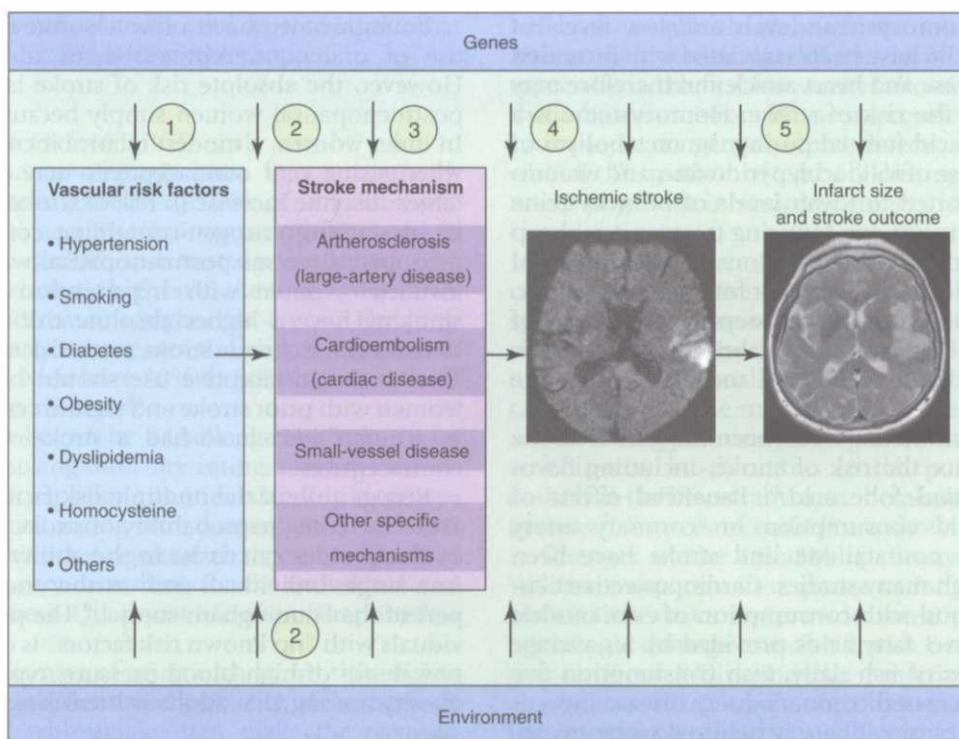
**Figure 32-2**

Percentage of strokes caused by different etiologies. (Reprinted from Townsend CM: *Sabiston textbook of surgery*, ed 17, Philadelphia, 2004, Saunders.)

**Figure 32-3**

Genetic factors and ischemic stroke. Genetic factors may affect stroke risk at various levels. They could act through conventional risk factors (1), interact with conventional and environmental risk factors (2), or contribute directly to an established stroke mechanism such as atherosclerosis or small-vessel disease (3). Genetic factors could further affect the latency to stroke (4) or infarct size and stroke outcome (5). Similarly, environmental factors and interactions between genes and the environment could occur at various levels. (Reprinted from Dichgans M: Genetics of ischaemic stroke, *Lancet Neurol* 6(2):149-161, 2007.)

increased fibrin deposition or increased blood viscosity include rheumatic heart disease, endocarditis, atherosclerosis, polycythemia, and thrombocytosis.

Leukemia is complicated occasionally by brain hemorrhages and microinfarcts. When the white blood cell count is very high (increased leukocrit), the white blood cells can pack capillaries, leading to microinfarcts and vascular rupture with small hemorrhages in the brain. Larger intraparenchymatous hemorrhages and subarachnoid hemorrhages (SAHs) are most often related to thrombocytopenia because of replacement of the bone marrow with leukocyte precursors.²⁷

Diabetes mellitus, a common endocrine disorder, has long been established as a risk factor for stroke. Diabetes is known to cause large artery atherosclerosis, increased cholesterol levels, and plaque formation. The vasodilatory ability of the cerebral arterioles is reduced in long-standing type 2 diabetes.⁴⁷

Cholesterol has long been considered a part of the stroke risk profile; however, the relation between raised lipid level and stroke remains unclear.⁹⁴ High total cholesterol levels create increased risk of ischemic stroke. These include the large artery and lacunar subtypes that have atherosclerotic pathogeneses. Younger individuals and those with low high-density lipoprotein levels are at greater risk; higher levels of high-density lipoprotein cholesterol are associated with decreased risk of ischemic stroke. Low-density lipoprotein cholesterol levels currently are believed to be biochemical predictors of coronary artery disease associated with carotid atherosclerosis.⁹⁹

High plasma homocysteine levels and low levels of folate and vitamin B6 have been associated with increased risk of carotid disease and heart attack and therefore may have an effect on the risk of stroke. Homocysteine is a sulfur-containing acid formed during the metabolism of methionine. The use of folic acid, pyridoxine, and vitamin B12 has been reported to lower levels of homocysteine in the blood. Homocysteine-lowering treatment is cheap and well tolerated; it has been considered a rational approach in individuals at high risk for stroke. However, the strength of association of homocysteine with risk of cardiovascular disease may be weaker than had previously been believed. Clearly more studies are warranted.³

A number of nutrients have been suggested to be important to reduce the risk of stroke, including flavonoids, carotene, and folic acid.²⁰ Beneficial effects of omega-3 fatty acid consumption on coronary artery disease, fatal and nonfatal MI, and stroke have been determined through many studies. Cardioprotective benefits have been found with consumption of even modest amounts of omega-3 fatty acids provided by an average intake of 1 to 2 oz of fish daily. Fish consumption five times per week decreased coronary artery disease mortality by 38%. Magnesium sulfate is believed to be neuroprotective, and extensive study has been done on its potential ability to preserve function if given within 8 hours of the onset of stroke. The results of these studies have not shown significant protection to this point.⁷⁸

Significant obesity, particularly abdominal adiposity, worsens the prognosis of individuals with coronary

disease. The protective effect of physical activity may be related to its role in controlling other risk factors such as hypertension, diabetes mellitus, and obesity. Reductions in plasma fibrinogens levels and platelet activity with corresponding increases in high-density platelet concentrations also are believed to add to the benefit. The beneficial effect of physical activity appears to be more apparent for men than women.

Cigarette smoking increases the risk of stroke by approximately 50%; the risk is directly related to the number of cigarettes smoked per day. Alcohol consumption has a direct dose-dependent effect on the risk of stroke. Three or more alcoholic drinks per day increase risk by 45%. Heavy consumption of alcohol—more than 14 drinks per week or more than four drinks per occasion in men and more than seven drinks per week or more than three drinks per occasion in women—causes increased risk through hypertension, hypercoagulable states, arrhythmia, and decreased cerebral blood flow. Evidence suggests that light to moderate drinking may have beneficial effects by increasing high-density lipoprotein cholesterol levels and decreasing platelet aggregation and fibrinogen levels, with a 32% decrease in risk.

Cocaine use is associated with hemorrhagic stroke by increased risk related to focal arterial vasoconstriction and occasionally to inflammatory vasculitis. Although the evidence remains inconclusive, other recreational drugs such as lysergic acid diethylamide (LSD) and marijuana are believed to increase the risk. Some concern exists regarding the use of over-the-counter cold medications, diet pills, ephedrine, and pseudoephedrine.

Young women have a low absolute risk of stroke, and use of oral contraceptives seems to be insignificant. However, the absolute risk of stroke is much greater in postmenopausal women simply because they are older. In older women, a modest relative increase in stroke risk when using oral contraceptives may produce a much larger absolute increase in risk of stroke. Thus differences in prescribing estrogen-containing compounds to premenopausal versus postmenopausal women appears be justified. Women with hypertension or a history of smoking have a higher absolute risk. Individuals who have had an ischemic stroke are at risk of a second stroke. Thus oral contraceptive use should be discouraged in women with prior stroke and should certainly be stopped in women who have had a stroke while taking oral contraceptives.

Recognition of the multiple risk factors that can interact to increase the probability of stroke is important. Use of risk profiles can assist in the ability to predict stroke in a single individual, such as the one established as a part of the Framingham study.¹¹⁰ The percentage of individuals with "no known risk factors" is declining, and the prevalence of high blood pressure, type 2 diabetes, and obesity among U.S. adults is increasing.

Clinical Manifestations

The first indication of the onset of stroke may be transient with focal symptoms, but it is the first warning that a stroke is about to occur. Early warning signs are listed in Box 32-1. Although the risk factors and early warning signs have been well publicized, individuals at highest

Box 32-1**WARNING SIGNS OF STROKE**

- Sudden weakness or numbness of the face, arm, or leg
- Sudden dimness or loss of vision, particularly in one eye
- Sudden difficulty speaking or understanding speech
- Sudden severe headache with no known cause
- Unexplained dizziness, unsteadiness, or sudden falls

Box 32-2**ABCD PREDICTS PROGRESSION OF STROKE**

- **Age:** 1 point for being over 60 years old
- **Blood pressure:** 1 point for systolic blood pressure above 140 mm Hg or diastolic pressure above 90 mm Hg
- **Clinical features:** 2 points for weakness on one side of the body; 1 point for speech trouble but no weakness
- **Duration:** 2 points for symptoms lasting longer than 60 minutes and 1 point for symptoms lasting less than 60 minutes
- Predictive value for stroke within 7 days: 0 to 4, 4% chance; 5, 12% chance; 6, 32% chance

Modified from Rothwell PM: A simple score (ABCD) to identify individuals at high early risk of stroke after transient ischaemic attack, *Lancet* 366(9479):29-36, 2005

risk do not appear to be aware of warning signs and may not consult a physician when the symptoms occur. Clinical manifestations are related to the type of stroke that occurs and are addressed later in the chapter.

Prognosis

The University of Oxford ABCD scale can be used to determine the chance of progression to a stroke with greater consequences (Box 32-2). Risk of second stroke varies between 3% and 5% in 5 years and is related to the concomitant cardiac and vascular disorders. The recurrence rate of stroke is highest in the first 30 days after the first stroke and remains higher for 1 year. The presence of atherosclerosis increases the chance of another thrombotic event. Men have 30% to 80% higher rates of recurrence than do women.⁸⁴

Living with stroke can be a challenge, with the onset of impairments causing difficulty eating, urinary incontinence, and difficulty speaking or understanding language. Hemiparesis remains a long-term consequence in almost half of stroke survivors. Cognitive changes, anxiety, and confusion can be very disturbing for the individual and add to caregiver stress. Quality of life often is reported as poor.

Concomitant diseases of aging such as arthritis, diabetes, osteoporosis, and decreased plasticity of the nervous system associated with aging often make the recovery from stroke a challenge. Medical complications occur in up to 85% of stroke survivors and present potential barriers to optimal recovery. Infections occur in almost 25% of stroke survivors, primarily in the urinary tract and chest. Incidence of deep vein thrombosis and pulmonary emboli is increased. Falls resulting from impaired mobil-

ity are also prevalent, with serious injury reported in 5% of the reported falls. Approximately 75% of stroke survivors will have a fall within the first 6 months after stroke. Pain and depression are reported in more than 30% of stroke survivors.⁸⁷ Urinary incontinence after stroke is a bad prognostic feature, both for survival and functional recovery.

Mortality associated with stroke has decreased in the past 20 years in all age groups. However, stroke still remains the number one cause of disability in the adult population. The mortality rate after stroke in African-Americans is higher than in whites and appears to be increasing.⁸⁸

The Global Stroke Initiative is proposed as an international collaboration of the World Health Organization in partnership with the International Stroke Society and the World Federation of Neurology on behalf of other related professional civic groups. The primary focus will be to harness the necessary resources to implement existing knowledge and strategies for stroke prevention, especially in low-income and middle-income countries and in disadvantaged populations in high-income countries.⁸⁹

Ischemic Stroke**Pathogenesis**

Occlusion of Major Arteries. Thrombosis and embolic occlusion of a major vessel are the most common causes of ischemic stroke. The heart is the most common source of embolic material as a result of damage to heart tissue from atherothrombotic disease. Atrial fibrillation is believed to cause thrombus formation in the fibrillating atrium. Left ventricular MI can be a source of emboli, especially in the first few weeks following the event when thrombus formation is most prevalent.⁸⁸ Mitral valve prolapse or congenital septal defects are also sources of emboli. Formation of emboli during or after coronary artery surgery or intracardiac surgery is a well-recognized complication.

Artery-to-artery embolism, usually arising from an atherothrombotic lesion in the carotid or vertebrobasilar system, may lead to stroke. The emboli from this lesion may travel along the course of circulation and may cause occlusion in the smaller branches. The proximal internal carotid artery is the most common site of atherosclerosis and atherothrombosis leading to stroke. Other causes of emboli may be thrombus in the pulmonary vein, fat emboli in the blood, and tumor emboli from a neoplastic process.²⁴ Sources of emboli are shown in Fig. 32-4.

Changes in the collateral pathways of the circle of Willis are apparent in response to internal carotid artery obstruction that may provide some protection against neurologic damage associated with occlusion. The anterior circle of Willis and the posterior communicating artery show increased diameter in some individuals when the internal carotid artery is blocked.⁴⁰ Fig. 32-5 shows the distribution of the circle of Willis.

Secondary Vascular Responses. When a cerebral artery is occluded, the formation of thromboemboli probably begins in the distal vessels of that artery. These presumed microvascular occlusions progressively increase in number and continue to impair blood flow in the

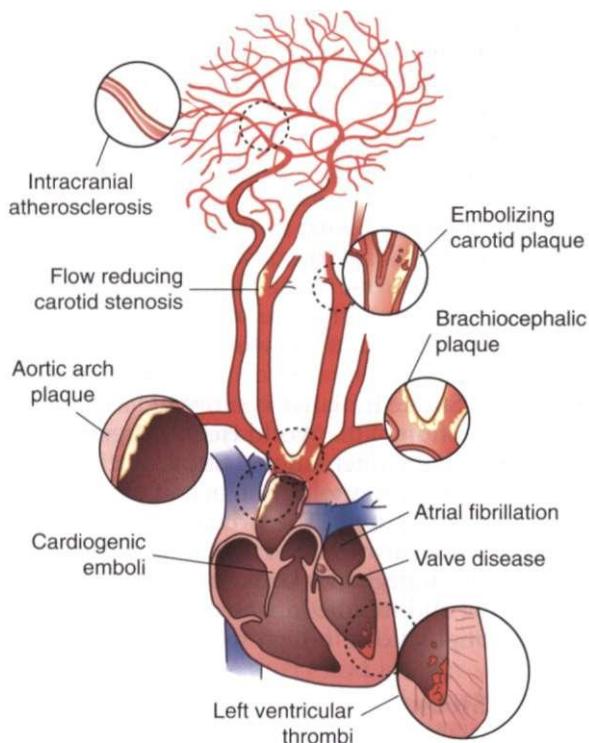


Figure 32-4

Cardiogenic and arterial atherosclerotic sources for stroke. (Reprinted from Townsend CM: *Sabiston textbook of surgery*, ed 17, Philadelphia, 2004, Saunders.)

brain. Cell death surrounding the area of blocked blood flow may be due to the squeezing effects of microvessels by the swelling of the *astrocyte*, one of the cellular support structures of the nervous system. Fig. 32-6 shows how the emboli can affect the brain tissue (see also the section on Cellular Dysfunction in Chapter 28). Astroglial swelling is one of the earliest cell changes induced by single-artery occlusion. The formation of fibrin in the grey matter surrounding the occluded vessel also may contribute to the lack of reperfusion of microvessels. Other factors include bleeding into the parenchyma, increased platelet aggregation, endothelial cells swelling in the walls of the vessels, and vasospasm.^{31,70}

Secondary Neuronal Damage. The tissue of the brain, or the *parenchyma*, is highly vulnerable to an interruption in its blood supply. When the cerebral blood flow falls below 20 mL/100 mg of tissue per minute, neuronal functioning is impaired. Neuronal death, or infarction, occurs when the brain receives less than 8 to 10 mL/100 mg/min. Frequently in an acute infarction a portion of the affected brain receives no blood, while a surrounding area receives sufficient blood from collateral circulation to maintain viability but not to sustain function. This territory has been termed the *ischemic penumbra*.¹⁰⁰ Although the major injury to the neurons in the brain is the hypoxia-ischemia related to the occlusion of the artery causing cell death near the core, further damage to the brain tissue and neurons occurs as a secondary response. There is a characteristic uncoupling between cerebral blood flow and metabolism in the infarcted area. There is decreased perfusion relative to the necessary

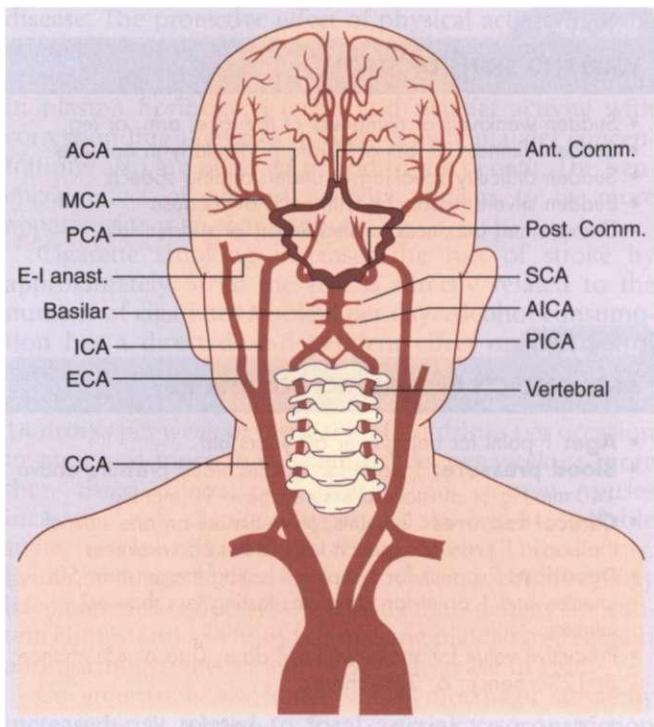


Figure 32-5

Extracranial and intracranial arterial supply to the brain. Vessels forming the circle of Willis are highlighted. ACA, Anterior cerebral artery; AICA, anterior inferior cerebellar artery; Ant. Comm., anterior communicating artery; CCA, common carotid artery; ECA, external carotid artery; E-I anast., extracranial-intracranial anastomosis; ICA, internal carotid artery; MCA, middle cerebral artery; PCA, posterior cerebral artery; PICA, posterior inferior cerebellar artery; Post. Comm., posterior communicating artery; SCA, superior cerebellar artery. (Modified from Lord R: *Surgery of occlusive cerebrovascular disease*, St Louis, 1986, C.V. Mosby.)

oxygen requirements. If blood flow to this ischemic area is restored before irreversible damage occurs, then the tissue will likely recover and resume normal function.

