thus increase penetration of substrate drugs into the brain, even when plasma concentrations are unchanged.

## ■ HEART FAILURE AND SHOCK

Under conditions of decreased tissue perfusion, the cardiac output is redistributed to preserve blood flow to the heart and brain at the expense of other tissues (Chap. 257). As a result, drugs may be distributed into a smaller volume of distribution, higher drug concentrations will be present in the plasma, and the tissues that are best perfused (the brain and heart) will be exposed to these higher concentrations, resulting in increased CNS or cardiac effects. In addition, decreased perfusion of the kidney and liver may impair drug clearance. Another consequence of severe heart failure is decreased gut perfusion, which may reduce drug absorption and thus lead to reduced or absent effects of orally administered therapies.

## ■ DRUG USE IN THE ELDERLY

In the elderly, multiple pathologies and medications used to treat them result in more drug interactions and ADRs. Aging also results in changes in organ function, especially of the organs involved in drug disposition. Initial doses should be less than the usual adult dosage and should be increased slowly. The number of medications, and doses per day, should be kept as low as possible.

Even in the absence of kidney disease, renal clearance may be reduced by 35–50% in elderly patients. Dosages should be adjusted on the basis of creatinine clearance. Aging also results in a decrease in the size of, and blood flow to, the liver and possibly in the activity of hepatic drug-metabolizing enzymes; accordingly, the hepatic clearance of some drugs is impaired in the elderly. As with liver disease (above), these changes are not readily predicted.

Elderly patients may display altered drug sensitivity. Examples include increased analgesic effects of opioids, increased sedation from benzodiazepines and other CNS depressants, and increased risk of bleeding while receiving anticoagulant therapy, even when clotting parameters are well controlled. Exaggerated responses to cardiovascular drugs are also common because of the impaired responsiveness of normal homeostatic mechanisms. Conversely, the elderly display decreased sensitivity to  $\beta$ -adrenergic receptor blockers.

ADRs are especially common in the elderly because of altered pharmacokinetics and pharmacodynamics, the frequent use of multidrug regimens, and concomitant disease. For example, use of long half-life benzodiazepines is linked to the occurrence of hip fractures in elderly patients, perhaps reflecting both a risk of falls from these drugs (due to increased sedation) and the increased incidence of osteoporosis in elderly patients. In population surveys of the noninstitutionalized elderly, as many as 10% had at least one ADR in the previous year.

## ■ DRUG USE IN CHILDREN

Although there are very few pediatric-specific drugs, there are many pediatric-specific drug indications (e.g., intravenous immunoglobulin and aspirin for Kawasaki disease) and ADRs (e.g., pyloric stenosis after erythromycin exposure in infants). Drug metabolism and drug response pathways mature at different rates after birth, and the relative size of various body compartments and function of various organs change during development. There is increased motivation to avoid organ toxicity, given the anticipated long post-drug-exposure life expectancy. There are few studies providing empiric evidence to guide pediatric dosing. In practice, doses are adjusted for size (weight or body surface area) as a first approximation unless age-specific data are available. As in adults, the lowest doses anticipated to achieve clinical benefit are generally prescribed, potentially followed by titration.

## INTERACTIONS BETWEEN DRUGS

Drug interactions can complicate therapy by increasing or decreasing the action of a drug; interactions may be based on changes in drug disposition or in drug response in the absence of changes in drug levels (Table 67-2). *Interactions must be considered in the differential diagnosis of any unusual response occurring during drug therapy.* Prescribers should recognize that patients often come to them with a legacy of drugs acquired during previous medical experiences, often with multiple physicians who may not be aware of all the patient's medications. A meticulous drug history should list all medications, including agents

TABLE 67-2 Drug Interactions

MECHANISM	EXAMPLE
<b>Pharmacokinetic Interactions Causing Decreased Drug Effect</b>	
Decreased absorption due to drug binding in the gut	Antacids or bile acid sequestrants decrease the absorption of many drugs: Antacids/tetracyclines Cholestyramine/digoxin
Decreased solubility due to altered gastric pH	H <sub>2</sub> receptor blockers or proton pump inhibitors decrease solubility and absorption of weak bases: Omeprazole/ ketoconazole
Induction of drug metabolism and/or drug transport:	Decreased concentrations and effects of: Warfarin Quinidine Cyclosporine Losartan Oral contraceptives Methadone Dabigatran
Decreased prodrug bioactivation	Proton pump inhibitors may prevent clopidogrel bioactivation CYP2D6 inhibitors (fluoxetine, paroxetine, quinidine, and others) may prevent codeine bioactivation
Reduced delivery of drug to active sites of action	Tricyclics prevent clonidine uptake into adrenergic neurons, preventing antihypertensive effects
<b>Pharmacokinetic Interactions Causing Increased Drug Effect</b>	
Inhibited drug metabolism	Omeprazole (inhibits many CYPs): Warfarin Theophylline Phenytoin CYP2D6 inhibitors <sup>a</sup> /β blockers CYP3A inhibitors <sup>b</sup> : HMG-CoA reductase inhibitors Colchicine (toxicity risk) Decreased cyclosporine dose requirement
Inhibited drug transport	Amiodarone (inhibits many CYPs and P-glycoprotein): Warfarin Digoxin Dabigatran
Inhibition of drug metabolism causing accumulation of toxic metabolites	Allopurinol (xanthine oxidase inhibitor) inhibits an alternate pathway for azathioprine and 6-mercaptopurine elimination, increasing risk for toxicity
Decreased elimination due to altered renal function	Inhibitors of renal tubular transport (phenylbutazone, probenecid, salicylates) increase methotrexate toxicity
<b>Pharmacodynamic Drug Interactions</b>	
Combined effects on the same biologic process	Excess bleeding with combinations of antiplatelet drugs, anticoagulants, and NSAIDs Long QT-related arrhythmias with QT-prolonging antiarrhythmics plus diuretics Hyperkalemia with ACE inhibitors plus potassium Hypotension with nitrates plus sildenafil
Antagonistic effects on the same biologic process	Loss of antihypertensive drug effects with NSAIDs

<sup>a</sup>See Table 67-1.

<sup>b</sup>Abbreviations: ACE, angiotensin-converting enzyme; CYP, cytochrome P; NSAID, nonsteroidal anti-inflammatory drug.

not often volunteered during questioning, such as OTC drugs, health food supplements, and topical agents such as eye drops. Lists of interactions are available from a number of electronic sources. While it is unrealistic to expect the practicing physician to memorize these, certain drugs consistently run the risk of generating interactions, often by inhibiting or inducing specific drug elimination pathways; these include CYP2D6, CYP3A, and P-glycoprotein inhibitors (Table 67-1) and CYP3A/P-glycoprotein inducers (Table 67-2). Accordingly, when these drugs are started or stopped, prescribers must be especially alert to the possibility of interactions.

## ADVERSE DRUG REACTIONS

The beneficial effects of drugs are coupled with the inescapable risk of untoward effects. The morbidity and mortality from these ADRs often present diagnostic problems because they can involve every organ and system of the body and may be mistaken for signs of underlying disease. In addition, some surveys have suggested that drug therapy for a range of chronic conditions such as psychiatric disease or hypertension does not achieve its desired goal in up to half of treated patients; thus, the most common “adverse” drug effect may be failure of efficacy.

ADRs can be classified in two broad groups. Type A reactions result from exaggeration of an intended pharmacologic action of the drug, such as increased bleeding with anticoagulants or bone marrow suppression with some antineoplastics, and tend to be dose-dependent. Type B reactions result from toxic effects unrelated to the intended pharmacologic actions. The latter effects are often unanticipated (especially with new drugs) and frequently severe and may result from recognized (often immunologic) as well as previously undescribed mechanisms. Type B reactions may occur at low dosages and are often termed dose-independent.