Distant from the ischemic and stroke sites are regions that also show alterations in metabolism despite being normal on anatomic imaging studies such as computed tomography or magnetic resonance imaging (see below). The most distinctive and characteristic example of such remote effects is crossed cerebellar diaschisis. There appears to be an uncoupling of oxygen consumption and glucose use that may reflect a change in brain metabolism caused by deafferentation. There are also other areas that are hypometabolic after a cortical infarct. These areas include the ipsilateral thalamus, the ipsilateral caudate nucleus, and the ipsilateral primary visual cortex (if the infarct is in the anterior visual pathways). There appears to be a decline in oxygen metabolism in the unaffected hemisphere from the acute to the subacute stage, which suggests a delayed effect from the corpus callosum fiber degeneration. There can be a delayed remote hypometabolism that develops during recovery that seems to be related to infarct size. For example, neurologic recovery does not appear to be a function of thalamic hypometabolism but appears to be influenced by prefrontal metabolism, possibly because this region is part of a

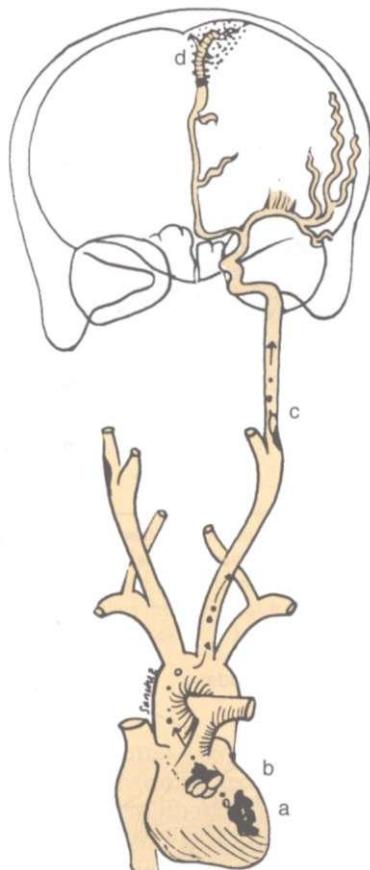


Figure 32-6

Examples of potential sources of embolism: cardiac mural thrombus (*a*); vegetation on heart valve (*b*); and emboli from carotid plaque (*c*). Also shown is an infarcted cortex from an embolism (*d*) in the area supplied by the terminal anterior cerebral artery. (Modified from Caplan LR: *Caplan's stroke: a clinical approach*, ed 3, Boston, 2000, Butterworth-Heinemann.)

network that has an important compensatory role in motor recovery.⁶⁶

Changes in the neurotransmitter substances normally present in the brain can cause damage in the hypoxic-ischemic state believed to reflect mitochondrial dysfunction and energy failure of the damaged tissue. In keeping with its widespread role in central excitatory neurotransmission, glutamate is normally present throughout central nervous system grey matter. The glutamate is stored in synaptic terminals, and when it is released into the extracellular space, rapid uptake normally occurs, so the resting level of glutamate outside the synaptic terminal is minimal. After an ischemic event, the cells that normally clear the excess glutamate are compromised, and excess glutamate is found in the extracellular space. Depolarization of the postsynaptic cell occurs in response to this increase in glutamate. The ultimate effect of the excess glutamate is to facilitate the entry of calcium ions into the cells. Excessive numbers of calcium ions begin the process that causes cell death. Cell death is related to edema within the neuron associated with excess levels of calcium, water, and chloride. Catabolic enzymes are activated by the release of calcium ions and can cause damage

of the proteins that support neurons, the glial cells. It appears that other mechanisms cause excess calcium during the ischemic process in addition to glutamate, including the dysfunction of the electrochemical gradient in the damaged membrane. Evidence exists of apoptosis, programmed cell death that occurs in response to the hypoxic damage.⁶²

The changes in the perfusion pressure associated with hypoxia can also cause the endothelial cells to trigger the release of neurotoxic substances such as free radicals. Oxygen free radicals can initiate many destructive processes in the brain tissue. See Chapter 28 for further information on oxygen free radicals. The overall result of the hypoxic event is a chain of reactions, some that occur simultaneously, extending the damage and death of brain tissue beyond the area of vascular supply.

Clinical Manifestations

Syndromes. Syndromes reflect the dysfunction associated with disruption of blood flow in specific areas of the brain.^{51,59} The syndromes are named according to the arteries that feed the specific areas. The syndrome can be partial or complete. When the blockage is in the more proximal component of the artery, the resulting area of hypoxia is greater than if the clot is lodged in a more distal part of the artery. Because of the collateral circulation provided by the circle of Willis, some areas of the brain are supplied by more than one artery. When one artery is blocked, circulation is provided to the tissues through the blood supply of other arteries. In this case, the clinical syndromes are not as extensive. The actual configuration of arteries is different in each individual, so the syndromes described here are not to be considered all encompassing. This is an overview of the types of symptoms that might be encountered when a particular artery is blocked.

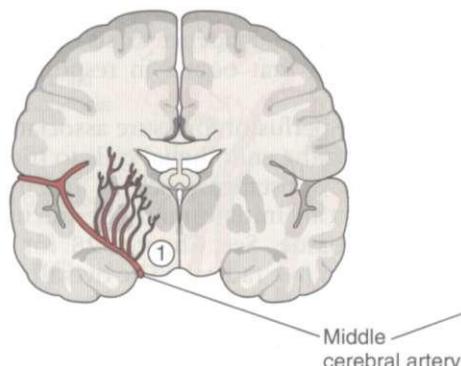
Middle Cerebral Artery Syndrome. If the entire middle cerebral artery is occluded at its stem, blocking both the penetrating and cortical branches, the clinical findings are contralateral *hemiplegia* and *hemianesthesia*, or the loss of movement and sensation on one half of the body. If the dominant hemisphere is affected, *global aphasia*, or the loss of fluency, ability to name objects, comprehend auditory information, and repeat language, is the result. (See the section on Parietal Lobe Syndromes in Chapter 28.)

Partial syndromes resulting from embolic occlusion of a single branch include brachial syndrome, or weakness of the upper extremity, and frontal opercular syndrome, or facial weakness with motor aphasia with or without arm weakness. A combination of sensory disturbance, motor weakness, and motor aphasia suggests that an embolus has occluded the proximal superior division branch and has infarcted large portions of the frontal and parietal cortices.

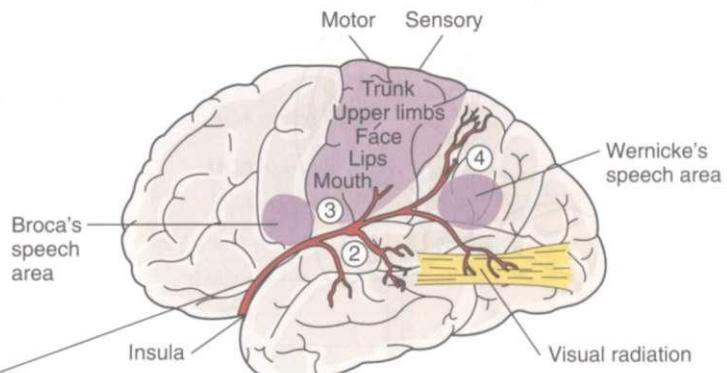
If Wernicke's aphasia occurs without weakness, the inferior division of the middle cerebral artery supplying the temporal cortex of the dominant hemisphere has been occluded. Jargon speech and an inability to comprehend written and oral language are prominent features. Hemiplegia or spatial agnosia without weakness indicates that the inferior division of the middle cerebral

MIDDLE CEREBRAL ARTERY

Anatomy



LATERAL SURFACE OF CEREBRAL HEMISPHERE.

**Figure 32-7**

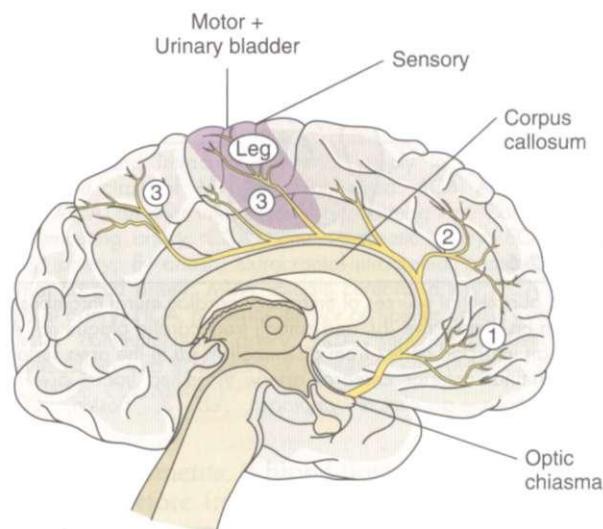
The middle cerebral artery is the largest branch of the internal carotid artery and the most common site of emboli. Its deep branches feed the internal capsule and basal ganglia. On the lateral surface the branches feed areas of the parietal, frontal, and temporal lobes. (Reprinted from Lindsay KW, Bone I, Callander R: *Neurology and neurosurgery illustrated*, New York, 1986, Churchill Livingstone.)

artery in the nondominant hemisphere is involved. Fig. 32-7 represents the area of the middle cerebral artery.

Anterior Cerebral Artery Syndrome. Infarction in the territory of the anterior cerebral artery is uncommon and is more often the result of embolism than to atherosclerosis. Collateral flow is able to compensate for most occlusion of the artery so that dysfunction is minimal. If both segments of the artery arise from a single anterior cerebral stem, the occlusion affects both hemispheres. Contralateral hemiparesis and sensory loss are usually seen with the lower extremity more involved. Profound *abulia*, a delay in verbal and motor response, is common. Akinetic mutism also can result in significant disability. Fig. 32-8 represents the area of blood flow of the anterior cerebral artery.

Internal Carotid Artery Syndrome. The clinical picture of internal carotid occlusion varies depending on whether the cause of ischemia is thrombus, embolus, or low flow. The cortex supplied by the middle cerebral territory is affected most often. Occasionally, the origins of both the anterior and middle cerebral arteries are occluded at the top of the carotid artery. Symptoms consistent with both syndromes result. With a competent circle of Willis producing adequate collateral circulation, the occlusion can be asymptomatic.

Posterior Cerebral Artery Syndrome. If the proximal posterior cerebral artery is occluded, including penetrating branches, the areas of the brain that are affected are the subthalamus, medial thalamus, and ipsilateral (same side) cerebral peduncle and midbrain. Signs include thalamic syndrome, including abnormal sensation of pain, temperature, proprioception, and touch. Sensations may be exaggerated and light pressure may be interpreted as painful stimuli. This may develop into intractable, searing pain, which can be incapacitating. The anterior pattern consists mainly of perseverations and superimposition of unrelated information, apathy, and amnesia. After paramedian infarct, the most frequent features are disinhibition syndromes with personality changes, loss of self-activation, amnesia and, in the case of extensive

**Figure 32-8**

The anterior cerebral artery branches from the internal carotid. Deep branches supply the internal capsule and basal ganglia. Superficial branches supply the frontal and parietal lobes. (Reprinted from Lindsay KW, Bone I, Callander R: *Neurology and neurosurgery illustrated*, New York, 1986, Churchill Livingstone.)

lesions, thalamic dementia; this pattern may often be difficult to distinguish from primary psychiatric disorders, especially when neurologic dysfunction is lacking. After inferolateral lesion, executive dysfunction may develop but is often overlooked, although it may occasionally lead to severe long-term disability. After posterior lesion, cognitive dysfunction with neglect and aphasia are well known.¹²

If the posterior cerebral artery is completely occluded at its origin, hemiplegia results from infarction of the cerebral peduncle. Involvement of the red nucleus or dentatorubrothalamic tract can produce contralateral ataxia. When palsy of cranial nerve III occurs with contralateral ataxia, it is known as Claude syndrome. Third nerve palsy occurring with contralateral hemiplegia is

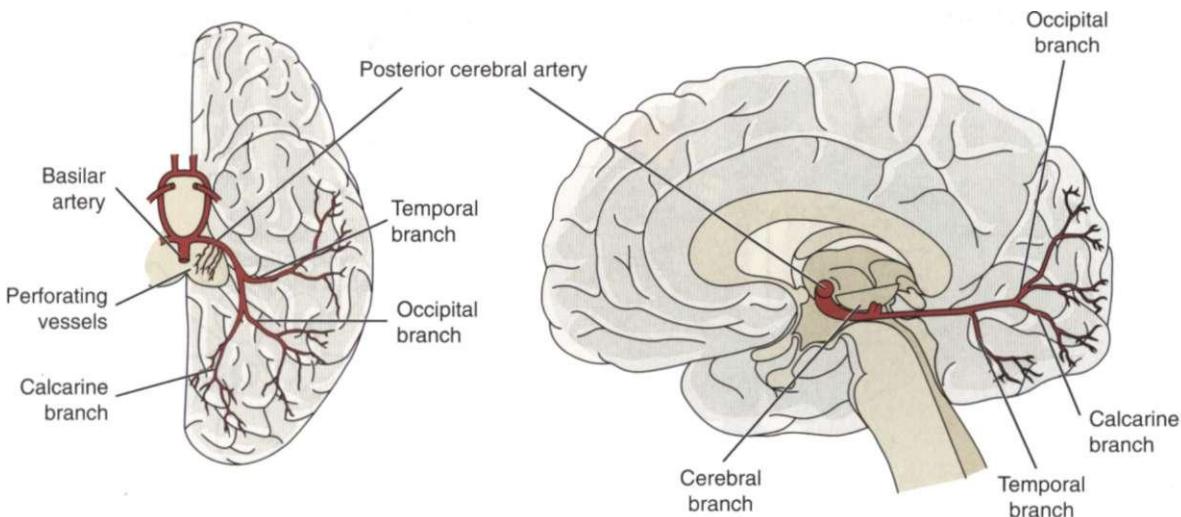


Figure 32-9

The posterior cerebral arteries branch from the basilar artery. The small perforating branches supply the midbrain structures and posterior thalamus. The temporal branch supplies the temporal lobe, and the occipital and calcarine supply the occipital lobe, including the visual cortex. (Reprinted from Lindsay KV, Bone I, Callander R: *Neurology and neurosurgery illustrated*, New York, 1986, Churchill Livingstone.)

known as Weber syndrome. Hemiballismus, or flailing of the extremity, usually results from a deep penetrating vessel causing infarct in the contralateral subthalamic nucleus. Paresis of upward gaze, drowsiness, and abulia (the lack of interest in movement) can be attributed to occlusion of the artery of Percheron. If the posterior cerebral stem is occluded, causing extensive infarction of the subthalamus, coma and decerebrate rigidity may result.

Peripheral supply of the posterior cerebral artery includes the temporal and occipital lobes. Occlusion of this component of the artery often affects the occipital lobe with homonymous hemianopsia, in which the visual field defect is on the side opposite to the lesion. Cortical blindness, the inability of the brain to record an image although the optic nerve is intact, is one of the visual disturbances that is seen with infarct in this region.

Medial temporal lobe involvement (including the hippocampus) can cause an acute disturbance in memory, particularly if it occurs in the dominant hemisphere. This resolves because memory has dual representation. Memory is represented on both sides of the brain; if one area is affected the intact side can compensate to a considerable extent. If the dominant hemisphere is affected and the infarct extends to involve the splenium of the corpus callosum, the individual may demonstrate alexia without agraphia, or impairment of reading without the impairment of writing. Agnosia, or difficulty in identification or recognition, affecting the ability to identify faces, objects, mathematical symbols, and colors, may occur. Anomia, impaired ability to identify objects by name, and visual hallucinations of brightly colored scenes and objects can occur with peripheral posterior cerebral infarction. Embolic occlusion of the top of the basilar artery can produce a clinical picture that includes any or all of the central or peripheral territory symptoms. Fig. 32-9 represents the area of blood flow of the posterior cerebral artery.

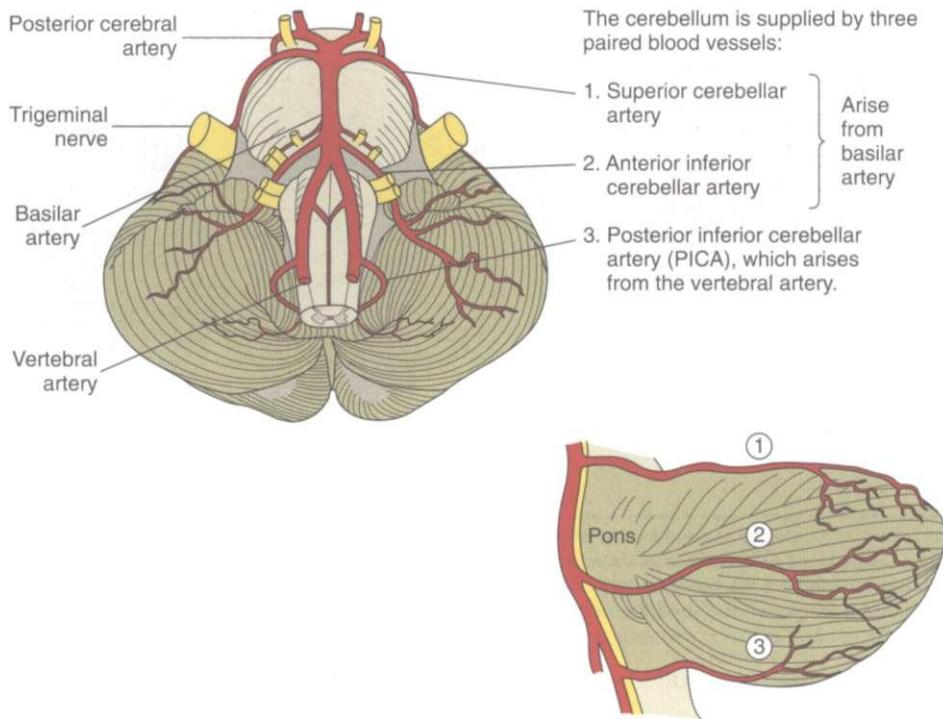
Vertebral and Posterior Inferior Cerebellar Artery Syndrome. Blood supply to the brainstem, medulla, and cerebellum is provided by the vertebral and posterior cerebellar arteries. Collateral circulation is provided by the bilateral component of the vertebral artery so that ischemia often is not manifested in the presence of atherosclerosis.

When infarction ensues, the lateral medulla and the posteroinferior cerebellum are affected, resulting in Wallenberg syndrome, which is characterized by vertigo, nausea, hoarseness, and dysphagia (difficulty swallowing). Other symptoms include ipsilateral ataxia (uncoordinated movement), ptosis (eyelid droop), and impairment of sensation in the ipsilateral portion of the face and contralateral portion of the torso and limbs. Individuals with lateral medullary infarction complain of numbness, burning, and cold in the face and limbs, with symptoms exaggerated by a cold environment, reflecting the spinal thalamic tract involvement.⁵⁰ The onset of symptoms may be delayed for up to 6 months.⁴³

A medial medullary infarction of the pyramid can result in contralateral hemiparesis of the arm and leg, sparing the face. If the medial lemniscus and the hypoglossal nerve fibers are involved, loss of joint position sense and ipsilateral tongue weakness can occur.

The edema associated with cerebellar infarction can cause sudden respiratory arrest from raised intracranial pressure (ICP) in the posterior fossa. Gait unsteadiness, dizziness, nausea, and vomiting may be the only early symptoms. Fig. 32-10 shows the area of distribution of the superior cerebellar, anterior inferior cerebellar, and posterior inferior cerebellar arteries.

Basilar Artery Syndrome. Atheromatous lesions can occur anywhere along the basilar trunk, but they occur most often in the proximal basilar and distal vertebral area. Ischemia as a result of occlusion of the basilar artery can affect the brainstem, including the corticospinal

**Figure 32-10**

A lesion in the cerebellar territory will produce both cerebellar and brainstem signs and symptoms. (Reprinted from Lindsay KW, Bone I, Callander R: *Neurology and neurosurgery illustrated*, New York, 1986, Churchill Livingstone.)

tracts, corticobulbar tracts, medial and superior cerebellar peduncles, spinothalamic tracts, and cranial nerve nuclei.

If the basilar artery is occluded, the brainstem symptoms are bilateral. When a branch of the basilar artery is occluded, the symptoms are unilateral, involving the sensory and motor aspects of the cranial nerves.

Superior Cerebellar Artery Syndrome. Occlusion of the superior cerebellar artery results in severe ipsilateral cerebellar ataxia, nausea and vomiting, and *dysarthria*, or slurring of speech. Scanning speech, a drawn-out and monotone speech pattern, reflects damage to the cerebellum. Loss of pain and temperature in the contralateral extremities, torso, and face occurs. *Dysmetria*, characterized by the inability to place the extremity at a precise point in space, is common, affecting the ipsilateral upper extremity.

Anterior Inferior Cerebellar Artery Syndrome. Principal symptoms include ipsilateral deafness, facial weakness, vertigo, nausea and vomiting, *nystagmus* (rhythmic oscillations of the eye), and ataxia. *Horner syndrome* ptosis, miosis (constriction of the pupil), and loss of sweating over the ipsilateral side of the face may occur. A paresis of lateral gaze may be seen. Pain and temperature sensation are lost on the contralateral side of the body.

Lacunar Syndrome. Lacunar infarcts are small infarcts of the end arteries found in the basal ganglia, internal capsule and pons. The lacunar infarcts have the characteristics of ischemic necrosis and the cysts are surrounded by astrocytic gliosis, or scarring of the support structures of the brain.⁴⁴ These small, cystic spaces resulting from healed ischemic infarcts are common in individuals with

hypertension or diabetes. A large majority are asymptomatic, but in about 20% of cases a stroke syndrome occurs with a slowly progressive (over 24 to 36 hours) dysfunction of the cells in the area of the lacune.⁴⁴ The lacunar syndrome is representative of the area of infarct in which the lacunae are predominant often in the deep structures of the brain and have their effect often on white matter. If the posterior limb of the internal capsule is affected, a pure motor deficit may result; in the anterior limb of the internal capsule, weakness of the face and dysarthria may occur. If the posterolateral thalamus is affected there is a pure sensory stroke. When the lacunae occur predominantly in the pons, ataxia, clumsiness, and weakness may be seen. Fig. 32-11 shows the areas of predilection for lacunae to develop.

MEDICAL MANAGEMENT

DIAGNOSIS. History of the neurologic event should be obtained, including timing, pattern of onset, and course. An embolic stroke occurs rapidly, with no warning. A more progressive and uneven onset is typical with thrombosis. The presenting symptoms will help to determine the location of the lesion.

Studies of the carotid artery and vertebral arteries are performed using ultrasound evaluation. Doppler ultrasound looks at the flow velocity of the blood through the artery. Plaque accumulation and ulceration can be identified by Doppler. Doppler studies are used to determine the need for carotid endarterectomy.⁴⁷

Neuroimaging of the brain has become a standard procedure in the diagnosis of stroke. Computed tomographic (CT) scan is the fastest, most convenient and



Figure 32-11

Usual sites of lacunar infarcts in the deep white matter. **A**, Internal capsule/putamen. **B**, Thalamus. **C**, Mesencephalon. **D**, Pons. (Reprinted from Pryse-Phillips W, Murray TJ: *Essential neurology: a concise textbook*, ed 4, New York, 1992, Medical Examination Publishing.)

widely available test to use for the diagnosis and early treatment of acute stroke. It can confirm the diagnosis and rule out other pathologies and extent of the lesion. Fig. 32-12 shows how an acute stroke looks on CT. However, CT scans may be normal in the acute stage of an embolic stroke. Bleeding into the brain tissue is seen acutely in a hemorrhagic stroke. Displacement of brain structures, such as the ventricles, by edema sometimes can be seen early in a large infarct. In ischemic stroke, CT scans reveal the area of decreased density and loss of grey/white matter differentiation resulting from edema. Cortical lesions appear wedge shaped and deeper lesions appear to be round or oval. Potential for hemorrhagic transformation of the ischemic infarct can be seen on CT.⁷³ Lacunar infarcts are sometimes visible on CT scans as small, punched-out, hypodense areas. Images of lacunae and be seen in Fig. 32-13. Identification of the penumbra and infarct core on hyperacute noncontrast and perfusion CT may lead to potentially more aggressive treatments related to reperfusion and to arrest progression of stroke damage in the early part of the stroke.⁷⁴ Fig. 32-14 demonstrates how the use of new imaging techniques may assist in this goal.

Magnetic resonance imaging (MRI) allows for the identification of an ischemic event within 2 to 6 hours of onset. The soft tissue contrast and multiplanar imaging capability offered by MRI have led to its wide acceptance as the method of choice for high-resolution brain imaging. Diffusion-weighted MRI (DWI) provides an indication of the brain tissue's physiologic response to ischemia and can document the evolution of stroke. Because halting the evolution of the stroke is the therapeutic goal, DWI may be useful in the evaluation of therapeutic effectiveness. Perfusion imaging uses a tight bolus of paramagnetic contrast agent and a sequence of rapid MRI scans to detect the passage of the agent through the brain

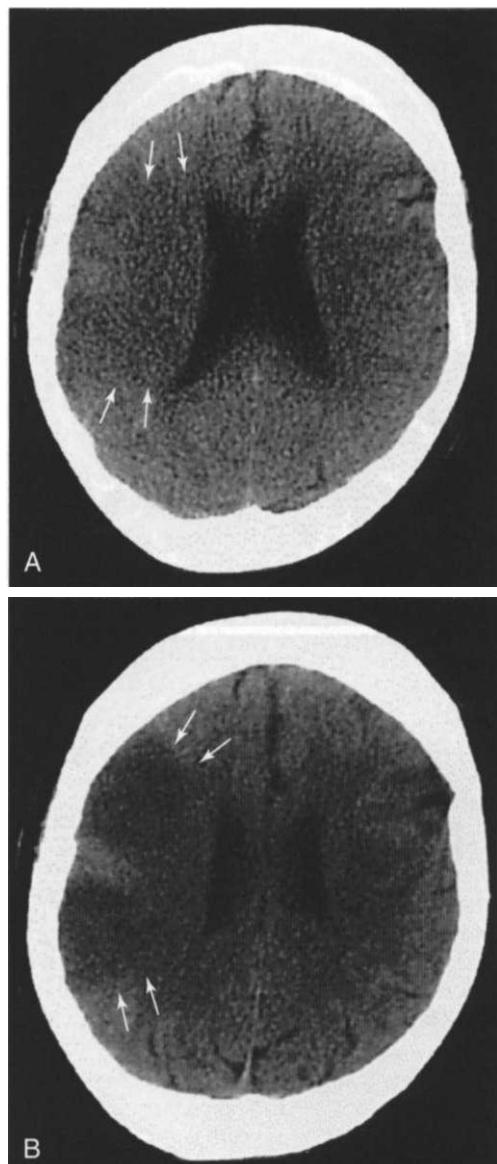


Figure 32-12

CT scan taken 2 hours, 50 minutes after large right middle cerebral artery occlusion. There are subtle, ultra-early ischemic changes, including loss of the grey-white interface (arrows) and subtle evidence of sulcal effacement. **B**, CT scan of same patient approximately 8 hours after symptom onset shows acute hypodensity (arrows) and more prominent sulcal effacement. (Reprinted from Marx JA: *Rosen's emergency medicine: concepts and clinical practice*, ed 6, St Louis, 2006, Mosby.)

tissue.⁷⁵ MRI stroke sequences can be used as a measure of ischemic penumbra and can help pinpoint potentially salvageable brain tissue, helping to identify who is going to be a good candidate for the later window of intervention using thrombolysis and who is not.⁷⁶

Positron emission tomographic (PET) imaging has been of great benefit in advancing the understanding of the pathophysiology of cerebrovascular disorders. PET imaging allows for the detection of stroke earlier and with higher sensitivity than anatomic imaging with either MRI or CT. Furthermore, PET imaging has been useful in evaluating the extent of the functional damage because areas

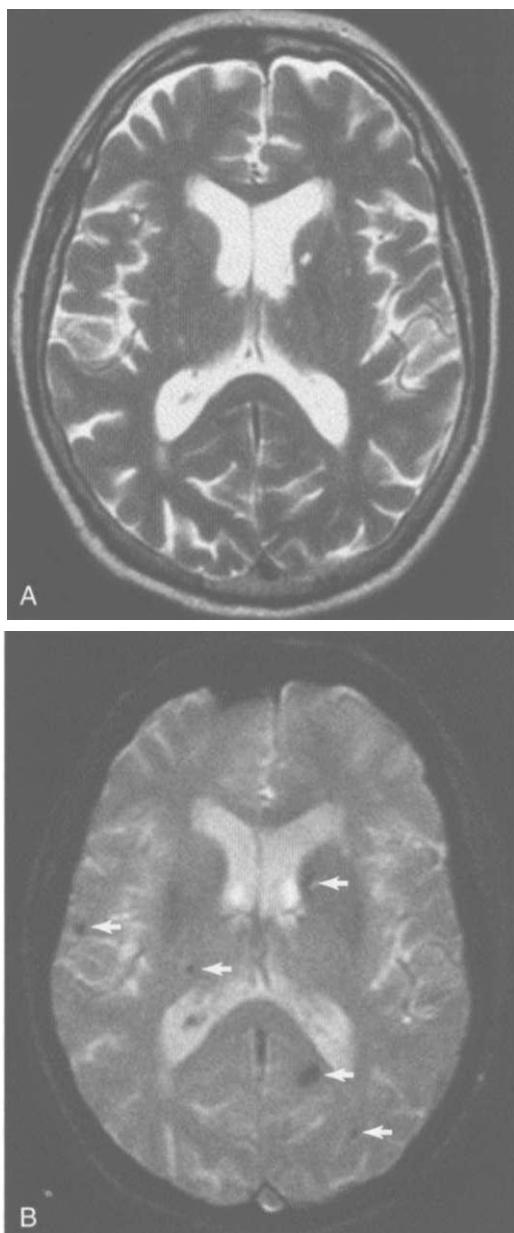


Figure 32-13

In these images, the left side of the brain is on the right of the panel. Axial T2-weighted fast spin-echo sequence (**A**) and corresponding axial T2*-weighted gradient echo sequence (**B**) from a 57-year-old man who presented with a left lacunar syndrome; his risk factors included hypertension and smoking. The T2-weighted fast spin-echo sequence shows several hyperintense foci in the cerebral white matter and basal ganglia but no microbleeds. The T2*-weighted gradient echo image shows several areas of focal signal loss consistent with microbleeds (arrows) in the right frontal lobe, right thalamus, left parietal lobe, and left caudate nucleus. (Reprinted from Werring DJ, et al: Cerebral microbleeds are common in ischemic stroke but rare in TIA, *Neurology* 65(12):1914-1918, 2005.)

not immediately affected by the infarct may show hypometabolism or decreased blood flow. Initial stroke severity has been shown to correlate with the initially affected volume as determined by PET, whereas neurologic deterioration during the first week after stroke correlates with the proportion of the initially affected volume that