Drugs may increase the frequency of an event that is common in a general population, and this may be especially difficult to recognize; an example is the increase in myocardial infarctions that was seen with the COX-2 inhibitor rofecoxib. Drugs can also cause rare and serious ADRs, such as hematologic abnormalities, arrhythmias, severe skin reactions, or hepatic or renal dysfunction. Prior to regulatory approval and marketing, new drugs are tested in relatively few patients who tend to be less sick and to have fewer concomitant diseases than those patients who subsequently receive the drug therapeutically. Because of the relatively small number of patients studied in clinical trials and the selected nature of these patients, rare ADRs are generally not detected prior to a drug's approval; indeed, if they are detected, the new drugs are generally not approved. Therefore, physicians need to be cautious in the prescription of new drugs and alert for the appearance of previously unrecognized ADRs.

Elucidating mechanisms underlying ADRs can assist development of safer compounds or allow a patient subset at especially high risk to be excluded from drug exposure. National adverse reaction reporting systems, such as those operated by the FDA (suspected ADRs can be reported online at <http://www.fda.gov/safety/medwatch/default.htm>) and the Committee on Safety of Medicines in Great Britain, can prove useful. The publication or reporting of a newly recognized ADR can in a short time stimulate many similar such reports of reactions that previously had gone unrecognized.

Occasionally, “adverse” effects may be exploited to develop an entirely new indication for a drug. Unwanted hair growth during minoxidil treatment of severely hypertensive patients led to development of the drug for hair growth. Sildenafil was initially developed as an antianginal, but its effects to alleviate erectile dysfunction not only led to a new drug indication but also to increased understanding of the role of type 5 phosphodiesterase in erectile tissue. These examples further reinforce the concept that prescribers must remain vigilant to the possibility that unusual symptoms may reflect unappreciated drug effects.

Some 25–50% of patients make errors in self-administration of prescribed medicines, and these errors can be responsible for ADRs. Similarly, patients commit errors in taking OTC drugs by not reading or following prescribing directions on the containers. Health care providers must recognize that providing directions with prescriptions does not always guarantee compliance.

In hospitals, drugs are administered in a controlled setting, and patient compliance is, in general, ensured. Errors may occur nevertheless—the wrong drug or dose may be given or the drug may be given to the wrong patient—and improved drug distribution and administration systems should help with this problem.

## SCOPE OF THE PROBLEM

One estimate in the United Kingdom was that 6.5% of all hospital admissions are due to ADRs and that 2.3% of these patients (0.15%) died as a result. The most common culprit drugs were aspirin, nonsteroidal anti-inflammatory drugs, diuretics, warfarin, ACE inhibitors, antidepressants, opiates, digoxin, steroids, and clopidogrel. One study in the late 1990s suggested that ADRs were responsible for >100,000 in-hospital deaths in the United States, making them the fourth to sixth most common cause of in-hospital death. Another study 10 years later showed no change in this trend.

In hospital, patients receive, on average, 10 different drugs during each hospitalization. The sicker the patient, the more drugs are given, and there is a corresponding increase in the likelihood of ADRs. When <6 different drugs are given to hospitalized patients, the probability of an ADR is 5%, but if >15 drugs are given, the probability is >40%. Serious ADRs are also well recognized with “herbal” remedies and OTC compounds; examples include kava-associated hepatotoxicity, L-tryptophan-associated eosinophilia-myalgia, and phenylpropanolamine-associated stroke, each of which has caused fatalities.

## TOXICITY UNRELATED TO A DRUG'S PRIMARY PHARMACOLOGIC ACTIVITY

Drugs or, more commonly, reactive metabolites generated by CYPs can covalently bind to tissue macromolecules (such as proteins or DNA) to cause tissue toxicity. Because of the reactive nature of these metabolites, covalent binding often occurs close to the site of production, typically the liver.

**Acetaminophen** The most common cause of drug-induced hepatotoxicity is acetaminophen overdosage (Chap. 340). Normally, reactive metabolites are detoxified by combining with hepatic glutathione. When glutathione becomes depleted, the metabolites bind instead to hepatic protein, with resultant hepatocyte damage. The hepatic necrosis produced by the ingestion of acetaminophen can be prevented or attenuated by the administration of substances such as *N*-acetylcysteine that reduce the binding of electrophilic metabolites to hepatic proteins. The risk of acetaminophen-related hepatic necrosis is increased in patients receiving drugs such as phenobarbital or phenytoin, which increase the rate of drug metabolism, or ethanol, which exhausts glutathione stores. Such toxicity has even occurred with therapeutic dosages, so patients at risk through these mechanisms should be warned.

**Immunologic Reactions** Most pharmacologic agents are haptens, small molecules with low molecular weights (<2000) that are therefore poor immunogens. Generation of an immune response to a drug therefore often requires *in vivo* activation and covalent linkage to protein, carbohydrate, or nucleic acid.

Drug stimulation of antibody production may mediate tissue injury by several mechanisms. The antibody may attack the drug when the drug is covalently attached to a cell and thereby destroy the cell. This occurs in penicillin-induced hemolytic anemia. Antibody-drug antigen complexes may be passively adsorbed by a bystander cell, which is then destroyed by activation of complement; this occurs in quinine- and quinidine-induced thrombocytopenia. Heparin-induced thrombocytopenia arises when antibodies against complexes of platelet factor 4 peptide and heparin generate immune complexes that activate platelets; thus, the thrombocytopenia is accompanied by “paradoxical” thrombosis and is treated with thrombin inhibitors. Drugs or their reactive metabolites may alter a host tissue, rendering it antigenic and eliciting autoantibodies. For example, hydralazine and procainamide (or their reactive metabolites) can chemically alter nuclear material, stimulating the formation of antinuclear antibodies and occasionally causing lupus erythematosus. Drug-induced pure red cell aplasia (Chap. 102) is due to an immune-based drug reaction.

Serum sickness ([Chap. 352](#)) results from the deposition of circulating drug-antibody complexes on endothelial surfaces. Complement activation occurs, chemotactic factors are generated locally, and an inflammatory response develops at the site of complex entrapment. Arthralgias, urticaria, lymphadenopathy, glomerulonephritis, or cerebritis may result. Foreign proteins (vaccines, streptokinase, therapeutic antibodies) and antibiotics are common causes. Many drugs, particularly antimicrobial agents, ACE inhibitors, and aspirin, can elicit anaphylaxis with production of IgE, which binds to mast cell membranes. Contact with a drug antigen initiates a series of biochemical events in the mast cell and results in the release of mediators that can produce the characteristic urticaria, wheezing, flushing, rhinorrhea, and (occasionally) hypotension.

Drugs may also elicit cell-mediated immune responses. One serious reaction is Stevens-Johnson syndrome/toxic epidermal necrolysis (SJS/TEN), which can result in death due to T-cell-mediated massive skin sloughing. Another probable immune-mediated drug reaction is the DRESS (drug reaction with eosinophilia and systemic symptoms) syndrome, a rare ADR with a chronic relapsing course, often triggered by antiseizure medications and possibly arising from herpes virus reactivation. As described in [Chap. 68](#), specific genetic variants appear necessary but not sufficient to elicit SJS/TEN or DRESS.

While the use of antibodies targeting immune checkpoints is dramatically improving prognosis in many cancers, these agents have also been associated with the unpredictable development of many apparently immune-related ADRs. Some, like colitis or thyroiditis, may be self-limited or medically manageable, while others, notably myocarditis, are rarer but can be rapidly fatal.

## ■ DIAGNOSIS AND TREATMENT OF ADVERSE DRUG REACTIONS

The manifestations of drug-induced diseases frequently resemble those of other diseases, and a given set of manifestations may be produced by different and dissimilar drugs. Recognition of the role of a drug or drugs in an illness depends on appreciation of the possible ADRs to drugs in any disease, on identification of the temporal relationship between drug administration and development of the illness, and on familiarity with the common manifestations of the drugs.