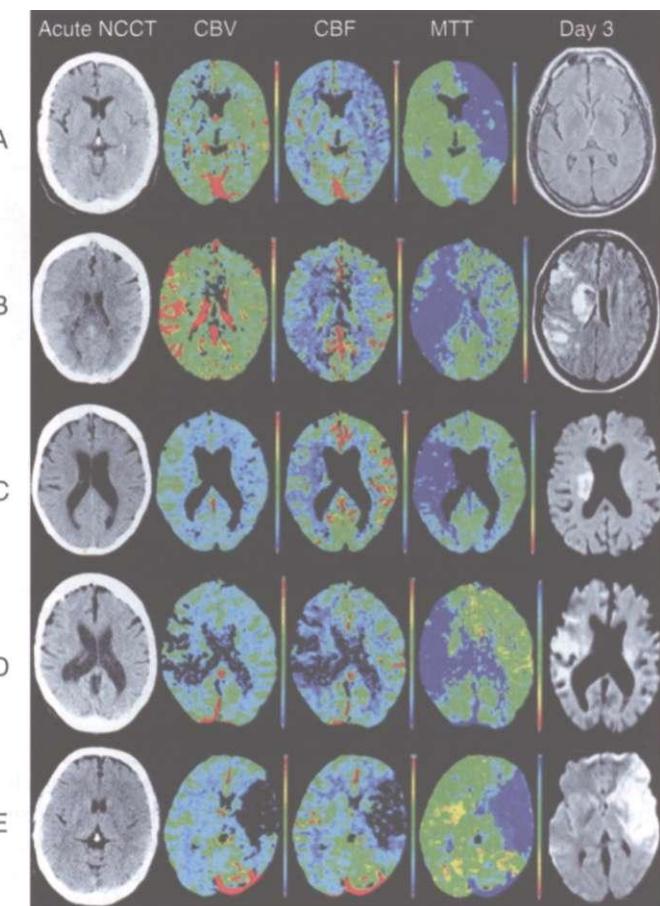


Figure 32-14

Patient A: Isolated focal swelling (IFS) on noncontrast CT (NCCT), hypoperfusion on mean transit time (MTT), and increased cerebral blood volume (CBV) on acute CT perfusion (CTP) maps, and no progression to infarction with subsequent major reperfusion. Patient B: IFS on NCCT, hypoperfusion on MTT, and increased CBV on acute CTP maps, but progression to infarction occurred without major reperfusion. Patient C: Hypoperfusion on MTT and increased CBV on acute CTP maps without any change apparent on acute NCCT. No infarction in cortical regions on follow-up with major reperfusion. Patient D: Hypoperfusion on MTT and decreased CBV on acute CTP maps without any apparent change on NCCT. Subsequent infarction present in reduced CBV regions on follow-up MRI. Patient E: Profound decrease in CBV and CBF on acute CTP maps with associated parenchymal hypoattenuation on NCCT. Extensive infarction on follow-up MRI. (Reprinted from Parsons M, Pepper EM, Bateman GA, et al: Identification of the penumbra and infarct core on hyperacute noncontrast and perfusion CT, *Neurology* 68(10):730-736, 2007.)

infarcted, and functional outcome correlates with the final infarct volume. Crossed cerebellar diaschisis is seen as hypometabolism and hypoperfusion in the cerebellar cortex contralateral to the site of the infarct and usually occurs during the first 2 months after infarction (Fig. 32-15).³⁶

Cerebral angiography can be used in the absence of CT or MRI but is an invasive procedure and used only when other forms of imaging are not appropriate.

TREATMENT. Treatment of individuals with ischemic stroke consists of managing the stroke and preventing further embolic strokes. Cerebral perfusion, or the blood

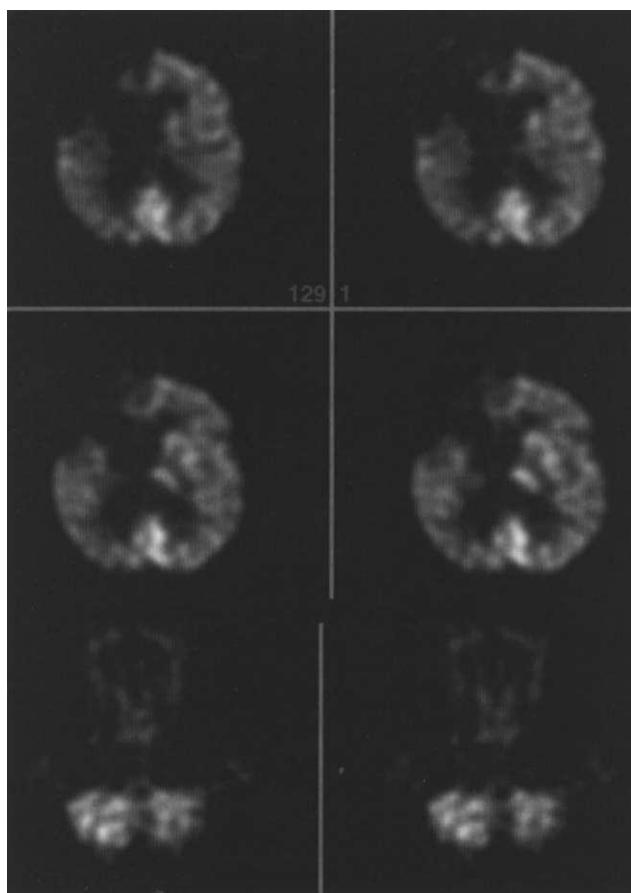


Figure 32-15

Fluorodeoxyglucose PET scan of a patient after embolic stroke in the distribution of the right anterior cerebral artery. There is severely decreased metabolism in the right frontal lobe extending to the midline. There is also crossed cerebellar diaschisis with decreased metabolism in the left cerebellum. (Reprinted from Newburg AB, Alavi A: The role of PET imaging in the management of patients with central nervous system disorders, *Radiol Clin North Am* 43(1):49-65, 2005.)

flow around the area of the stroke, is the main concern when the cause is embolic. Blood pressure should not be lowered unless it is as high as 230/120 mm Hg. The goal is not to try to normalize the pressure, but to bring it down from dangerously high levels. If the blood pressure is low, raising it is appropriate in the first few hours after the stroke. An excessive rise in blood pressure may cause an increase in edema. When clinically stable, individuals with blood pressure over 140/90 mm Hg should be given medication to lower blood pressure. Unless contraindicated, use of diuretics and β -blockers should be the medication of choice. Angiotensin-converting enzyme inhibitors have been used with diabetes mellitus, heart failure, and MI.⁶⁷

Emboli that lodge in the artery stem can cause edema. If not controlled the edema can spread and create pressure in the area of the cerebellum and brainstem. Even a small amount of edema in the cerebellum can cause respiratory arrest from compression of the brainstem and lead to coma and death. It is the most common fatal complication. Water restriction and agents that raise the

serum osmolarity should be considered with the onset of significant edema.

Thrombolytic and antithrombotic agents form the cornerstone of ischemic stroke treatment and prevention.² Recombinant tissue plasminogen activator is used for the emergent care of embolic stroke. Tissue plasminogen activator activates plasminogen to form plasmin, which actively digests fibrin strands, and is effective in dissolving the thrombosis or blood clot responsible for the blockage. By promoting early recanalization of occluded vessels and early reperfusion of ischemic fields, there is potential to salvage penumbral neuronal tissue. If it is received within 3 hours after the initial stroke, the person is 30% more likely to recover from the stroke. The greatest risk factor is the chance of hemorrhage and the inappropriate use in a stroke that is hemorrhagic. It must be determined on CT that the stroke is purely embolic; guidelines are established by the National Institute of Neurological Disorders and Stroke study.²⁷ With the use of DWI imaging and further understanding of the status of the ischemic penumbra, the window of opportunity may become larger and therapies more effective.

Several prognostic factors must be considered for selecting candidates for intravenous thrombolysis. Younger age, absence of cardiac disease or diabetes, lower blood pressure on admission, lower neurologic score, absence of early ischemic parenchymal changes, large artery thrombus visible on baseline brain CT, and a developed collateral circulation are all factors associated with a more favorable outcome. Risk factors for developing brain hemorrhage include time to treatment, dose of thrombolytics, blood pressure level, severity of neurologic deficit, and severity of ischemia. Besides hemorrhage, potential complications of thrombolysis include reperfusion injury, arterial reocclusion, and secondary embolization due to thrombus fragmentation. Thus adequate hospital facilities and personnel are required for administration of thrombolytic therapy as well as for monitoring and managing potential complications. Following tissue plasminogen activator administration, blood pressure should be closely monitored and kept at less than 180/105 mm Hg and antithrombotic agents should be avoided for 24 hours.

Intracranial clot retrieval is now possible with the Mechanical Embolus Removal in Cerebral Ischemia (MERCI) retrieval system (Concentric Medical, Inc, Mountain View, CA). When outcomes using MERCI were compared with those in individuals who were treated and those who were not, good outcomes occurred in 49% versus 10%, respectively, and mortality rate was 25% versus 52%, respectively. The retriever device goes in as a straight wire that turns into a corkscrew when it comes out of the guide catheter that is screwed into the clot; a balloon is pumped proximal to the clot to prevent antegrade flow. The clot is then pulled out. Most stroke centers are now offering this system with trials done up to 8 hours after symptom onset when used with very large clots.⁹¹

PROPHYLAXIS

Anticoagulation. Anticoagulation therapy has played a prominent role in the prevention of acute infarction for

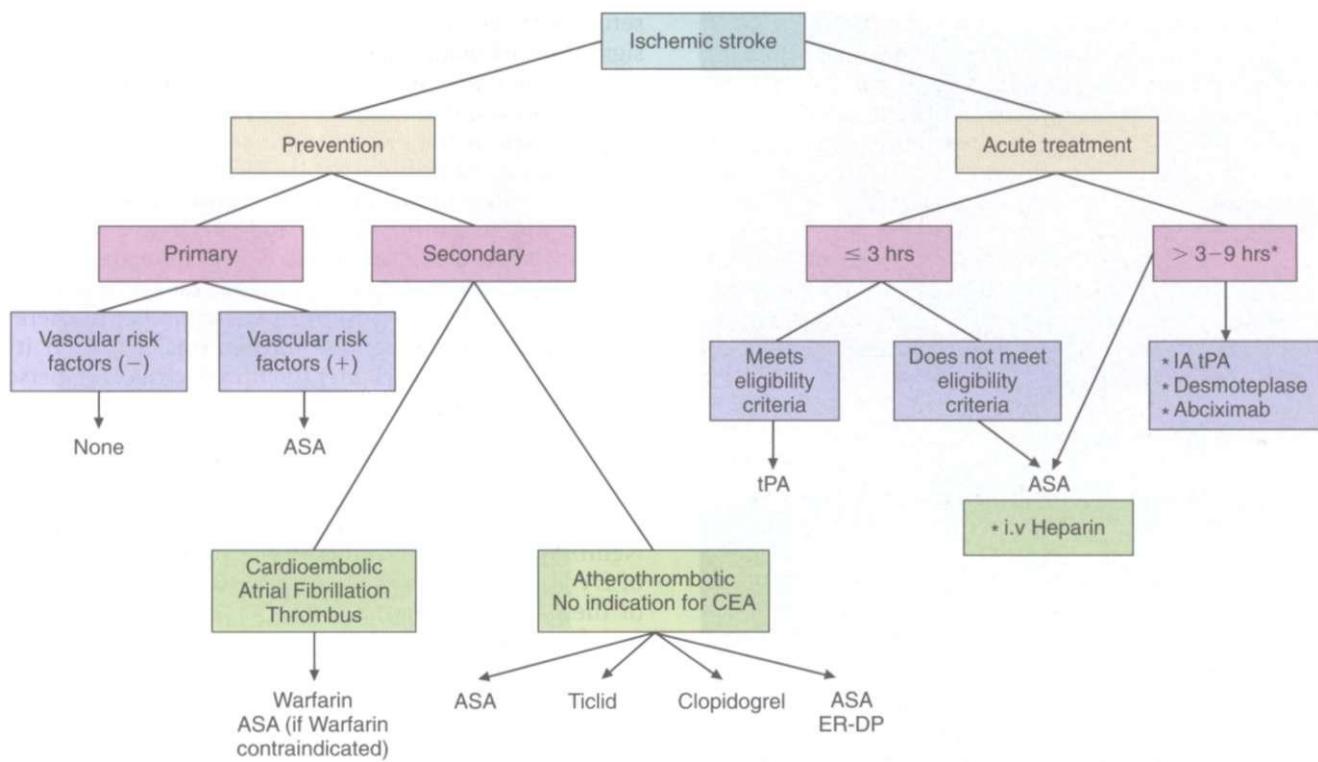


Figure 32-16

Prevention and treatment of ischemic stroke.*Experimental or ongoing trials. †Used in clinical practice for specific stroke syndromes. ASA, Aspirin; ER-DP, extended-release dipyridamole; IA tPA, intra-arterial tissue plasminogen activator; Ticlid, ticlopidine. (Reprinted from Ocana LC: Antithrombotic and thrombolytic therapy for ischemic stroke, *Clin Geriatr Med* 22(1):135-154, 2006.)

several decades, and current research supports its use in high-risk individuals. Large, randomized trials have also highlighted the effectiveness and safety of early and continuous antiplatelet therapy in reducing atherothrombotic stroke recurrence. Large, randomized trials have shown the benefit of four different agents: (1) aspirin, (2) ticlopidine, (3) clopidogrel, and (4) dipyridamole.⁷¹

Aspirin has become the antiplatelet standard for individuals with acute ischemic stroke who are not receiving thrombolysis. Several other antiplatelet agents such as ticlopidine, clopidogrel, and aspirin-dipyridamole have been shown to be more effective. The prevention of cardioembolic stroke is best accomplished with oral anticoagulation, barring any contraindications. Antiplatelets such as aspirin are used to decrease risk of second MI and may reduce the chance of stroke after MI.

Clopidogrel, a platelet adenosine diphosphate receptor antagonist, appears to be an effective antiplatelet drug that has rare interactions with other medication, although it should be used with caution in conjunction with heparin or warfarin or nonsteroidal antiinflammatory drugs.⁷²

Anticoagulation should not be used with high blood pressure or other risk factors of hemorrhagic stroke. Studies are underway to determine use in acute post-stroke management.⁷³ Heparin can be used prophylactically against deep venous thrombosis and pulmonary embolism.

Warfarin sodium (Coumadin, Panwarfin) appears to be about twice as effective as aspirin in the prevention of

stroke in individuals with atrial fibrillation. Use of warfarin after MI has shown reduced stroke risk overall but increases the chance for hemorrhagic stroke. Persons older than 75 years have the highest risk of stroke and can benefit from anticoagulation. The risk of bleeding increases with age, and the ability to determine the risk/benefit ratio is complex. These medications are probably currently underutilized in the older individuals at risk for stroke.⁷³ When there are contraindications to warfarin, aspirin is an alternative therapy. Fig. 32-16 shows an algorithm for treatment options in stroke.

Lipid-Lowering Agents. Cholesterol-lowering agents such as statins decrease the risk of stroke after MI. Studies show that the anti-stroke effects may be separate from the lipid-lowering properties through changes in the endothelium, inflammatory response, plaque stabilization, and thrombus formation. Several organizations have endorsed the use of statins for stroke prevention. The United States Food and Drug Administration has added ischemic stroke as an indication for statin therapy. The use of statins, in accordance with National Cholesterol Education Program Adult Treatment Panel III guidelines, is endorsed by the American Heart Association and American Academy of Neurology for both primary and secondary prevention of stroke.⁷⁰

PET studies have also been used to monitor the success of various treatment regimens. PET has been used to evaluate the effects of thrombolytic therapy in acute stroke and has found that critically hypoperfused tissue can be preserved by early reperfusion and that large

infarcts can be prevented by early reperfusion to viable tissue. In the future, functional imaging modalities that could eventually include tracers for neuronal integrity might be used to help in the selection of individuals for thrombolytic therapy, possibly permitting the extension of the critical time period for inclusion of individuals to aggressive stroke management strategies.⁶⁶

Neuroprotection. Medications aimed at creating neuroprotection to decrease the amount of cell death secondary to excitotoxicity are being developed, and clinical studies are underway.²⁵ Approaches directed at presynaptic reduction of pathologic glutamate release may control the damage caused by excess extracellular glutamate. Reducing the amplification of excitotoxic calcium ion release also may help control cell death. In this category are endogenous growth factors, which may improve recovery from calcium overload and appear to improve outcome after focal brain ischemia. Enhancing gamma-aminobutyric acid activity may limit the neurotoxic effects of increased glutamate. Serotonin agonists appear to decrease infarction size in animal studies.²⁵ Clinical trials have been disappointing for many of these medications.

A tetracycline derivative, minocycline, reduces inflammation and appears to protect against focal cerebral ischemia after stroke. It is most effective when started before ischemia develops but can be effective after the onset of ischemia. It has no therapeutic effect on astrogliosis or spreading depression but may provide some protection from glutamate toxicity.¹¹³ Timing is critical in the administration of these drugs. The window of opportunity may be 2 to 6 hours after infarction. These antiexcitotoxic therapies may be suitable for either hemorrhagic or ischemic stroke and someday may be given by paramedics before full neurologic evaluation.¹⁰³

Nerve Growth. Animal studies show positive results when stem cells have been implanted into the brain. Although the ability to repair damaged tissue and reform neural connections is limited when vast amounts of parenchyma are lost, seeded lesions show the potential for growing and differentiating into neurons. Enhancement of neural processes, reformation of cortical tissue, and promotion of connectivity all appear to be possible.