A suspected ADR developing after introduction of a new drug naturally implicates that drug; however, it is also important to remember that a drug interaction may be responsible. Thus, for example, a patient on a chronic stable warfarin dose may develop a bleeding complication after introduction of amiodarone; this does not reflect a direct reaction to amiodarone but rather its effect to inhibit warfarin metabolism. Many associations between particular drugs and specific reactions have been described, but there is always a “first time” for a novel association, and any drug should be suspected of causing an ADR if the clinical setting is appropriate.

Illness related to a drug's intended pharmacologic action is often more easily recognized than illness attributable to immune or other mechanisms.

For example, side effects such as cardiac arrhythmias in patients receiving digitalis, hypoglycemia in patients given insulin, or bleeding in patients receiving anticoagulants are more readily related to a specific drug than are symptoms such as rash, which may be caused by many drugs or by other factors. Drug fever often escapes initial diagnosis because fever is such a common manifestation of disease.

Electronic listings of ADRs can be useful. However, exhaustive compilations often provide little sense of perspective in terms of frequency and seriousness, which can vary considerably among patients.

Eliciting a drug history from each patient is important for diagnosis. Attention must be directed to OTC drugs and herbal preparations as well as to prescription drugs. Each type can be responsible for ADRs, and adverse interactions may occur between OTC drugs and prescribed drugs. Loss of efficacy of oral contraceptives or cyclosporine with concurrent use of St. John's wort (a P-glycoprotein inducer) is an example ([Table 67-2](#)). In addition, it is common for patients to be cared for by several physicians, and duplicative, additive, antagonistic, or synergistic drug combinations may therefore be administered if

the physicians are not aware of the patients' drug histories. Electronic health records (EHRs) may help mitigate this problem, but only if all treating physicians use the same EHR system. Medications stopped for inefficacy or adverse effects should be documented to avoid pointless and potentially dangerous reexposure. A frequently overlooked source of additional drug exposure is topical therapy; for example, a patient complaining of bronchospasm may not mention that an ophthalmic beta blocker is being used unless specifically asked. A history of previous ADRs in patients is common. Since these patients have shown a predisposition to drug-induced illnesses, such a history should dictate added caution in prescribing new drugs.

Laboratory studies may include demonstration of serum antibody in some persons with drug allergies involving cellular blood elements, as in agranulocytosis, hemolytic anemia, and thrombocytopenia. For example, both quinine and quinidine can produce platelet agglutination *in vitro* in the presence of complement and the serum from a patient who has developed thrombocytopenia following use of this drug. Biochemical abnormalities such as G6PD deficiency, serum pseudocholinesterase level, or genotyping may also be useful in diagnosis, especially after an ADR has occurred in the patient or a family member ([Chap. 68](#)).

Once an ADR is suspected, discontinuation of the suspected drug followed by disappearance of the reaction is presumptive evidence of a drug-induced illness. Confirming evidence may be sought by cautiously reintroducing the drug and seeing if the reaction reappears. However, that should be done only if confirmation would be useful in the future management of the patient. Because rechallenge does carry risks, it is generally avoided unless the suspected culprit drug is critical to the patient's care. When the reaction is thought to be immunologic, challenge is generally avoided. With concentration-dependent ADRs, lowering the dosage may cause the reaction to disappear, and raising it may cause the reaction to reappear. Serious immunologically mediated ADRs have been treated with high-dose steroids; other immunosuppressive agents such as rituximab, infliximab, or mycophenolate mofetil; or plasmapheresis.

If the patient is receiving many drugs when an ADR is suspected, the drugs likeliest to be responsible can usually be identified; this should include both potential culprit agents as well as drugs that alter their elimination. All drugs may be discontinued at once or, if this is not practical, discontinued one at a time, starting with the ones most suspect, and the patient observed for signs of improvement. The time needed for a concentration-dependent ADR to disappear depends on the time required for the concentration to fall below the range associated with the ADR; that, in turn, depends on the initial blood level and on the rate of elimination or metabolism of the drug. Adverse effects of drugs with long half-lives or those not directly related to serum concentration may take a considerable time to disappear.

## THE DRUG DEVELOPMENT PROCESS

Drug therapy is an ancient feature of human culture. The first treatments were plant extracts discovered empirically to be effective for indications like fever, pain, or breathlessness. This symptom-based empiric approach to drug development was supplanted in the twentieth century by identification of compounds targeting more fundamental biologic processes, such as bacterial growth or elevated blood pressure. The term “magic bullet,” coined by Paul Ehrlich to describe the search for effective compounds for syphilis, captures the essence of the hope that understanding basic biologic processes will lead to highly effective new therapies.

A common starting point for the development of many widely used modern therapies has been basic biologic discovery that implicates potential target molecules: examples of such target molecules include HMG-CoA reductase, a key step in cholesterol biosynthesis, or the *BRAF* V600E mutation that appears to drive the development of some malignant melanomas and other tumors. The development of compounds targeting these molecules has not only revolutionized treatment for diseases such as hypercholesterolemia or malignant melanoma, but has also revealed new biologic features of disease. Thus, for example, initial spectacular successes with vemurafenib (which targets

*BRAF V600E*) were followed by near-universal tumor relapse, strongly suggesting that inhibition of this pathway alone would be insufficient for tumor control. This reasoning, in turn, supports a view that many complex diseases will not lend themselves to cure by targeting a single magic bullet, but rather single drugs or combinations that attack multiple pathways whose perturbation results in disease. The use of combination therapy in settings such as hypertension, tuberculosis, HIV infection, and many cancers highlights the potential for such a “systems biology” view of drug therapy.

A common approach in contemporary drug development is to start with a high-throughput screening procedure to identify “lead” chemical(s) modulating the activity of a potential drug target. The next step is application of increasingly sophisticated medicinal chemistry-based modification of the “lead” to develop compounds with specificity for the chosen target, lack of “off-target” effects, and pharmacokinetic properties suitable for human use (e.g., consistent bioavailability, long elimination half-life, and no high-risk pharmacokinetic features). Drug evaluation in human subjects then proceeds from initial safety and tolerance (phase 1) to dose finding (phase 2) and then to large efficacy trials (phase 3). This is a very expensive process, and the vast majority of lead compounds fail at some point. Thus, new approaches to identify likely successes and failures early are needed. One idea, described further in *Chap. 68*, is to use genomic and other high-throughput profiling approaches not only to identify new drug targets but also to identify disease subsets for which drugs approved for other indications might be “repurposed,” thereby avoiding the costly development process.

## SUMMARY

Modern clinical pharmacology aims to replace empiricism in the use of drugs with therapy based on in-depth understanding of factors that determine an individual’s response to drug treatment. Molecular pharmacology, pharmacokinetics, genetics, clinical trials, and the educated prescriber all contribute to this process. No drug response should ever be termed *idiosyncratic*; all responses have a mechanism whose understanding will help guide further therapy with that drug or successors. This rapidly expanding understanding of variability in drug actions makes the process of prescribing drugs increasingly daunting for the practitioner. However, fundamental principles should guide this process:

- The benefits of drug therapy, however defined, should always outweigh the risk.
- The smallest dosage necessary to produce the desired effect should be used.
- The number of medications and doses per day should be minimized.
- Although the literature is rapidly expanding, accessing it is becoming easier; electronic tools to search databases of literature and unbiased opinion will become increasingly commonplace.
- Genetics play a role in determining variability in drug response and may become a part of clinical practice.
- EHR and pharmacy systems will increasingly incorporate prescribing advice, such as indicated medications not used; unindicated medications being prescribed; and potential dosing errors, drug interactions, or genetically determined drug responses.
- Prescribers should be particularly wary when adding or stopping specific drugs that are especially liable to provoke interactions and adverse drug reactions.
- Prescribers should use only a limited number of drugs, with which they are thoroughly familiar.

## FURTHER READING

B JS et al: Challenges and opportunities in the development of medical therapies for pediatric populations and the role of extrapolation. *Clin Pharmacol Ther* 103:419, 2018.

H N: Pharmacodynamic principles and the time course of immediate drug effects. *Transl Clin Pharmacol* 25:157, 2017.

M CA et al: The future of cardiovascular therapeutics. *Circulation* 133:2610, 2016.