Surgical Intervention. Carotid endarterectomy is the treatment of choice for low-flow or embolic TIA in individuals less than 80 years old.⁴ If stenosis is greater than 70% in a sclerotic lesion at the origin of the internal carotid artery, endarterectomy is indicated. Because women have arteries that are 10% smaller than men to begin with, the absolute size of the artery becomes significantly smaller with 70% occlusion. Therefore this equation may need to be looked at differently in women.

Careful selection of candidates for surgery is essential, as is an experienced team of surgeons and other health care providers to manage the postoperative course. Controversy surrounds the role of prophylactic endarterectomy in persons with asymptomatic extracranial carotid stenosis.²²

Control of Symptoms. Pharmacotherapy of spasticity in stroke is controversial. Weakness of the extremities can

result, and if the spasticity is contributing to stability, that may be lost with use of medications. Baclofen and benzodiazepines work at the level of the spinal cord; dantrolene works on the muscle fibers.

Treatment to decrease the firing of specific muscles with botulinum toxin gives more discrete control of the choice of muscle to be injected. Choosing the appropriate muscle or group of muscles is critical in a successful outcome. The effects of botulinum toxin usually last for approximately 3 to 6 months, so it is a temporary solution.

Urinary incontinence can be a disabling sequela of stroke. Urge incontinence is treated with behavioral therapy and anticholinergics. An areflexic bladder can be managed with self-catheterization or use of a Foley catheter.

Depression after stroke is common and does not appear to be related to the area of lesion. Depression after stroke responds to treatment and should be guided by the other concomitant medical conditions and the side effects of the particular medication. Use of tricyclic antidepressants shows improvement within 3 to 6 weeks and should be continued for a minimum of 6 months.⁵⁹

PROGNOSIS. The prognosis for survival after cerebral infarction is better than after cerebral or SAH. Loss of consciousness after an ischemic stroke implies a poorer prognosis than remaining conscious. Individuals with ischemic stroke are at risk for other strokes or MIs. The risk factors and type of damage related to the stroke syndrome relate to degree of disability and mortality.

Neurobiochemical markers of brain damage are being studied to determine a relation with outcome after stroke. Two such markers, protein S-100B and neuron-specific enolase, show a relation between the blood level 2 to 4 days after stroke and functional impairment and discharge from acute level of care.¹¹²

Recovery from stroke is the fastest in the first few weeks after onset, with the most measurable neurologic recovery (approximately 90%) in the first 3 months.⁷² However, movement patterns can continue to be influenced by intervention with goal-directed activities, and repetition of movement appears to improve the speed and control of the movement in the individual up to 5 or more years after stroke. (See Special Implications for the Therapist, Stroke Rehabilitation, later in this chapter.)

Intracerebral Hemorrhage

Overview and Definition

Intracerebral hemorrhage (ICH) is bleeding from an arterial source into brain parenchyma (often referred to as an *intraparenchymal hemorrhage*) and is regarded as the most deadly of stroke subtypes. Primary ICH describes spontaneous bleeding in the absence of a readily identifiable precipitant and is usually attributable to microvascular disease associated with hypertension or aging. Secondary ICH occurs most often in association with trauma, impaired coagulation, toxin exposure, or an anatomic lesion. Chronic hypertension causes fibrinoid necrosis in the penetrating and subcortical arteries, weakening of the arterial walls, and formation of small aneurysms

outpouchings, or microaneurysms, that predispose to spontaneous ICH. Bleeding usually arises from the deep penetrating arteries of the circle of Willis, including the lenticulostriate, thalamogeniculate, and thalamo-perforating arteries and perforators of the basilar artery. Acute rises in blood pressure and blood flow can also precipitate ICH even in the absence of preexisting severe hypertension. A ruptured vascular malformation is the second most common cause of ICH.

Bleeding is limited by the resistance of tissue pressure in the surrounding brain structures. If a hematoma is large, distortion of structures and increased ICP cause headache, vomiting, and decreased alertness. Because the cranial cavity is a closed system, enlargement of a hematoma or development of severe edema may shift brain tissues into another compartment, or herniate, and cause deterioration in the clinical condition.

Supratentorial ICH, so named because it occurs above the cerebellar tentorium, is classified as being lobar (i.e., involving the hemispheres of the cerebrum) or deep (i.e., implying involvement of structures of the midbrain, such as the thalamus, putamen, or caudate nucleus). Infratentorial, below the tentorium, refers to involvement of either the brainstem, usually the pons, or cerebellum.²⁵

Incidence

The incidence of ICH is low among persons younger than 45 years, and it increases dramatically after the age of 65 years. In one study the incidence of ICH doubled with each advancing decade until age 80 years, after which the incidence became 25 times higher.²⁴ ICH tends to occur more frequently in men. In the United States, African-Americans are more likely to have an ICH than are whites. Worldwide rates are higher in Asian populations than in Western populations. ICH is a major cause of morbidity and death and accounts for 10% to 15% of all strokes in whites and about 30% of strokes in African-Americans and individuals of Asian origin. Locations of hypertensive ICHs are the putamen (40%), lobar (22%), thalamus (15%), pons (8%), cerebellum (8%), and caudate (7%). Figs. 32-17 and 32-18 represent the areas most likely to be involved in ICH and occurrences.

Spontaneous ICH can also occur in association with the prescription of anticoagulants, primary or metastatic brain tumors or granulomas, and use of sympathomimetic drugs. Aneurysms rarely bleed only into the brain, but when they do, they cause a local hematoma near the brain surface.

Etiologic and Risk Factors

Spontaneous ICH in the parenchyma of the brain usually is from an anomaly of the vessel structure or changes brought on by hypertension. Hypertension represents the single most important modifiable risk factor for ICH. Cerebral amyloid angiopathy (CAA) causing abnormal changes in the vessels of the brain accounts for approximately 10% of ICHs. CAA is recognized as an important cause of ICH in elderly persons.²⁹

Excessive use of alcohol has been associated with massive spontaneous ICH. Alcohol has a number of acute and chronic effects that may contribute to hemorrhagic

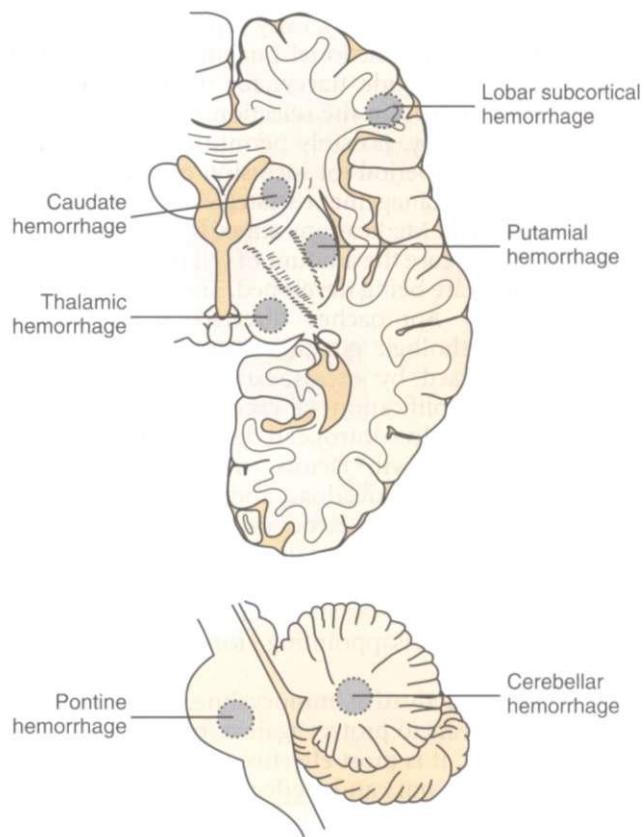


Figure 32-17

Horizontal cerebral section (top) and sagittal brainstem section (bottom) showing most common sites of ICH. (Modified from Caplan LR: *Caplan's stroke: a clinical approach*, ed 3, Boston, 2000, Butterworth-Heinemann.)

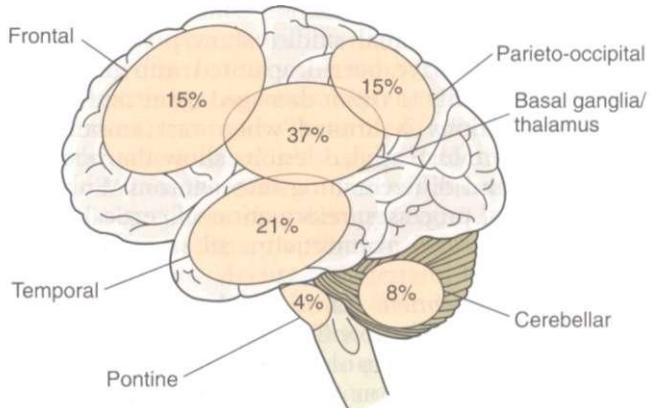


Figure 32-18

Sites of predilection of ICH. (Modified from Lindsay KW, Bone I, Callander R: *Neurology and neurosurgery illustrated*, New York, 1986, Churchill Livingstone.)

stroke, such as direct effects on cerebral vessels, hypertension, and impaired coagulation. Cocaine and amphetamine use is acknowledged as an important cause of ICH.

ICH is the most important adverse effect of thrombolytic therapy. Hemorrhage from fibrinolytic agents can occur within 12 to 24 hours and are typically lobar, occurring in the cortex and subcortical white matter.²⁹

Long-term anticoagulant therapy is associated with an increased risk for ICH. Many individuals with anticoagulant-associated ICH are also hypertensive, so that the extent of increased risk is difficult to clearly identify independently.⁸³

Use of other medications in conjunction with thrombolytic therapy may place individuals at risk for ICH. A number of drugs, such as nonsteroidal antiinflammatory agents, nitrates, and propranolol, may affect platelet function and contribute to bleeding.¹¹⁴

Other possible risk factors include liver disease, prior ischemic stroke, and cigarette smoking. Obesity, sickle cell anemia, mitral valve prolapse, patent foramen ovale, and polycythemia have been identified as possible risk factors. More research in this area is ongoing and will provide more insight into the relation of chronic disease and lifestyle to ICH.

Pregnancy may increase the risk of ICH. Eclampsia accounts for more than 40% of ICHs in pregnancy and is a common cause of death secondary to eclampsia.

Pathogenesis

Histopathologic changes in the cerebral microvasculature of hypertensive individuals include processes that affect both the contents and the walls of the blood vessels of the brain. These changes are seen in small cerebral arteries and arterioles where they branch, and they are more severe in the small penetrating vessels in the deep white matter than in cortical vessels of similar size. Changes are more severe distally than proximally. Smooth muscle cells are progressively replaced by collagen (hyalinization). Altered permeability of the vessel wall leads to fibrinoid changes in the vessel wall. This results in accumulation of proteinaceous material and fat deposits on the subintimal wall. The vessel wall becomes prone to leakage or rupture.¹⁰⁸

Those with hypertension have a substantial reduction in the percentage of smooth muscle in the vessel wall. This decreased smooth muscle mass most likely represents structural weakening, resulting in rupture and hemorrhage. Necrosis of the endothelium may be a result of vessel ischemia. The changes in smooth muscle and the thickening of the intimal wall increase the metabolic requirements and impede the flow of oxygen to the outermost part of the vessel wall.

CAA is characterized by protein fibrils in the arterioles and small cerebral arteries and is formed by aberrant protein synthesis. Amyloid replaces smooth muscle in the media, separating the elastic membranes. Lymphocytic infiltrates, hyaline arteriole degeneration, and fibrinoid necrosis are characteristic changes in the vessel wall. The parenchymal changes seen in CAA reflect the consequences of the vascular pathology and direct deposition of amyloid in the brain tissue. Brains with evidence of CAA frequently demonstrate periventricular demyelination, believed to be caused by ischemia from amyloid deposition in the vessels supplying the deep white matter.^{30,39}

In drug-related ICH, some underlying vascular pathologic lesion may be present, such as an arteriovenous malformation (AVM) or chronic vasculitis. The ICH occurs as a result of a sudden increase in blood pressure

triggered by the drug. The proposed mechanism for the increased incidence of ICH in the individual with increased alcohol ingestion is decreased circulating levels of clotting factors produced by the liver. Thrombocytopenia, which is often associated with alcoholism, may underlie or potentiate hemorrhage.³⁵

Hemorrhagic transformation, or conversion of an ischemic cerebral infarction, refers to secondary bleeding believed to occur either with early reperfusion into a damaged vascular bed with impaired autoregulation or as a result of development of collateral circulation into the same vascular bed.

When hemorrhage occurs, it spreads along a path of least resistance, primarily following the fiber tracts of the white matter. Grey matter, with its dense cell structure, is more resistant to the shearing forces of the growing hematoma and is more likely than white matter to be compressed rather than infiltrated by the spreading hematoma. Edema forms in the parenchyma surrounding the hematoma. Blood is reabsorbed by macrophages at the periphery of the hemorrhage, leaving a cavity surrounded by necrotic tissue. This process usually takes weeks to months.¹⁰⁷

Clinical Manifestations

Neurologic symptoms occur gradually in most cases, representing the expansion of the hematoma. In some cases (approximately 30%) onset is sudden, which is also characteristic of an ischemic stroke. The earliest signs relate to blood issuing into parenchymatous structures. For example, a hematoma in the left putamen and internal capsule would first cause weakness of the right limbs; a cerebellar hematoma would cause gait ataxia. As the hematomas enlarge, the focal symptoms increase. If the hematoma becomes large enough to raise ICP, headache, vomiting, and decreased alertness develop. Some hematomas remain small and the only symptoms relate to the focal collection of blood. Once the condition is stabilized, the symptoms improve in parallel with the resorption of the hematoma.

Although headache is an important symptom of ICH, it is present in severe form in only 30% to 40% of cases. Headache is most common as a sign of superficial and large hemorrhages.

The incidence of seizure correlates with the location of the hemorrhage. Cerebral cortex hemorrhage causes the most prevalent seizure activity. Two thirds of the seizures are generalized and one third are focal. Focal seizures affect the body on the contralateral side (see Chapter 36). The level of consciousness at onset is unrelated to the occurrence of seizure.

Syndromes. Syndromes associated with ICH are representative of the area of bleed and reflect brain activity of the particular site.⁸ Table 32-1 gives typical signs in individuals with intracerebral hemorrhages at various sites.

Putamen. Approximately 50% to 80% of hemorrhages occur in the putamen. The result is contralateral sensorimotor deficit resulting from its proximity to the internal capsule. Small putamen hemorrhages may mimic lacunar syndromes, such as pure motor weakness. A type of aphasia may be present that mimics Broca aphasia when

Table 32-1 Signs in Patients with ICHs at Various Sites

Location	Motor/Sensory	Eye Movements	Pupils	Other Signs
Putamen or internal capsule	Contralateral hemiparesis and hemisensory loss	Ipsilateral conjugate deviation	Normal	Left: aphasia Right: left-sided neglect
Thalamus	Contralateral hemisensory loss	Down and in, upgaze palsy	Small, react poorly	Somnolence, decreased alertness Left: aphasia
Lobar				
Frontal	Contralateral limb weakness	Ipsilateral conjugate gaze	Normal	Abulia
Temporal	None	None		Hemianopia Left: aphasia
Occipital	None	None		Hemianopia
Parietal	Slight contralateral hemiparesis and hemisensory loss	None		Hemianopia Left: aphasia Right: left-sided neglect Poor drawing and copying
Caudate	None or slight contralateral hemiparesis	None	Normal	Abulia, agitation, poor memory
Pons	Quadripareisis	Bilateral horizontal gaze paresis, ocular bobbing	Small, reactive	Coma
Cerebellar	Gait ataxia, ipsilateral limb hypotonia	Ipsilateral gaze or cranial nerve VI paresis	Small	Vomiting, inability to walk, tilt when sitting

the lesion is in the mid-putamen. Wernicke's aphasia is seen with a posterior putamen lesion. Pupillary abnormalities, visual field loss, and oculomotor deficits are common. Conjugate gaze deviation toward the side of the lesion may be present. Abulia and motor impersistence are seen when the anterior putamen is affected. Headache and vomiting also occur in about 25% of cases.