M KT et al: The role of clinical pharmacology across novel treatment modalities. *Clin Pharmacol Ther* 108:413, 2020.

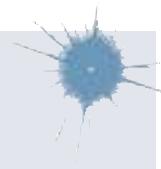
S J et al: Clinical and economic burden of adverse drug reactions. *J Pharmacol Pharmacother* 4:S73, 2013.

Z -G MJ et al: Transporters in drug development: 2018 ITC recommendations for transporters of emerging clinical importance. *Clin Pharmacol Ther* 104:890, 2018.

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## Pharmacogenomics

Dan M. Roden



The previous chapter discussed mechanisms underlying variability in drug action, highlighting pharmacokinetic and pharmacodynamic pathways to beneficial and adverse drug events. Work in the past several decades has defined how genetic variation can play a prominent role in modulating these pathways. Initial studies described unusual drug responses due to single genetic variants in individual subjects, defining the field of pharmacogenetics. A more recent view extends this idea to multiple genetic variants across populations, and the term “pharmacogenomics” is often used. Understanding the role of genetic variation in drug response could improve the use of current drugs, avoid drug use in those at increased risk for adverse drug reactions (ADRs), guide development of new drugs, and even be used as a lens through which to understand mechanisms of diseases themselves. This chapter will outline the principles of pharmacogenomics, the evidence as currently available that genetic factors play a role in variable drug actions, and areas of controversy and ongoing work.

### ■ PRINCIPLES OF GENETIC VARIATION AND DRUG RESPONSE SEE ALSO CHAPS. 466 AND 467

A goal of traditional Mendelian genetics is to identify DNA variants associated with a distinct phenotype in multiple related family members (*Chap. 467*). However, it is unusual for a drug response phenotype to be accurately measured in more than one family member, let alone across a kindred. Some clinical studies have examined drug disposition traits (such as urinary drug excretion after a fixed test dose) in twins and have, in some instances, shown greater concordance in monozygotic compared to dizygotic pairs, supporting a genetic contribution to the trait under study. However, in general, non-family-based approaches are usually used to identify and validate DNA variants contributing to variable drug actions. Both candidate gene and genome-wide studies have been used, and as with any genomic study, results require replication before they should be accepted as valid.

**Types of Genetic Variants Influencing Drug Response (Table 68-1)** The most common type of genetic variant is a single nucleotide polymorphism (SNP), and nonsynonymous SNPs (i.e., those that alter primary amino acid sequence encoded by a gene) are a common cause of variant function in genes regulating drug responses, often termed *pharmacogenes*. Small insertions and deletions can similarly alter protein function or lead to functionally important splice variation. Examples of synonymous coding region variants altering pharmacogene function have also been described; the postulated mechanism is an alteration in the rate of RNA translation, and hence in folding of the nascent protein. Variation in pharmacogene promoters has been described, and copy number variation (gene deletion or multiple copies of the same gene) is also well described.

Table 68-1 lists examples of individual types of genomic variation and the impact they can have on function of pharmacogenes. Multiple genotyping approaches may be needed to detect important variants; for example, SNP assays may fail to detect large gene duplications, and highly polymorphic regions (such as the major histocompatibility locus on chromosome 6 that includes multiple genes of the human leukocyte antigen [HLA] family) are currently best evaluated by sequencing.

TABLE 68-1 Examples of Genetic Variation and Ancestry

STRUCTURAL VARIANT	EXAMPLE		FUNCTIONAL EFFECT	MINOR ALLELE FREQUENCY (%) <sup>a</sup>		
	COMMON NAME	dbSNP		EUROPEAN	AFRICAN	EAST ASIAN
Single nucleotide polymorphism (SNP) (or single nucleotide variant, SNV)	CYP2C9*2	rs1799853	R144C: Reduction of function	12.7	2.4	<sup>b</sup>
	CYP2C9*3	rs1057910	I359L: Loss of function	6.9	1.3	3.4
	CYP2C9*8	rs7900194	R150H: Reduction of function	<sup>b</sup>	5.6	<sup>b</sup>
	CYP2C19*2	rs4244285	Splicing defect: Loss of function	14.8	18.1	31.0
	CYP2C19*3	rs4986893	Premature stop: Loss of function	<sup>b</sup>	<sup>b</sup>	6.7
	CYP2C19*17	rs12248560	Gain of function	45	45	<5
	CYP2D6*4 <sup>c</sup>	rs3892097	Splicing defect: Loss of function	23.1	11.9	0.4
	CYP2D6*10 <sup>c</sup> : Multiple SNPs define CYP2D6*10 (reduction of function allele):					
		rs1065852	P34S	24.9	15.1	59.1
		rs1135840	S486T			
Insertion/deletion	CYP3A5*3	rs776746	Splicing defect: Loss of function	90	33	85
	VKORC1*2	rs9923231	Promoter variant associated with decreased warfarin dose	39	11	91
	VKORC1	rs61742245	D36Y: Reduction of function, associated with increased warfarin dose	5% in East Africa, Middle East, Oceania; rare elsewhere		
	ABCB1	rs1045642	Synonymous variant; may affect mRNA stability and protein folding	47.2	79.8	62.5
	UGT1A1*28		Reduction of function promoter variant (7 TA repeats versus 6 repeats in reference allele); homozygotes have Gilbert's syndrome	31.6	39.1	14.8
Multiple variants constituting specific haplotypes	HLA-B*15:01		Predispose to immunologically mediated adverse drug reactions	<sup>b</sup>	<sup>b</sup>	5
	HLA-B*57:01			6.8	1.0	1.6
Gene deletion	CYP2D6*5		Loss of function	2.7	6	5.6
Gene duplication	CYP2D6*1xN	Duplication of normal allele	Ultra-rapid metabolizer phenotype	0.8	1.5	0.3
	CYP2D6*4xN	Duplication of loss of function allele		Up to 3% in North Africa and the Middle East		
				0.3	1.4	<sup>b</sup>

Note: Allele frequencies from <https://gnomad.broadinstitute.org/> and <https://cpicpgx.org/>.

<sup>a</sup>Includes heterozygotes and homozygotes. <sup>b</sup>Allele frequency <0.05%. <sup>c</sup>CYP2D6 is highly polymorphic, and multiple SNPs may be required to define a specific variant. For example, rs1065852 is present in both \*4 and \*10 variants. See <https://www.pharmvar.org/>.

Table 68-1 also highlights the fact that the frequency of important variation across pharmacogenes can vary strikingly by ancestry, with the result that certain ethnic groups may be at unusually high risk of displaying variant response to specific drugs.

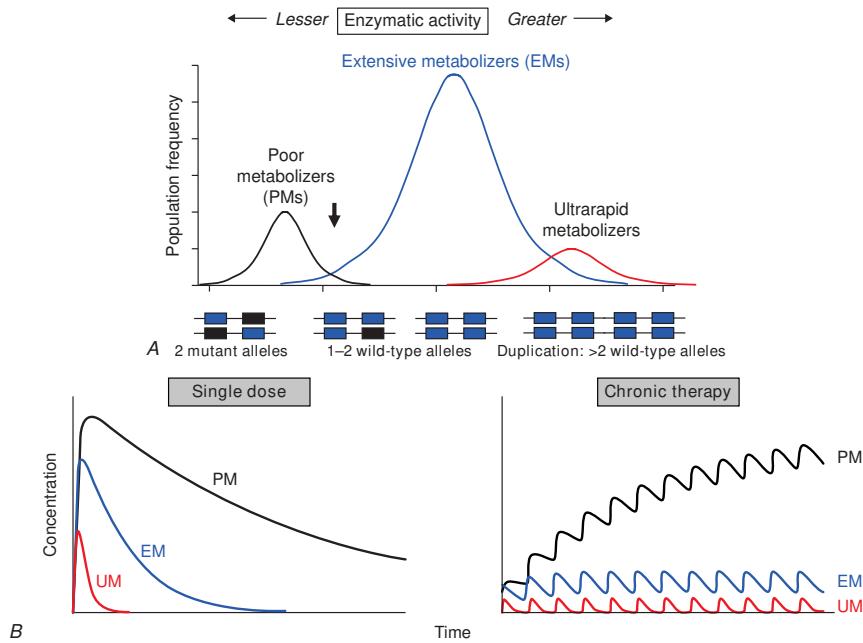
**Candidate Gene Approaches** Most studies to date have used an understanding of the molecular mechanisms modulating drug action to identify candidate genes in which variants could explain variable drug responses. One very common scenario is that variable drug actions can be attributed to variability in plasma drug concentrations. When plasma drug concentrations vary widely (e.g., more than an order of magnitude), especially if their distribution is non-unimodal as in Fig. 68-1, variants in single genes controlling drug concentrations often contribute. In this case, the most obvious candidate genes are those responsible for drug metabolism and elimination. Other candidate genes are those encoding the target molecules with which drugs interact to produce their effects or molecules modulating that response, including those involved in disease pathogenesis.

**Genome-Wide Association Studies** The field has also had some success with “unbiased” approaches such as genome-wide association (GWA) (Chap. 466), particularly in identifying single variants associated with high risk for certain forms of drug toxicity, and in validating the results of candidate gene studies. GWA studies have identified variants in the HLA locus that are associated with high risk for severe skin rashes during treatment with the anticonvulsant carbamazepine and hepatotoxicity with flucloxacillin, an antibiotic never marketed in the United States. A GWA study of simvastatin-associated myopathy

identified a single noncoding SNP in *SLCO1B1*, encoding OATP1B1, a drug transporter known to modulate simvastatin uptake into the liver, which accounts for 60% of myopathy risk. African-American subjects are known to have higher dose requirements to achieve stable anticoagulation with warfarin, due in part to variations in *CYP2C9* and *VKORC1*, discussed below. In addition, a GWA study identified novel SNPs near *CYP2C9* that contribute to this effect in African Americans.

## ■ GENETIC VARIANTS AFFECTING PHARMACOKINETICS

Clinically important genetic variants have been described in multiple molecular pathways of drug disposition (Table 68-2). A distinct multimodal distribution of drug disposition (as shown in Fig. 68-1) argues for a predominant effect of variants in a single gene in the metabolism of that substrate. Individuals with two alleles (variants) encoding for nonfunctional protein make up one group, often termed *poor metabolizers* (PM phenotype). For most genes, many variants can produce such a loss of function, and assessing whether they are on the same or different alleles (i.e., the *diplotype*) can complicate the use of genotyping in clinical practice. Furthermore, some variants produce only partial loss of function, and the presence of more than one variant may be required to define a specific allele. Individuals with one functional allele, or multiple reduction of function alleles, make up a second group (*intermediate metabolizers*) and may or may not be distinguishable from those with two functional alleles (normal metabolizers, sometimes termed *extensive metabolizers*, EMs). *Ultra-rapid metabolizers* (UMs) with especially high enzymatic activity (occasionally due



**FIGURE 68-1** A. Distribution of CYP2D6 metabolic activity across a population. The heavy arrow indicates an antimode, separating poor metabolizer subjects (PMs, black), with two loss-of-function CYP2D6 alleles (black), indicated by the intron-exon structures below the chart. Individuals with one or two functional alleles are grouped together as extensive metabolizers (EMs, blue). Also shown are ultra-rapid metabolizers (UMs, red), with 2–12 functional copies of the gene, displaying the greatest enzyme activity. (Adapted from M-L Dahl et al: *J Pharmacol Exp Ther* 274:516, 1995.) B. These simulations show the predicted effects of CYP2D6 genotype on disposition of a substrate drug. With a single dose (left), there is an inverse “gene-dose” relationship between the number of active alleles and the areas under the time-concentration curves (smallest in UM subjects; highest in PM subjects); this indicates that clearance is greatest in UM subjects. In addition, elimination half-life is longest in PM subjects. The right panel shows that these single-dose differences are exaggerated during chronic therapy: steady-state concentration is much higher in PM subjects (decreased clearance), as is the time required to achieve steady state (longer elimination half-life).

**TABLE 68-2 Genetic Variants and Drug Responses**

GENE	DRUGS	EFFECT OF GENETIC VARIANTS <sup>a</sup>
<b>Variants in Drug Metabolism Pathways</b>		
<i>CYP2C9</i>	Losartan Warfarin Phenytoin	Decreased bioactivation and effects (PMs) Decreased dose requirements; possible increased bleeding risk (PMs) Decreased dose requirement (PMs)
<i>CYP2C19</i>	Omeprazole, voriconazole Celecoxib Clopidogrel Citalopram, escitalopram	Decreased effect in EMs Exaggerated effect in PMs Decreased effect in PMs and IMs Consider alternate drug in PMs and alternate drug or dose increase in IMs Possible increased bleeding risk in carriers of gain-of-function variants
<i>CYP2D6</i>	Codeine, tamoxifen Codeine Tricyclic antidepressants <sup>b</sup> Metoprolol, carvedilol, timolol, propranolol Fluvoxamine	Decreased bioactivation and drug effects in PMs Respiratory depression in UMs Increased adverse effects in PMs: Consider dose decrease Decreased therapeutic effects in UMs: Consider alternate drug Increased beta blockade in PMs Reduce dose or chose alternate drug in PMs
<i>CYP3A5</i>	Tacrolimus, vincristine	Decreased drug concentrations and effect (CYP3A5*3 carriers)
Dihydropyrimidine dehydrogenase ( <i>DYPD</i> )	Capecitabine, 5-fluorouracil, tegafur	Possible severe toxicity (PMs)
NAT2	Rifampin, isoniazid, pyrazinamide, hydralazine, procainamide	Increased risk of toxicity in PMs
Thiopurine S-methyltransferase ( <i>TPMT</i> )	Azathioprine, 6-mercaptopurine, thioguanine	PMs: Increased risk of bone marrow aplasia EMs: Possible decreased drug action at usual dosages
Uridine diphosphate glucuronosyltransferase ( <i>UGT1A1</i> )	Irinotecan Atazanavir	PM homozygotes: Increased risk of severe adverse effects (diarrhea, bone marrow aplasia) High risk of hyperbilirubinemia during treatment; can result in drug discontinuation
Pseudocholinesterase ( <i>BCHE</i> )	Succinylcholine and other muscle relaxants	Prolonged paralysis (autosomal recessive); diagnosis established by genotyping or by measuring serum cholinesterase activity

(Continued)

TABLE 68-2 Genetic Variants and Drug Responses (Continued)

GENE	DRUGS	EFFECT OF GENETIC VARIANTS <sup>a</sup>
<b>Variants in Other Genes</b>		
Glucose 6-phosphate dehydrogenase (G6PD)	Rasburicase, primaquine, chloroquine	Increased risk of hemolytic anemia in G6PD-deficient subjects
HLA-B*15:02	Carbamazepine	Carriers (1 or 2 alleles) at increased risk of SJS/TEN (mainly Asian subjects)
HLA-B*31:01	Carbamazepine	Carriers (1 or 2 alleles) at increased risk of SJS/TEN and milder skin toxicities (Caucasian and Asian subjects)
HLA-B*15:02	Phenytoin	Carriers (1 or 2 alleles) at increased risk of SJS/TEN
HLA-B*57:01	Abacavir	Carriers (1 or 2 alleles) at increased risk of SJS/TEN
HLA-B*58:01	Allopurinol	Carriers (1 or 2 alleles) at increased risk of SJS/TEN
IFNL3 (IL28B)	Interferon	Variable response in hepatitis C therapy
SLCO1B1	Simvastatin	Encodes a drug uptake transporter; variant nonsynonymous single nucleotide polymorphism increases myopathy risk especially at higher dosages
VKORC1	Warfarin	Decreased dose requirements with variant promoter haplotype Increased dose requirement in individuals with nonsynonymous loss-of-function variants
ITPA	Ribavirin	Variants modulate risk for hemolytic anemia
RYR1	General anesthetics	Variants predispose to malignant hyperthermia
CFTR	Ivacafitor, lumacaftor	Targeted therapies for cystic fibrosis indicated only in certain genotypes
<b>Variants in Other Genomes (Infectious Agents, Tumors)</b>		
Chemokine C-C motif receptor (CCR5)	Maraviroc	Drug effective only in HIV strains with CCR5 detectable
C-KIT	Imatinib	In gastrointestinal stromal tumors, drug indicated only with c-kit-positive cases
ALK (anaplastic lymphoma kinase)	Crizotinib	Indicated in patients with non-small cell lung cancer and ALK mutations
Her2/neu overexpression	Trastuzumab, lapatinib	Drugs indicated only with tumor overexpression
K-ras mutation	Panitumumab, cetuximab	Lack of efficacy with KRAS mutation
Philadelphia chromosome	Dasatinib, nilotinib, imatinib	Decreased efficacy in Philadelphia chromosome-negative chronic myelogenous leukemia