Thalamus. Sensory losses, or dysesthesias, are common with thalamic hemorrhage, and some motor deficit occurs secondary to internal capsular involvement. The lateral thalamus abuts the posterior limb of the internal capsule. Oculomotor dysfunction also is seen, the most frequent abnormalities being vertical gaze palsies, often with downward eye deviation and convergence spasm. Constriction (miosis) of the pupil is seen in 50% of cases. In dominant hemisphere thalamic lesions, aphasia, disorientation, and memory disturbances may be seen. With nondominant lesions, apraxia (impairment of a learned motor activity) may exist. Midline hematomas are associated with alterations in the level of consciousness during the acute phase followed by prefrontal signs, such as change in character, speaking to oneself, memory disturbance, and impaired learning. Although not as common, the individual may experience symptoms such as headache, nausea, and vomiting to the same degree as with putamen hemorrhage.

Cerebellum. A hallmark of cerebellar hemorrhages is ataxia. Additional symptoms may be nausea and vomiting, and dizziness with nystagmus and vertigo often is present. The individual may be dysarthria. Brainstem signs, such as facial paresis, can be present with a hemorrhage that extends to the brainstem. The signs of cerebellar hemorrhage should be carefully monitored, as the

progression to compression of vital structures in the region of the fourth ventricle and medulla can be rapid and can produce life-threatening changes.

Pons. Brainstem hemorrhages commonly arise in the midline of the pons, leading to coma, quadripareisis, and nonreactive pupils with absent horizontal eye movement. Lateral pontine hemorrhage can result in extraocular paresis with deviation away from the side of the lesion. Quick, downward jerks of the eye occur with a slow, upward drift. Pupils are small but reactive. Contralateral sensory and motor symptoms and ipsilateral cerebellar signs also are seen.

Caudate. Caudate hemorrhages can rupture into the ventricles and therefore have a presentation like that of a SAH. Headache, vomiting, and loss of consciousness may occur. The internal capsule may be involved, causing sensorimotor involvement.

Internal Capsule. Internal capsule hemorrhages often result in a pure motor, pure sensory, or sensorimotor stroke with ataxia. The internal capsule is a white matter tract that is situated lateral to the basal ganglia as it connects to the cerebral cortex.

Lobar. Lobar hematomas are centered in the immediate subcortical white matter. Symptoms are lobe-specific (see the section on Clinical Manifestations of Ischemic Stroke in this chapter and Higher Brain Disorders in Chapter 28). Seizures are more common with lobar hemorrhages than with deeper bleeds.

MEDICAL MANAGEMENT

DIAGNOSIS. The availability of CT allows for prompt diagnosis of ICH. The specific area of damage can be imaged and the amount of blood identified. CT also has documented acute clot retraction progression of hyper-

tensive ICH and early hemorrhagic infarction. It accurately documents the size and location of the hematoma, the presence and extent of any mass effect, and the presence of hydrocephalus and intraventricular hemorrhage. CT scans should be performed immediately in individuals suspected of having an ICH. Follow-up CT scans are requested when there is a change in clinical signs or state of alertness in order to monitor changes in the size of the lesion and ventricular system and to detect important pressure shifts. If the clinical syndrome and CT findings are typical of hypertensive hemorrhage in the basal ganglia, caudate nucleus, thalamus, pons, or cerebellum, angiography is usually not necessary. If the hemorrhage is in an atypical location, the individual is young and not hypertensive, angiography is indicated to exclude an AVM, aneurysm, vasculitis, or tumor. Individuals who have ICH after cocaine use have a high likelihood of vascular malformations and aneurysms and need angiography. Particular attention should be directed to the presence of a coagulopathy. A drug screen should be obtained to evaluate use of sympathomimetics if substance abuse is suspected. Increased sympathetic outflow due to the hemorrhage may lead to an increase in dysrhythmias. Dysrhythmias also may signal impending brainstem compression from an expanding hemorrhage.

MRI can provide multiplanar views and can discriminate subtle tissue changes and rapidly flowing blood. However, it is of limited usefulness in the first 24 hours after ICH. MRI has the capability to detect previous hemorrhage, and it can image the posterior fossa more clearly than can CT.

Prothrombin time, partial thromboplastin time, and platelet count should be performed in all individuals to rule out a bleeding disorder. Coagulation factor deficiencies can be detected by evaluation of liver enzymes. Bleeding time, platelet aggregation studies, and fibrinogen assay also can be indicators of disorders related to possible repeat hemorrhage.

The differential diagnosis for ICH is similar to that of ischemic stroke and includes migraine, seizure, tumor, abscess, hypertensive encephalopathy, and trauma. Hypertensive encephalopathy and migraine also can present with headache, nausea, and vomiting. Although focal neurologic signs are uncommon, they may occur with these entities. With hypertensive encephalopathy, individuals usually have marked elevation in blood pressure and other evidence of end-organ injury, including proteinuria, cardiomegaly, papilledema, and malignant hypertensive retinopathy. These individuals usually improve significantly with treatment of hypertension. Migraines often are associated with an aura, and the individual often has a history of similar headaches.

The difference between ICH and labyrinthitis can be especially difficult to determine in the elderly. The abrupt onset of vertigo, vomiting, and nystagmus can represent a peripheral process, such as labyrinthitis, or a central process, such as cerebellar or brainstem infarct or hemorrhage. Age older than 40 years and a history of hypertension or other risk factors for ICH increase the possibility of a cerebellar hemorrhage. Findings specifically referable to the brainstem must be sought; these include hiccups, diplopia, facial numbness, dysphagia, and ataxia. Vertig-

nous individuals often have a strong desire to remain immobile with their eyes closed, but this must not preclude a thorough cranial nerve and cerebellar examination, including gait. Gross ataxia should be present with cerebellar stroke and absent with labyrinthine disease. A head CT scan should be strongly considered in individuals older than age 40 years to assist in differentiating labyrinthitis and cerebellar hemorrhage.

A screen for toxic substances in the blood should be performed, especially in the younger population. Acquired immunodeficiency syndrome should be considered as a possible cause of ICH. Biopsy of brain tissue can be diagnostic of CAA, cerebral vasculitis, and neoplasm. Evaluation of cerebrospinal fluid may indicate levels of toxicity; however, individuals with increased ICP are at risk during the procedure for possible herniation causing compression of the brainstem.

TREATMENT. The acute reduction of elevated blood pressure is advisable and is most readily accomplished with rapid-acting, potent antihypertensive medication along with effective control of increased ICP, which exacerbates blood pressure elevation.⁴⁹ A major issue in the management of ICH is control of edema (see the section on Treatment of Ischemic Stroke in this chapter). Anticonvulsant therapy should be considered with lobar hemorrhage.

The frequency of ICH may increase with the use of long-term anticoagulation therapy. Treatment with vitamin K is useful to correct an elevated prothrombin time; however, this takes 12 to 24 hours. Fresh-frozen plasma immediately restores diminished clotting factors. Protamine sulfate is the treatment of choice for reversal of the heparin effect. Thrombocytopenia responds to plasma infusion and plasma exchange.

An individual with a potential ICH requires rapid assessment and transport to a facility that has CT scanning capability and intensive care management. The prehospital management is similar to that for ischemic stroke. The circumstances surrounding the event and other concomitant medical conditions also should be ascertained. An evaluation of the initial level of consciousness, Glasgow Coma Scale, any gross focal deficits, difficulty with speech, clumsiness, gait disturbance, or facial asymmetry should be noted.

Supportive care involving attention to airway management and perfusion is of the highest priority. Individuals with hemorrhagic stroke are more likely to have an altered level of consciousness that may progress rapidly to unresponsiveness, requiring emergent endotracheal intubation. Intravenous access and cardiac monitoring should be initiated. Evaluation of blood glucose and appropriate dextrose and naloxone administration should be considered in any patient with altered mental status.

There is disagreement regarding optimal blood pressure management in an individual with ICH. Hypertension may cause deterioration by increasing ICP and potentiating further bleeding from small arteries or arterioles. Hypotension may decrease cerebral blood flow, worsening brain injury. In general, recommendations for treatment of hypertension in individuals with ICH are

more aggressive than those for individuals with ischemic stroke. The current consensus for ICH is to recommend antihypertensive treatment with parenteral agents for systolic pressures greater than 160 to 180 mm Hg or diastolic pressures greater than 105 mm Hg. Treatment for lower blood pressures is controversial. Disadvantages include the need for careful monitoring (ideally with an indwelling arterial catheter) and the theoretical risk of worsening the hemorrhage secondary to the vasodilatory effects of nitroprusside on cerebral vessels. Labetalol is another therapeutic option.

Hyperventilation and diuretics such as mannitol move fluid from the intracranial compartment, thereby reducing cerebral edema. These interventions should not be used prophylactically. Although this effect may be temporarily helpful in the acute setting, the brain tissue re-equilibrates, and rebound swelling can occur and worsen the individual's clinical status. These agents also can cause dehydration and lead to hypotension. The use of steroids in cerebral hemorrhage, previously a common practice, may be harmful and is not recommended. Other experimental modalities include barbiturate coma and hypothermia. Seizure activity can cause neuronal injury, elevations in ICP, and destabilization of an already critically ill individual. In addition, nonconvulsive seizure may contribute to coma. Seizure prophylaxis (18 mg/kg phenytoin) should be considered for individuals with ICH, especially individuals with lobar hemorrhage.

Selected individuals with sizable lobar hemorrhage and progressive neurologic deterioration may benefit from surgical drainage. Surgery is more efficacious in individuals with cerebellar hemorrhage. The clinical course in cerebellar hemorrhage is notoriously unpredictable. Individuals with minimal findings may deteriorate suddenly to coma and death with little warning. For this reason, most neurosurgeons consider emergent surgery for individuals with cerebellar hemorrhage within 48 hours of onset.

PROGNOSIS. Although the overall mortality from ICH is high, functional recovery among survivors is also high. The most important predictor of mortality is hemorrhage size. The individuals who are comatose at onset or who have a wide spectrum of neurologic deficits tend to do poorly compared with those who remain alert and have focal neurologic symptoms. Survival depends on the location, size, and rapidity of development of the hematoma. ICHs are at first soft and dissect along white matter fiber tracts. If the individual survives the initial changes in ICP, blood is absorbed and a cavity or slit forms that may disconnect brain pathways. Individuals with small hematomas located deep and near midline structures often develop secondary herniation and mass effect and have a high mortality rate. Survivors invariably have severe neurologic deficits. In individuals with medium-sized hematomas, the deficit varies with the location and size of the hematomas. Most individuals survive with some residual neurologic signs. The older the individual, the less complete the expected recovery.

Survival for individuals with hemorrhage in the posterior fossa is more dependent on location of hemorrhage

than size. Midline pontine hemorrhage is often fatal, whereas lateral hemorrhages carry a better prognosis.

Subarachnoid Hemorrhage

Overview and Definition

SAH can begin with the sudden onset of a "thunderclap" with searing pain; sometimes the headache begins with exertion. SAH results in frank blood in the subarachnoid space between the arachnoid and the pia, which are contiguous membranes that surround the brain tissue. SAH can be spontaneous, is often seen in normotensive persons, and results in a sudden, severe headache. One percent to 4% of all individuals presenting to the emergency department with a headache have an SAH.

Etiologic and Risk Factors

Aneurysm and vascular malformations are responsible for most SAHs. SAH can be the result of trauma, developmental defects, neoplasm, or infections that cause rupture into the subarachnoid space. Hypertension may be seen in 32% and fever (higher than 37.5°C) in 5%. Vascular malformations are responsible for approximately 6% of hemorrhages into the subarachnoid space. Included in vascular malformations are venous malformation, AVM, and cavernous malformation. The highest incidence of SAH is in women over the age of 70 years. Risk factors for SAH include smoking, excessive alcohol consumption, and hypertension. Definite genetic transmission of the tendency to develop berry aneurysm has not been proven; however, a tendency for familial occurrence of aneurysms is apparent. First-degree relatives of persons who have experienced an SAH have a threefold to sevenfold increased risk of an SAH. If transmitted genetically the effect will most likely be on the connective tissue. Aneurysms are also more common among individuals with hereditary connective tissue disorders. Individuals with hemorrhage resulting from an aneurysm tend to be younger than those with hemorrhage secondary to hypertension.

Individuals with fibromuscular dysplasia, polycystic kidney disease, or connective tissue diseases have a higher incidence of aneurysms. Embolization, often from endocarditis, can cause mycotic aneurysms. Fungi or tumor tissue can travel to the brain. About one fifth of individuals with aneurysms have more than one vascular anomaly or other aneurysms.

Clinical Manifestations

Forty percent of individuals who have SAH present with a sentinel headache. A sentinel headache results from a minor aneurysm leak that precedes rupture by days or weeks. Individuals who experience a sentinel headache typically report headache as the only symptom and have a normal physical examination.

Common associated symptoms include nausea and vomiting (75%), syncope (36%), neck pain (24%), coma (17%), confusion (16%), lethargy (12%), and seizures (7%). Physical examination in individuals who have SAH can have variable findings. For example, nuchal rigidity may take several hours to develop and is present in only 35% to 52% of individuals. Thirty-six percent have a

normal level of consciousness, whereas 28% are somnolent or confused. Focal motor weakness is detected in only 10%, and cranial nerve palsies are seen in 9%. Often noted initially is cessation of physical and intellectual activity, vomiting, and alteration of consciousness. Drowsiness, restlessness, and agitation are especially common. Severe focal neurologic signs such as hemiplegia and hemianopia are absent at onset unless the aneurysm also bleeds into the brain.

MEDICAL MANAGEMENT

DIAGNOSIS. Up to 38% of individuals who have an SAH are misdiagnosed initially. Misdiagnosis of SAH is associated with increased morbidity and mortality. The most common misdiagnoses for SAH are viral meningitis, migraine, and headache of uncertain etiology. Often individuals have subtle presentations and normal neurologic examinations. It is important to realize that the headache of SAH may occur in any location, may be mild, may resolve spontaneously, or may be relieved by analgesics. Prominent vomiting may lead to a misdiagnosis of viral syndrome, gastroenteritis, influenza, or viral meningitis. The presence of blood irritating the cervical or lumbar theca may lead to a misdiagnosis of cervical strain or sciatica.

A CT scan of the head without intravenous contrast is the diagnostic modality of choice in individuals suspected of having SAH. The sensitivity of CT for SAH is approximately 90% to 95%. The longer the duration is from onset of symptoms, the lower is the sensitivity of CT for SAH. Therefore a lumbar puncture should be performed in all individuals suspected of having an SAH when the CT scan is negative or inadequate. The hematoma caused by an aneurysm tends to be of a different character than that caused by hypertension. The location of hemorrhage is also a clue to the diagnosis of aneurysm. Primary sites for hematoma resulting from aneurysms are in the area of the corpus callosum and anterior horns, the frontal lobe, and the temporal lobes. Angiography is required to establish that an intracerebral hematoma has been caused by a ruptured aneurysm.

TREATMENT. Once the diagnosis of SAH is made, the physician should obtain prompt neurosurgical consultation and arrange for transport to the closest emergency department. The treatment of individuals with SAH involves the prevention and management of the relatively common secondary complications of SAH: rebleeding, vasospasm, hydrocephalus, hyponatremia, and seizures. About one half of individuals with SAH have vasospasm, and this problem may resolve or progress to cerebral infarction. Fifteen percent to 20% of individuals with vasospasm die despite maximal therapy. Angiographic vasospasm has a typical temporal course: onset between 3 to 5 days after hemorrhage, maximal narrowing at 5 to 14 days, and gradual resolution over 2 to 4 weeks. Measures of proven value in decreasing the risk of delayed cerebral ischemia are a liberal supply of fluids, avoidance of antihypertensive drugs, and administration of the calcium antagonist nimodipine.

PROGNOSIS. Mortality rate from SAH is high in elderly persons. Functional outcomes are poor, and few individ-

uals 75 years or older are able to live independently at discharge. Early aggressive surgical treatment of elderly individuals admitted in good condition may lead to better outcomes. Seizure-like episodes occur in 25% of individuals after SAH.

If the resulting hematoma is less than 3 cm, the prognosis is good. Evacuation of hematomas that are larger should include resection of the causative aneurysm. Prompt removal may result in dramatic and early improvement of neurologic function. Repeat hemorrhage is more likely to occur if the hematoma is evacuated without treatment of the ruptured aneurysm.^{73,92}

Types of Subarachnoid Hemorrhage

Berry aneurysm is a congenital abnormal distention of a local vessel that occurs at a bifurcation, where the medial layer of the vessel is the weakest. About 90% of SAHs are due to berry aneurysms. Aneurysms are probably caused by a combination of congenital defects in the vascular wall and degenerative changes. Aneurysms usually occur at branching sites on the large arteries of the circle of Willis at the base of the brain. When an aneurysm ruptures, blood is released under arterial pressure into the subarachnoid space and quickly spreads through the cerebrospinal fluid around the brain and spinal cord. Aneurysms are less often caused by arterial dissection through the adventitia of arterial walls, embolism of infected material of distal cerebral arteries (mycotic aneurysms), and degenerative elongation and tortuosity of arteries (dolichoectasia). Fig. 32-19 shows the typical formations of berry aneurysms.