<sup>a</sup>Drug effect in homozygotes unless otherwise specified. <sup>b</sup>Many tricyclic antidepressants and selective serotonin uptake inhibitors are metabolized by CYP2D6, CYP2C19, or both, and some metabolites have pharmacologic activity. See <https://www.pharmgkb.org/view/dosing-guidelines.do>.

**Abbreviations:** EM, extensive metabolizer (normal enzymatic activity); IM, intermediate metabolizer (heterozygote for loss-of-function allele); PM, poor metabolizer (homozygote for reduced or loss-of-function allele); SJS/TEN, Stevens-Johnson syndrome/toxic epidermal necrolysis; UM, ultra-rapid metabolizer (enzymatic activity much greater than normal, e.g., with gene duplication, Fig. 68-1).

Further data at:

U.S. Food and Drug Administration: <http://www.fda.gov/Drugs/ScienceResearch/ResearchAreas/Pharmacogenetics/ucm083378.htm>

Pharmacogenetics Research Network/Knowledge Base: <http://www.pharmgkb.org>

The Clinical Pharmacogenomics Implementation Consortium: <https://www.pharmgkb.org/page/cpic>

Dutch Pharmacogenetics Working Group: <https://www.knmp.nl/patientenzorg/medicatiebewaking/farmacogenetica/pharmacogenetics-1/pharmacogenetics>

to gene duplication; Table 68-1 and Fig. 68-1) have also been described for some traits. Many drugs in widespread use can inhibit specific drug disposition pathways (see Chap. 67, Table 67-1), and so EM individuals receiving such inhibitors can respond like PM patients (*phenocopying*). Polymorphisms in genes encoding drug uptake or drug efflux transporters may be other contributors to variability in drug delivery to target sites and, hence, in drug effects.

**CYP3A** Members of the CYP3A family (*CYP3A4*, *CYP3A5*) metabolize the greatest number of drugs in therapeutic use. CYP3A4 activity is highly variable (up to an order of magnitude) among individuals, but nonsynonymous coding region polymorphisms (those that change the encoded amino acid) are rare. Thus, the underlying mechanism likely reflects genetic variation in regulatory regions.

Most subjects of European or Asian origin carry a polymorphism that disrupts splicing in the closely related *CYP3A5* gene. As a result, these individuals display reduced CYP3A5 activity, whereas CYP3A5 activity tends to be greater in subjects of African origin. Decreased efficacy of the antirejection agent tacrolimus in subjects of African origin has been attributed to more rapid CYP3A5-mediated elimination, and a lower risk of vincristine-associated neuropathy has been reported in CYP3A5 “expressers.”

**CYP2D6** CYP2D6 is second to CYP3A4 in the number of commonly used drugs that it metabolizes. CYP2D6 activity is polymorphically distributed, and 5–10% of European- and African-derived populations

(but few Asians) display the PM phenotype (Fig. 68-1). Dozens of loss-of-function variants in *CYP2D6* have been described; the PM phenotype arises in individuals with two such alleles. In addition, UMs with multiple functional copies of *CYP2D6* have been identified especially in East Africa, the Middle East, and Oceania. PMs have slower elimination rates and lower clearance of substrate drugs; as a consequence (Fig. 68-1B), steady-state concentrations are higher and the time taken to achieve steady state is longer than in EMs (Chap. 67). Conversely, UMs display very low steady-state parent drug concentrations and an abbreviated time to steady state.

Codeine is biotransformed by CYP2D6 to the potent active metabolite morphine, so its effects are blunted in PMs and exaggerated in UMs. Deaths due to respiratory depression in children given codeine after tonsillectomy have been attributed to the UM trait, and the U.S. Food and Drug Administration (FDA) has revised the package insert to include a prominent “black box” warning against its use in this setting, and, in fact, forbidding its use in children less than 12 years old. In the case of drugs with beta-blocking properties metabolized by CYP2D6, greater signs of beta blockade (e.g., bronchospasm, bradycardia) have been reported in PM subjects than in EMs. This can be seen not only with orally administered beta blockers such as metoprolol and carvedilol, but also with ophthalmic timolol and with the sodium channel-blocking antiarrhythmic propafenone, a CYP2D6 substrate with beta-blocking properties. UMs may require very high dosages of nortriptyline and other tricyclic antidepressants to achieve a therapeutic

effect. Tamoxifen undergoes CYP2D6-mediated biotransformation to an active metabolite, so its efficacy may be in part related to this polymorphism. In addition, the widespread use of selective serotonin reuptake inhibitors (SSRIs) to treat tamoxifen-related hot flashes may also alter the drug's effects because many SSRIs, notably fluoxetine and paroxetine, are also CYP2D6 inhibitors (Table 67-2).

**CYP2C19** The PM phenotype for CYP2C19 is common (20%) among Asians and rarer (2–3%) in other populations; the frequency of the PM trait is especially high (>50%) in Oceania. The impact of polymorphic CYP2C19-mediated metabolism has been demonstrated with the proton pump inhibitor omeprazole, where ulcer cure rates with "standard" dosages were much lower in EM patients (29%) than in PMs (100%). Thus, understanding the importance of this polymorphism would have been important in developing the drug, and knowing a patient's *CYP2C19* genotype could improve therapy. CYP2C19 is responsible for bioactivation of the antiplatelet drug clopidogrel, and several large retrospective, and more recently prospective, studies have documented decreased efficacy (e.g., increased myocardial infarction after placement of coronary stents or increased stroke or transient ischemic attacks) among subjects with one or two reductions of function alleles. In addition, some studies suggest that omeprazole and possibly other proton pump inhibitors phenocopy this effect by inhibiting CYP2C19.

**CYP2C9** There are common variants in *CYP2C9* that encode proteins with reduction or loss of catalytic function. These variant alleles are associated with increased rates of neurologic complications with phenytoin, hypoglycemia with glipizide, and reduced warfarin dose required to maintain stable anticoagulation. Rare patients homozygous for loss-of-function alleles may require very low warfarin dosages. Up to 50% of the variability in steady-state warfarin dose requirement is attributable to polymorphisms in *CYP2C9* and in the promoter of *VKORC1*, which encodes the warfarin target with lesser contributions by genes such as *CYP4F2* controlling vitamin K metabolism. The angiotensin receptor blocker losartan is a prodrug that is bioactivated by CYP2C9; as a result, PMs and those receiving inhibitor drugs may display little response to therapy.

**DPYD** Individuals homozygous for loss-of-function alleles in dihydropyrimidine dehydrogenase, encoded by *DPYD*, are at increased risk for severe toxicity when exposed to the substrate anticancer drug 5-fluorouracil (5-FU), as well as to capecitabine and tegafur, which are metabolized to 5-FU. Dose reductions have been recommended in intermediate metabolizers.

**Transferase Variants** Thiopurine S-methyltransferase (TPMT) bioactivates the antileukemic drug 6-mercaptopurine (6-MP), and 6-MP is itself an active metabolite of the immunosuppressive azathioprine. Homozygotes for alleles encoding inactive TPMT (1/300 individuals) predictably exhibit severe and potentially fatal pancytopenia on standard doses of azathioprine or 6-MP. On the other hand, homozygotes for fully functional alleles may display less anti-inflammatory or antileukemic effect with standard doses of the drugs. GWA studies have also identified loss-of-function variants in *NUDT15* that reduce degradation of thiopurine metabolites and, thereby, also increase risk of excessive myelosuppression.

*N*-acetylation is accomplished by hepatic *N*-acetyl transferase (NAT), which represents the activity of two genes, *NAT1* and *NAT2*. Both enzymes transfer an acetyl group from acetyl coenzyme A to the drug; polymorphisms in *NAT2* are thought to underlie individual differences in the rate at which drugs are acetylated and thus define "rapid acetylators" and "slow acetylators." Slow acetylators make up 50% of European and African populations but are less common among East Asians. Slow acetylators have an increased incidence of the drug-induced lupus syndrome during procainamide and hydralazine therapy and of hepatitis with isoniazid.

Individuals homozygous for a common promoter polymorphism that reduces transcription of uridine diphosphate glucuronosyltransferase (*UGT1A1*) have benign hyperbilirubinemia (Gilbert's syndrome;

Chap. 337). This variant has also been associated with diarrhea and increased bone marrow depression with the antineoplastic prodrug irinotecan, whose active metabolite is normally detoxified by UGT1A1-mediated glucuronidation. The antiretroviral atazanavir is a UGT1A1 inhibitor, and individuals with the Gilbert's variant develop higher bilirubin levels during treatment. While this is benign, the hyperbilirubinemia can complicate clinical care because it may raise the question of whether coexistent hepatic injury is present.

**Transporter Variants** The risk for myotoxicity with simvastatin and possibly other statins appears increased with variants in *SLCO1B1*. Variants in *ABCB1*, encoding the drug efflux transporter P-glycoprotein, may increase digoxin toxicity. Variants in the uptake transporters *MATE1* and *MATE2* have been reported to modulate metformin's glucose-lowering activity.

## ■ GENETIC VARIANTS AFFECTING PHARMACODYNAMICS

A variant in the *VKORC1* promoter, especially common in Asian subjects (Table 68-1), reduces transcriptional activity and warfarin dose requirement. Multiple polymorphisms identified in the  $\beta_2$ -adrenergic receptor appear to be linked to specific drug responses in asthma and congestive heart failure, diseases in which  $\beta_2$ -receptor function might be expected to determine drug response. Polymorphisms in the  $\beta_2$ -receptor gene have also been associated with response to inhaled  $\beta_2$ -receptor agonists, while those in the  $\beta_1$ -adrenergic receptor gene have been associated with variability in heart rate slowing and blood pressure lowering. In addition, in heart failure, the arginine allele of the common  $\beta_1$ -adrenergic receptor gene polymorphism R389G has been associated with decreased mortality and decreased incidence of atrial fibrillation during treatment with the investigational beta blocker bucindolol.

Drugs may also interact with genetic pathways of disease to elicit or exacerbate symptoms of the underlying conditions. In the porphyrias, CYP inducers are thought to increase the activity of enzymes proximal to the deficient enzyme, exacerbating or triggering attacks (Chap. 416). Deficiency of glucose-6-phosphate dehydrogenase (G6PD), most often in individuals of African, Mediterranean, or South Asian descent, increases the risk of hemolytic anemia in response to the antimalarial primaquine (Chap. 100) and the uric acid-lowering agent rasburicase, which does not cause hemolysis in patients with normal amounts of the enzyme. Patients with mutations in *RYR1* encoding the skeletal muscle intracellular release calcium (also termed type 1 ryanodine receptor) are asymptomatic until exposed to certain general anesthetics, which can trigger the rare syndrome of malignant hyperthermia. Certain antiarrhythmics and other drugs can produce marked QT prolongation and torsades de pointes (Chap. 246), and in a minority of affected patients, this adverse effect represents unmasking of previously subclinical congenital long QT syndrome.

**Immunologically Mediated Drug Reactions** The Stevens-Johnson syndrome/toxic epidermal necrolysis (SJS/TEN) is a potentially fatal skin and systemic reaction now increasingly recognized to be linked to specific HLA alleles (Table 68-2). Cases of drug-induced hepatotoxicity and of the drug rash with eosinophilia and systemic symptoms (DRESS) syndrome have also been linked to variants in this region. The frequency of risk alleles often varies by ancestry (Table 68-1). The HLA risk alleles appear to be necessary but not sufficient to elicit these reactions. For example, HLA-B 57:01 is a risk allele for abacavir-related SJS/TEN and flucloxacillin-related hepatotoxicity. However, while 55% of abacavir-exposed subjects will develop a reaction, only 1/10,000 subjects exposed to flucloxacillin develop hepatotoxicity. Thus, a third factor, the nature of which has not yet been established, seems necessary.

**Tumor and Infectious Agent Genomes** The actions of drugs used to treat infectious or neoplastic disease may be modulated by variants in these nonhuman germline genomes. Genotyping tumors is a rapidly evolving approach to target therapies to underlying mechanisms and to avoid potentially toxic therapy in patients who would derive

no benefit (Chap. 71). Trastuzumab, which potentiates anthracycline-related cardiotoxicity, is ineffective in breast cancers that do not express the Herceptin receptor. Imatinib targets a specific tyrosine kinase, BCR-Abl1, that is generated by the translocation that creates the Philadelphia chromosome typical of chronic myelogenous leukemia (CML). Imatinib is also an inhibitor of another kinase, c-kit, and the drug is remarkably effective in c-kit-driven cancer, such as gastrointestinal stromal tumors (Chap. 71). Vemurafenib does not inhibit wild-type *BRAF* but is active against the V600E mutant form of the kinase. Crizotinib is highly effective in non-small cell lung cancers harboring anaplastic lymphoma kinase (ALK) mutations.

## ■ INCORPORATING PHARMACOGENETIC INFORMATION INTO CLINICAL PRACTICE

The discovery of common variant alleles with relatively large effects on drug response raises the prospect that these variants could be used to guide therapy. Desired outcomes could be better ways of choosing likely effective drugs and dosages, or avoiding drugs that are likely to produce severe adverse drug events or be ineffective in individual subjects. Indeed, the FDA now incorporates pharmacogenetic data into package inserts meant to guide prescribing. A decision to adopt pharmacogenetically guided dosing for a given drug depends on multiple factors. The most important are the magnitude and clinical importance of the genetic effect and the strength of evidence linking genetic variation to variable drug effects (e.g., anecdote versus post-hoc analysis of clinical trial data versus randomized clinical trial [RCT]). The evidence can be strengthened if statistical arguments from clinical trial data are complemented by an understanding of underlying physiologic mechanisms. Cost versus expected benefit may also be a factor.

**Point of Care Versus Preemptive Approaches** Two approaches to pharmacogenetic implementation have been put in place at “early adopter” institutions and are currently being evaluated. In the first, variant-specific assays are ordered at the time of drug prescription and delivered rapidly (often within an hour or two), and the results are then used to guide therapy with that specific drug. The alternative to this “point-of-care” approach is a “preemptive” approach in which pharmacogenetic testing for large numbers of potential variants across many drugs is undertaken prior to prescription of any such drug. The data are then available in electronic health record (EHR) systems and coupled to real-time clinical decision support (CDS). When a drug whose effects are known to be influenced by pharmacogenetic variants is prescribed, the EHR system looks up whether variants likely to affect response are present; if so, CDS will alert health care providers that an alternate drug or a different dose may be required.