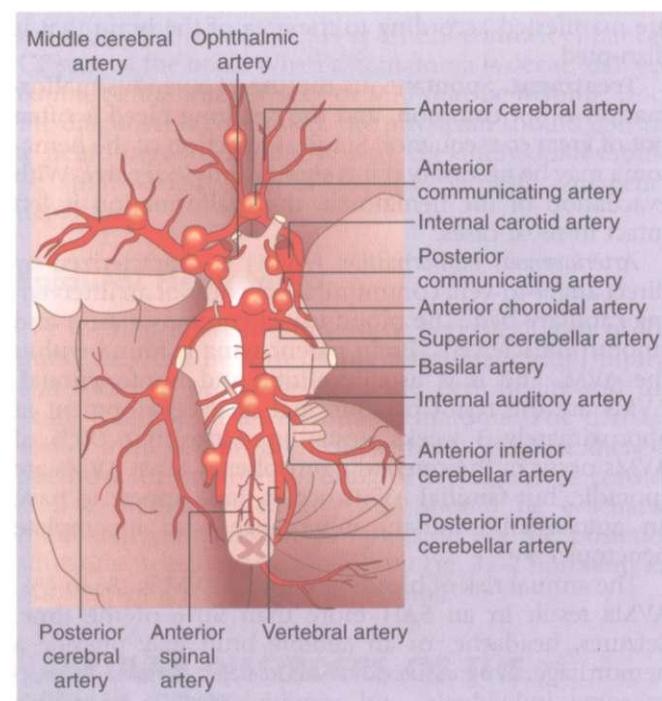


Figure 32-19

Berry aneurysms typically develop at the bifurcations of arteries on the undersurface of the brain. (Reprinted from Goldman L: *Cecil textbook of medicine*, ed 22, Philadelphia, 2004, WB Saunders.)

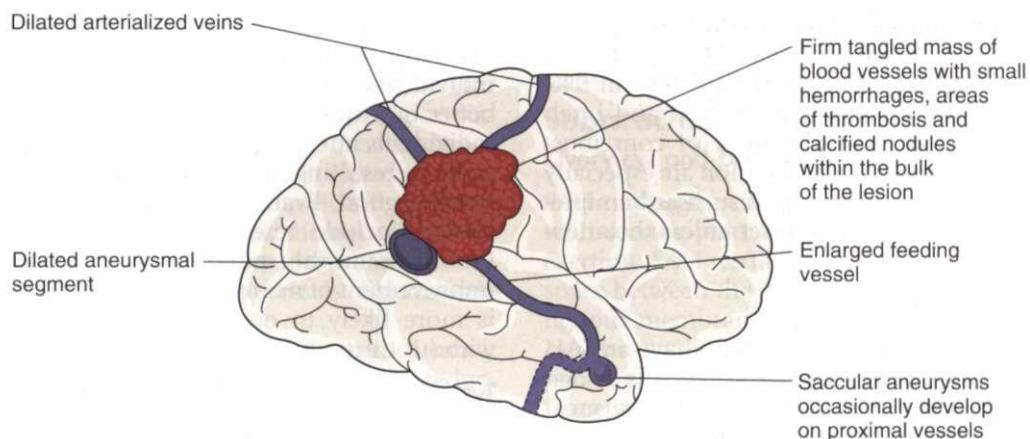


Figure 32-20

Typical deformation of blood vessels and brain tissue in relation to an AVM. (Reprinted from Lindsay KW, Bone I, Callander R: *Neurology and neurosurgery illustrated*, New York, 1986, Churchill Livingstone.)

Venous malformations are composed entirely of veins, which are usually thickened and hyalinized, with minimal elastic tissue or smooth muscle. The veins converge on a draining vein. Normal brain parenchyma is interspersed among the vessels. Venous malformation is the most common form of vascular malformation, constituting approximately 50% of malformations. The risk of hemorrhage from venous malformation has been estimated at 20% per year. Individuals with a cerebellar malformation have the greatest risk of hemorrhage. Occasionally, seizures may be associated with venous malformations. Headaches and focal neurologic deficits are manifested according to the area of the brain that is disrupted.

Treatment. Spontaneous rupture of a venous malformation is not common, and the resulting bleed is often not of great consequence. Surgical resection of the hematoma may be necessary if it is significantly extensive. With evacuation of the hematoma, the malformation is left intact in most cases.

Arteriovenous malformation (AVM) is characterized by direct artery-to-vein communication without an intervening capillary bed. The blood vessel contains elastin and smooth muscle cells. Brain parenchyma is found within the AVM, and it is usually gliotic and nonfunctional. AVMs are the result of abnormal fetal development at approximately 3 weeks' gestation. More than 90% of AVMs occur in the cerebral hemispheres. Most AVMs are sporadic, but familial AVMs occur; these appear to have an autosomal-dominant inheritance with incomplete penetrance.

The annual risk of bleeding from an AVM is 1% to 4%. AVMs result in an SAH more than 50% of the time. Seizures, headache, or an audible bruit may precede a hemorrhage. Progressive focal neurologic deficits develop in some individuals, and cognitive decline may also precede a hemorrhage. AVM-associated hemorrhages occur predominantly in the third and fourth decades of life.

Malformations less than 3 cm in diameter are more likely to bleed than are larger AVMs because arterial pres-

sure is higher in the smaller vessels. A single draining vein, obstructed drainage, or a periventricular or intraventricular location increases the risk of hemorrhage.

Angiography is the definitive diagnostic procedure for an AVM. CT scanning is diagnostic for a dense lesion in the brain. Suspicion of an AVM arises when an area of decreased density is seen around the hematoma and heterogeneous densities appear within the hematoma. MRI is not useful in the diagnosis; however, AVM can be suspected based on MRI with evidence of intravascular moving blood. An AVM should be suspected as a cause of hemorrhage in persons younger than 40 years, especially if they are normotensive. Figs. 32-20 and 32-21 represent the vascular disorder and its appearance on imaging.⁷⁹

Approximately 10% of individuals die from an AVM hemorrhage. In the first year following the hemorrhage, the chance of recurrence is 6%. A concomitant aneurysm increases the chance of recurrent bleeding to 7%.⁷

Neuroradiologic embolization, stereotactic radiotherapy, and surgery are the current treatments for AVM. These techniques are used alone or in combination depending on the size and site of the lesion. Vasospasm after surgery is a side effect, and it appears that surgeries in the posterior circulation are better tolerated than those in the anterior circulation.⁵⁵

Cavernous malformations consist of dilated, endothelium-lined, fibrous channels. No smooth muscle or elastin is present in the vascular walls. Neural tissue is present only at the periphery of the lesion. Thrombosis and calcification within the malformation occur, and gliosis (scarring) often surrounds the malformation.

Cavernous malformations represent approximately 10% of vascular malformations. Multiple malformations can occur in the same person. It is believed that cavernous malformations are inherited through autosomal dominance, with close to 100% penetration. Hispanics are at particular risk for the familial disorder. No apparent relation exists between malformation

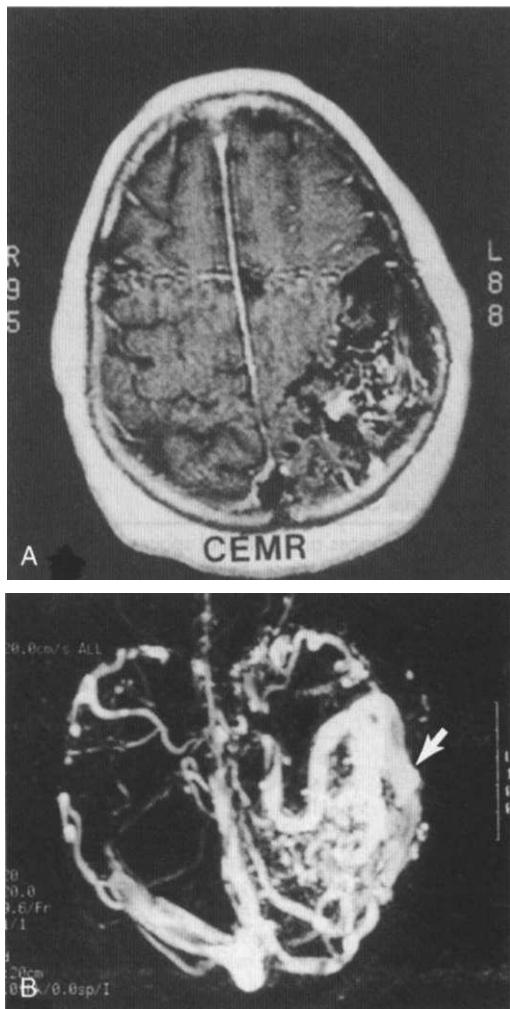


Figure 32-21

The AVM as seen with MRI (A) and MR angiography (B). Arrow points to enlarged vessel in periphery of AVM. (Reprinted from Ramsey R: *Neuroradiology*, Philadelphia, 1994, WB Saunders.)

size and age and the likelihood of hemorrhage. Women tend to be more susceptible to hemorrhage than men. Subclinical bleeding frequently occurs around the malformation.

MRI is the imaging procedure of choice for visualizing cavernous malformations. The malformation appears as a well-defined region with a central area of mixed signal intensity surrounded by a rim of hypointensity.

The majority of individuals recover from a cavernous malformation hemorrhage, and the risk of repeat bleeding is low. Spontaneous rupture of a venous malformation is not common, and the resulting hemorrhage is often not of great consequence. Surgery is the treatment of choice for malformations that have hemorrhaged and are in an accessible part of the brain. The majority of individuals recover from a cavernous malformation hemorrhage, and the risk of recurrence is low.

Syndromes are associated with the location of the hemorrhage, as they are in ICH.

Subdural Hemorrhage

A subdural hemorrhage, or hematoma, is most often the result of tearing of the bridging veins between the brain surface and dural sinus. It results in accumulation of blood in the dural space. If it is a small amount, the body can reabsorb the fluid; if the blood is of great enough volume, as can occur with trauma, it becomes a space-occupying lesion. The lesion is reflected in the area of the hemorrhage and the result can be herniation of the cortex into the adjoining spaces. Fig. 32-22 illustrates the actual spaces and potential spaces in the cranial meninges. Compression of the brain tissue can result in both localized lesions and general decrease in the level of consciousness. Fig. 32-23 represents the pressures on the brain that accompany a subdural hemorrhage. Chronic subdural hematoma (CSH) is defined as a subdural hemorrhage that is more than 20 days old. The peak incidence for CSH occurs in the sixth and seventh decades, with up to 80% occurring in elderly men. In elderly persons, CSH often is caused by minor trauma, especially falls. In the majority of cases there is no underlying brain injury. Fragility of the bridging veins and cerebral atrophy allow increased movement of the brain within the skull, thereby predisposing elderly individuals to CSH. Anticoagulant therapy is a recognized risk factor for CSH. Fig. 32-24 shows the change in brain pressures before and after removal of a CSH.¹⁰⁴

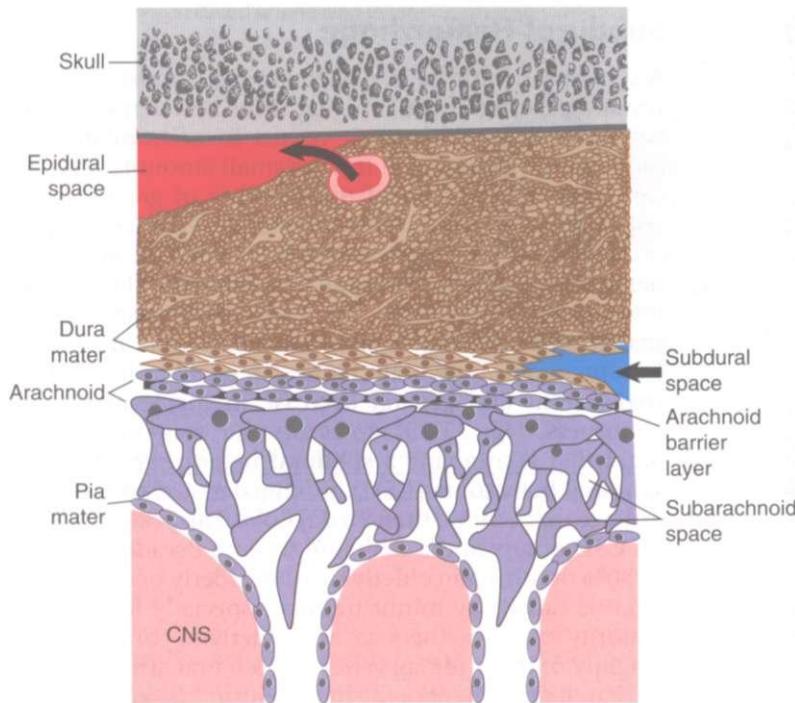
Elderly individuals who have CSH typically present with a complaint of headache and/or changes in mental status. Mild generalized headache is present in up to 90% of individuals who have CSH. Any elderly individual who has headache, especially with a change in mental or functional status, should be evaluated for CSH. The diagnostic modality of choice for CSH is a non-contrast-enhanced CT scan of the head. When a hematoma is dense, delayed contrast-enhanced CT scan or MRI may be helpful. Once the diagnosis is confirmed, the physician should consult a neurosurgeon promptly, and the individual should be transported rapidly to the closest emergency department.

Epidural Hematoma

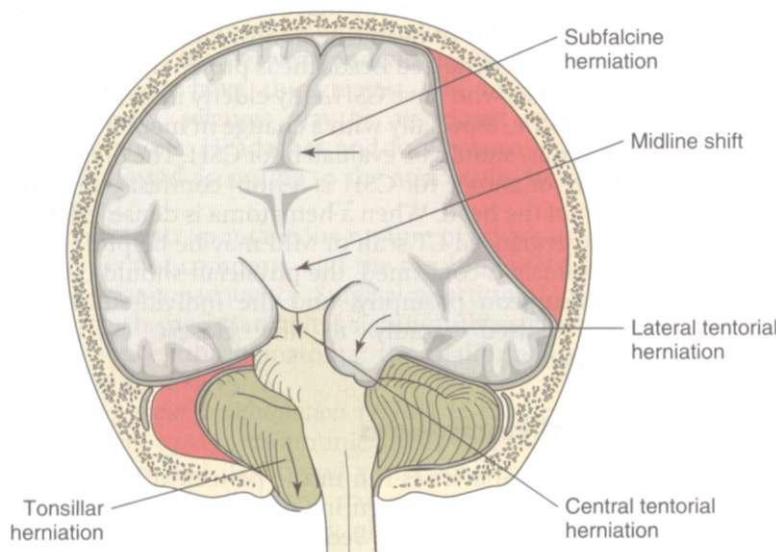
The meningeal arteries run in the periosteal layer of the dura. They can be torn during a traumatic skull injury, and bleeding occurs between the periosteum and the skull, resulting in an epidural hematoma. The damage comes from compression of the brain. Because there is potential for extensive pooling of blood, this is considered a medical emergency and should be evacuated immediately to prevent compression on the posterior structures, which may cause death. Fig. 32-25 presents an MRI showing an epidural hematoma.

VASCULAR DISORDERS OF THE SPINAL CORD

Vascular disorders of the spinal cord are rare; however, vascular disorders of the brain and spinal cord have many common factors. Because of anatomic differences, some

**Figure 32-22**

Actual spaces and potential spaces in the cranial meninges. Epidural space between dura and skull can be opened up by blood from a ruptured meningeal artery. Subdural space may be opened up by blood from a vein that tears as it crosses the arachnoid to enter a dural sinus. (Reprinted from Nolte J: *The human brain*, St Louis, 2002, Mosby.)