**Challenges** There are multiple challenges in putting in place either system. Assay validity and reproducibility have been issues in the past, but are less likely now. National consortia are now being put in place to develop standards for pharmacogenetic CDS. While common variants in genes such as those listed in Table 68-1 have been clearly associated with variable drug responses, the effect of rare variants, now readily discoverable by large-scale sequencing, is unknown. The extent to which a dose adjustment might be recommended may vary depending on whether zero, one, or two variant alleles are present, and whether such variants are reduction of function, loss of function, or gain of function. The Clinical Pharmacogenetics Implementation Consortium (CPIC) and the Dutch Pharmacogenetics Working Group have developed and published guidelines for multiple drug-gene pairs focusing on the question of what might be an appropriate drug dose adjustment given the availability of genetic data. These resources do not directly address the question of when or how such genetic testing should be undertaken.

**Developing Evidence That Pharmacogenetic Testing Alters Drug Outcomes** A major issue is whether pharmacogenetic testing affects important drug response outcomes. When the evidence is compelling, alternate therapies are not available, and there are clear recommendations for dosage adjustment in subjects with variants, there is a strong argument for deploying genetic testing as a guide to

prescribing; HLA-B 57:01 testing for abacavir is an example described below. In other situations, the arguments are less compelling: the magnitude of the genetic effect may be smaller, the consequences may be less serious, alternate therapies may be available, or the drug effect may be amenable to monitoring by other approaches.

One school argues that the physiology and pharmacology are known and that RCTs are, therefore, unnecessary (and conceivably unethical). The analogy is sometimes drawn to well-recognized dose adjustment of renally excreted drugs in the presence of renal dysfunction. RCTs have not been conducted and the idea of such dose adjustment is well accepted in the medical community and recommended in FDA-approved drug labels. Others have argued that the effect of genetic variants is generally modest and variability in drug actions has many nongenetic sources, so genetic testing might provide marginal benefit at best.

Efforts to demonstrate the value of pharmacogenetic testing have met with mixed results. An RCT clearly showed that HLA-B 57:01 testing eliminates SJS/TEN due to abacavir. Similarly, regulatory authorities in some countries in Southeast Asia mandated HLA-B 15:02 testing prior to initiation of carbamazepine; however, in this case, an unfortunate outcome in some jurisdictions was that prescribers stopped using carbamazepine, often substituting phenytoin (another drug associated with SJS/TEN), so the incidence of the severe ADR was unchanged.

RCTs evaluating the effect of using pharmacogenetically guided therapy to optimize warfarin treatment have shown either no effect or a modest benefit of incorporating genetic information into prescribing the drug. Initial RCTs focused on time in therapeutic range in the first 4–12 weeks of treatment, whereas one more recent trial demonstrated that genotype-guided therapy could reduce the frequency of over-anticoagulation. Retrospective analyses of bleeding cases versus non-bleeding controls in EHRs and administrative databases have suggested a role for CYP2C9 3 or for the V433M variant in *CYP4F2* in mediating this risk.

Two large trials have randomized patients with acute coronary syndromes to newer antiplatelet therapies (ticagrelor or prasugrel) or clopidogrel if *CYP2C19* variants were absent; in one, clopidogrel was superior, and in the second, a trend in the same direction, which did not reach the prespecified endpoint, was observed.

New effective alternate therapies to warfarin and clopidogrel that appear to lack important pharmacogenetic variants have emerged. One approach to therapy, therefore, is to use pharmacogenetic testing to identify subjects in whom variants are absent and therefore standard doses of the conventional inexpensive drugs are likely to be effective and to reserve alternate more expensive therapies for subjects likely to have variant responses to warfarin or clopidogrel.

## ■ GENETICS AND DRUG DEVELOPMENT

Genetic tools are now being increasingly used to identify or validate new drug targets. Initial studies suggest that a new drug development program is more likely to succeed if evidence from human genetics supports the role of a possible drug target in disease pathogenesis and suggests that the risk of toxicity due to high-risk pharmacokinetics or other mechanisms is small. Furthermore, studies of the relationships between variants in genes encoding drug target molecules and a range of phenotypes (e.g., those in EHRs) are being used for drug “repurposing,” identifying new indications for existing drugs.

**Finding Protective Alleles Can Identify Drug Targets** One example of using genetics to identify a new drug target started with the discovery that very rare gain-of-function variants in *PCSK9* are a rare cause of familial hypercholesterolemia. Subsequently, population studies showed that carriers of loss-of-function SNPs (2.5% of African Americans) had decreased low-density lipoprotein cholesterol, decreased incidence of coronary artery disease, and no deleterious consequences in other organ systems. These data triggered the development of PCSK9 monoclonal antibodies, which were marketed <10 years after the initial population studies. Other targets implicated by similar population genetic studies include HSD17B13 for

prevention of chronic liver disease, SLC30A8 for the prevention of type 2 diabetes, and APOC3 for hypertriglyceridemia. Discovering rare protective alleles may require very large data sets (>100,000), such as EHR systems coupled to DNA biobanks or epidemiologic cohorts like the UK Biobank.

**Cancer** In cancer, tumor sequencing has identified new targets for drug development, often constitutively active kinases. A problem in this area has been the rapid emergence of drug resistance, often after extraordinary initial responses. For example, 40% of melanomas appear to be driven by the V600E mutant form of *BRAF*, and the specific inhibitor vemurafenib can produce clinically spectacular remission. However, durable responses are rare, and it is now apparent that combination therapy, often with inhibitors of the MEK pathway, can provide improved therapy. Another approach that is rapidly gaining wide use in cancer involves drugs that reverse immune system inhibition ([Chap. 73](#)). In some patients, the release of this “brake” can provide durable remissions, whereas in others, severe adverse events, including colitis, pneumonitis, and myocarditis, have been reported. Understanding the mechanisms underlying variability to these therapies is a major emerging challenge in the field.

**Using Multiple Data Types** The development of methods to understand associations across multiple large data sets is another approach that is being explored in drug development. For example, a GWA study of risk of rheumatoid arthritis identified multiple risk loci, and many encode proteins that are known targets for intervention in the disease. Interestingly, others encode proteins that are targets for drugs used in other conditions, such as certain cancers, raising the question of whether such drugs could be “repurposed” for rheumatoid arthritis.

While the field has, to date, focused on individual high effect size variants (that are often common in a population), newer approaches combining many (dozens to millions) common variants into polygenic risk scores to predict drug responses are also being explored. An extension of this approach is the broader issue of systems pharmacology, in which multiple sources of data are used to identify potential molecules or pathways that would be amenable to treatment, by new

drugs or by existing agents, using analysis of genomic, transcriptomic, proteomic, and other large data sets. Similar approaches are being developed to predict toxicity expected from targeting specific genes or disease pathways.

## SUMMARY

The science of pharmacogenomics has evolved from isolated examples of rare adverse drug actions to a more comprehensive view of the role of genetic variation in mediating the effects of most drugs. Current principles include:

- Genetic variants with an important effect on drug actions can be common, and their frequencies often vary by ancestry.
- One common mechanism is modulation of drug concentrations.
- No practitioner can be expected to remember all variants important for all drugs. Electronic data systems can now be accessed to describe this information. Ultimately, this information will be used by linking individual pharmacogenetic data to smart EHR systems.
- Incorporating genetic approaches into drug development projects holds the promise of more rapid development of targeted, safe, and effective therapies.

## FURTHER READING

- C MJ et al: Global pharmacogenomics within precision medicine: Challenges and opportunities. *Clin Pharmacol Ther* 107:57, 2020.
- D D et al: Phenome-wide association studies across large population cohorts support drug target validation. *Nat Commun* 9:4285, 2018.
- L JA et al: The Pharmacogenomics Research Network Translational Pharmacogenetics Program: Outcomes and metrics of pharmacogenetic implementations across diverse healthcare systems. *Clin Pharmacol Ther* 102:502, 2017.
- O O et al: Pharmacogenetics of adverse drug reactions. *Adv Pharmacol* 83:155, 2018.
- R MV et al: The clinical pharmacogenetics implementation consortium: 10 years later. *Clin Pharmacol Ther* 107:171, 2020.
- R DM et al: Pharmacogenomics. *Lancet* 394:521, 2019.