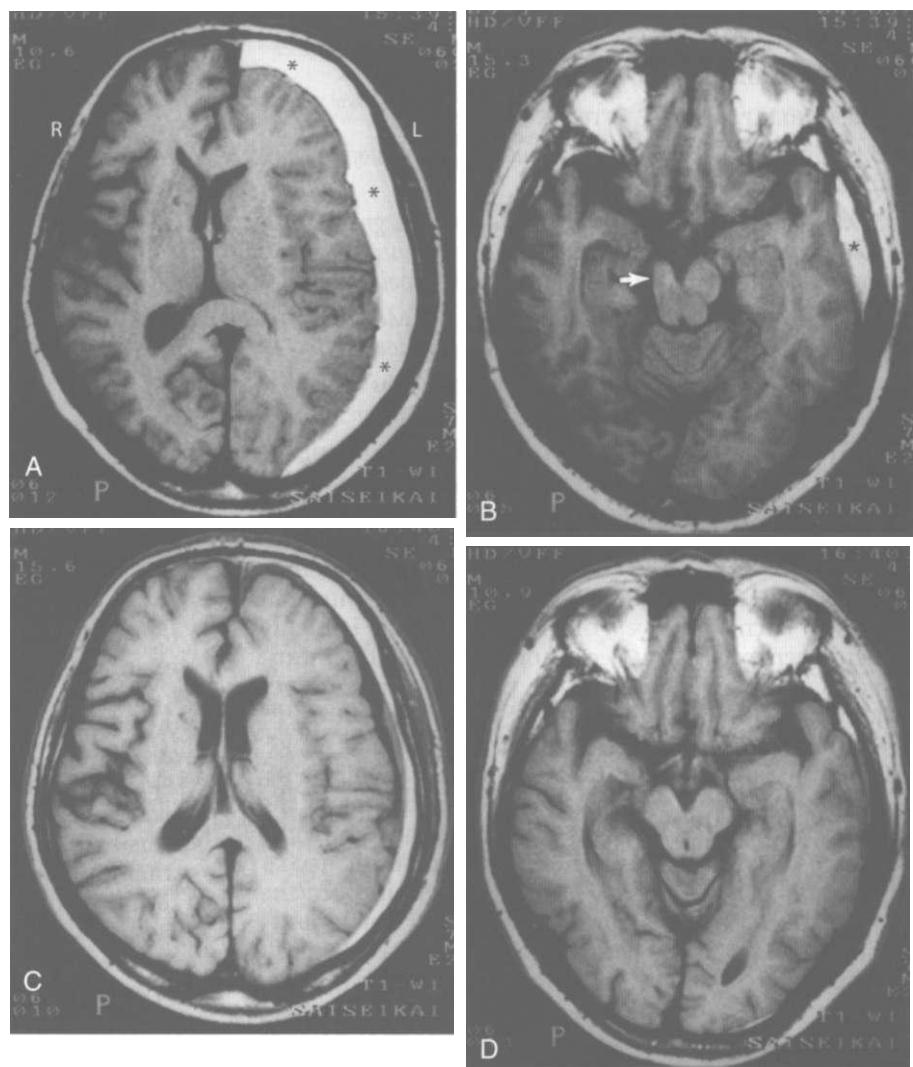
**Figure 32-23**

Compression of brain tissue with herniation into adjacent structures produced by the subdural hemorrhage. (Reprinted from Lindsay KW, Bone I, Callander R: *Neurology and neurosurgery illustrated*, New York, 1986, Churchill Livingstone.)

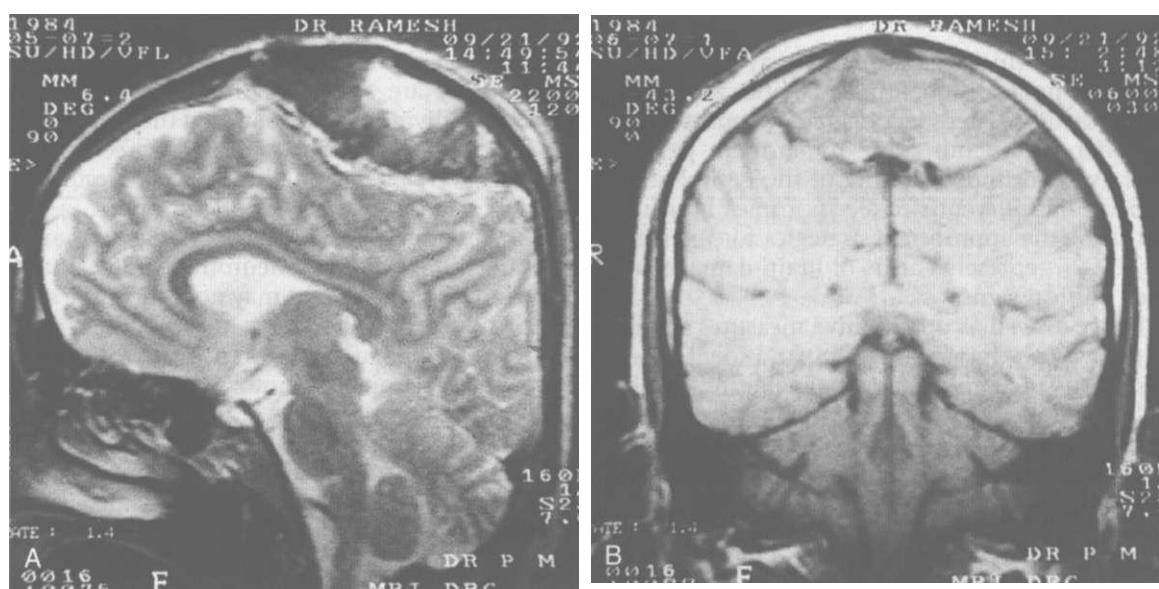
special issues must be considered in vascular disorders of the spinal cord. Infarctions in the spinal cord can be a result of any of the same causes as those in the brain; however, some of the symptoms appear to affect the lower motor neuron at the site of the anterior horn, and the result may be more flaccid extremities and muscle atrophy.

An AVM in the spine can cause pain and burning below the level of the lesion with progressive spastic paraparesis, with or without lower motor neuron lesion. Bowel and bladder dysfunction are seen when the AVM occurs in the lumbar region.

Transverse myelitis, the dysfunction of both halves of the spinal cord in a transverse section, can be related to vascular disorders. In addition to congenital vascular malformation, transverse myelitis can be caused by viral infection, multiple sclerosis, and degenerative disorders. Necrosis of the spinal cord often occurs at several levels, resulting in sensory and motor loss and pain. The lesion may involve nerve roots or just the central structures. The majority of individuals with transverse myelitis experience some degree of recovery (see also Chapter 34).

**Figure 32-24**

A, CSH (*) over the surface of the left cerebral hemisphere, compressing its subarachnoid spaces and lateral ventricle. **B**, Shifting midline structures to the right and deforming the cerebral peduncle (arrow) by pressing it against the tentorium cerebelli, causing left-sided weakness. **C** and **D**, Return to midline of structures and release of pressure after surgical evacuation. (Reprinted from Itoyama Y, Fujioka S, Ushio Y: Kernohan's notch in chronic subdural hematoma: findings on magnetic resonance imaging: case report, *J Neurosurg* 82(4):645-646, 1995.)

**Figure 32-25**

Epidural hematoma seen on MRI. **A**, Sagittal view. **B**, Coronal view. (Reprinted from Ramesh VG, Sivakumar S: Extradural hematoma at the vertex: a case report, *Surg Neurol* 43:138, 1995.)

SPECIAL IMPLICATIONS FOR THE THERAPIST

32-1

Stroke Rehabilitation**PREFERRED PRACTICE PATTERNS**

5A: Primary Prevention/Risk Reduction for Loss of Balance and Falling

5D: Impaired Motor Function and Sensory Integrity Associated with Nonprogressive Disorders of the Central Nervous System—Acquired in Adolescence or Adulthood

5I: Impaired Arousal, Range of Motion, and Motor Control Associated with Coma, Near Coma, or Vegetative State

6E: Impaired Ventilation and Respiration/Gas Exchange Associated with Ventilatory Pump Dysfunction or Failure

The disability resulting from stroke is a major problem for the stroke survivor, the family, and health care providers. A team of professionals is necessary to address the multitude of problems present after stroke. Therapists play a key role in this team, and there is now stronger evidence relating therapeutic intervention to decreased levels of disability. Stroke is highly heterogeneous in its effects, and each individual must be managed according to the particular impairment and disability that remains after the onset of stroke.¹³

The organization of movement changes after stroke. Mobility can be limited by a number of impairments. These changes reflect damage in specific areas of the brain. Basic reflex patterns can change and limit the ability to rely on automatic postural control mechanism for balance. A lack of normal inhibition of the H-reflex in the soleus during activation of tibialis anterior during balance activity has been noted in individuals after stroke. The increased H-reflex activity disrupts the normal on-off cycle in the muscles of the distal extremity and can cause an abnormal balance strategy.^{54,58} Box 32-3 gives examples of typical motor impairments after stroke.

Examination

Identification of which impairments may be causing an inability to perform functional activities and cause disability is critical. There is a degree of spontaneous recovery after stroke, but some impairment persists over time. A good understanding of the typical characteristics of the different stroke syndromes is critical to establishing the appropriate strategies for intervention. Fig. 32-26 represents areas of brain damage and associated clinical signs.

Qualitative as well as quantitative measures should show sensitivity to change over time and identify relevant issues for the stroke survivor, including quality of life.¹⁰⁶ Many measures are currently used and there are efforts to benchmark levels of function that can help determine rehabilitation potential as early in the process as possible.^{18,45,93}

Predicting upper limb recovery after stroke appears to be related to the early ability to shoulder shrug and perform at least synergistic hand movement.⁴⁸ Measurement of movement with a computer-assisted reach can quantify constraint forces and range of motion of the upper extremity. This may lead to more precise

Box 32-3**MOVEMENT PROBLEMS ASSOCIATED WITH STROKE**

- Decreased force production
- Sensory impairments
- Abnormal synergistic organization of movement
- Altered temporal sequencing of muscle contractions
- Impaired regulation of force control
- Delayed responses
- Abnormal muscle tone
- Loss of range of motion
- Altered biomechanical alignment

monitoring of movement and ability to determine recovery.³⁸

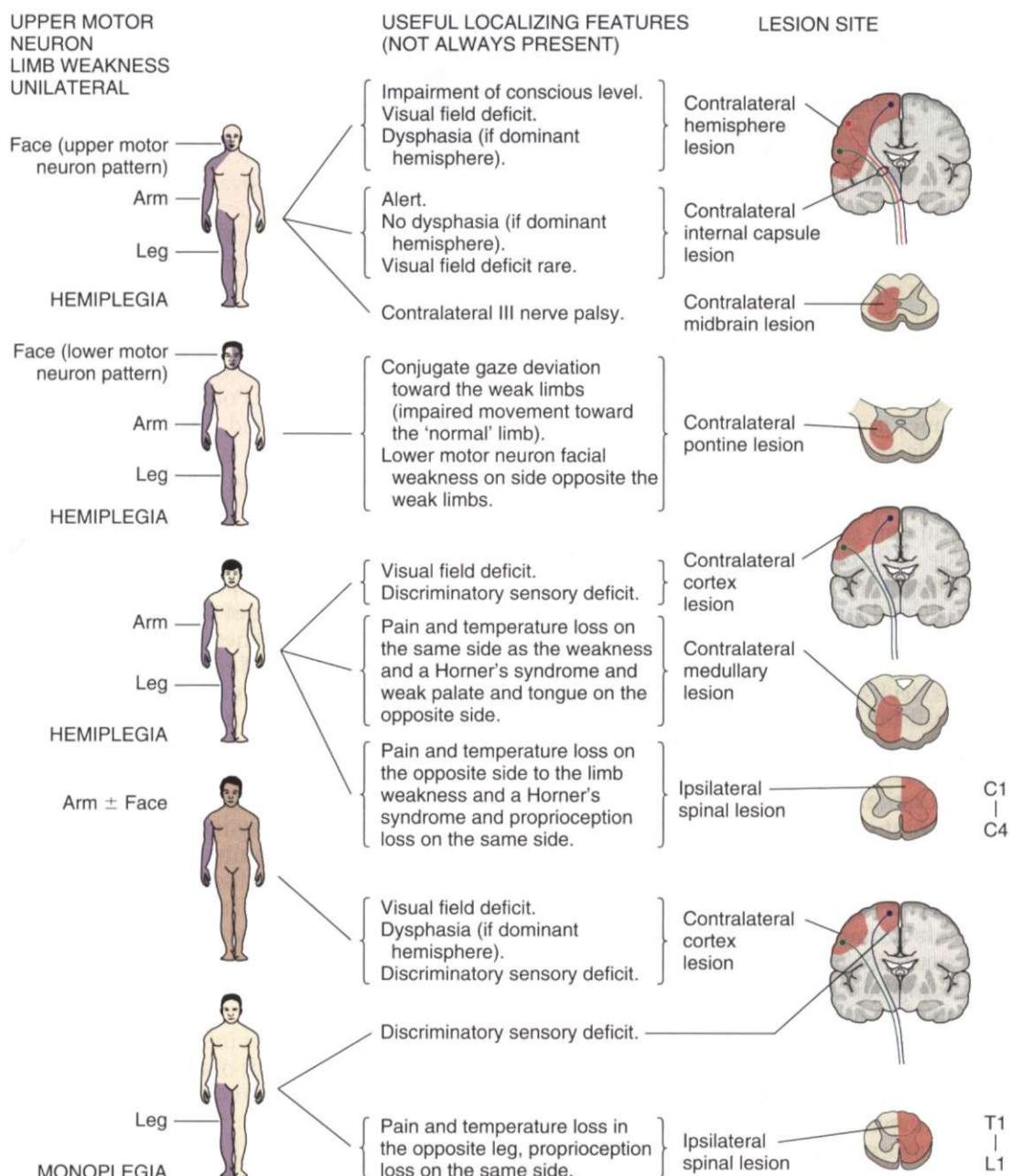
The focus of measurement tools has traditionally been directed toward the contralateral side; however, the degree of impairment and disability of the ipsilateral side always has been questioned.¹¹ Unilateral tapping speed of the ipsilateral fingers may point toward ability to determine if the unaffected side has maintained functional integrity.⁷⁶ MRI demonstrates ipsilateral activation in the primary sensory cortex during contralateral tasks performed in an individual after stroke.³⁸

Discrete differences exist according to the side of hemispheric lesion, with a right hemisphere lesion causing impairment of pacing, transporting, and coordinating two body parts and left hemisphere lesions resulting in impairment in calibrating movements. Despite these differences, there does not appear to be an overall difference in functional level as measured by instrumental activities of daily living between individuals according to which hemisphere the stroke affected.¹⁰

Intervention

Brain reorganization after neural injury is of great interest to therapists, as understanding the relation between alterations in neural structure and functional recovery are critical to the interventions chosen for each individual. It appears that the nature of the infarct may drive the plasticity related to recovery, and while a recovery after a small infarct may result in reorganization around the area of the infarct, a large lesion may require more extensive changes in remote metabolism, blood flow, neurotransmitter function, and axonal sprouting that may not follow the same pattern of plasticity. Inherent in the processes of rehabilitation-dependent motor recovery are restoration and reorganization of motor maps within the cortex surrounding the lesion.^{26,68,95}

Skill acquisition for recovery of function is the main goal in movement retraining. Increased knowledge of neural plasticity will lead to more precision in determining the optimal task practice for motor learning. Problem solving is critical for improving skill, but impairments of motor control such as decreased force production, increased tone, and poor control of degrees of freedom in movement must be adequately addressed. Implicit motor learning also depends on a neural

**Figure 32-26**

Localizing features of damage to specific areas of the brain and spinal cord. (Reprinted from Lindsay KW, Bone I, Callander R: *Neurology and neurosurgery illustrated*, New York, 1986, Churchill Livingstone.).

network that can be affected in the pathogenesis of stroke.^{7,53}

Constraint-induced training with the unaffected limb is effective and is being used in a variety of formats. Increased dexterity and function are possible even after extended time after stroke.¹⁰¹ The specifics of training, including problem solving and manipulating the spatial and temporal aspects of the performance, appear to be inherent in the successful outcomes.

Movement of the upper extremity facilitated with electromyography-triggered stimulus and use of elec-

trical stimulation orthoses continues to be studied with positive effects on movement and functional use of the upper extremity.^{28,105} Robotics are used to assist and retrain movement.¹ There has been a rapid increase in available robotic devices that allow augmentation to hands-on therapy. Robots that assist three-dimensional movement are being developed to mimic the trajectories of human movement.²³

Virtual reality applications are being developed with a focus on attention, executive function, memory, and spatial ability. Functional training for activities

Continued.

such as crossing the street, driving, preparing meals, and navigating by wheelchair are possible with virtual reality.⁸¹

Fall prevention is always a primary goal for the individual sustaining a stroke. Falls are frequent and in more than 5% of cases result in significant injury. Falls are common during the transition from sit to stand, and the kinematics of this activity has been studied. Evidence shows that people who fall take more time to rise and to sit down and demonstrate increased center of pressure sway in mediolateral directions. Weight on the nonparetic leg is significantly increased during the activity.^{14,41}

Obtaining functional and normal-looking gait has long been the goal of therapists and stroke survivors. Research continues in this area.^{64,97} Treadmill training with partial body weight support shows functional changes over typical terrain, with more normal movement of the affected limb during both stance and swing.^{43,102} Computer-assisted gait training results in increased stride length and speed of walking.^{96,97} Balance retraining with center of pressure feedback provides more even distribution and control of center of gravity.⁸⁸

Although a therapeutic goal is often to move clients out of assistive devices, studies show that for some parameters of gait the orthosis or assistive device still provides control over some of the critical components of gait. Rigid ankle braces resulted in longer relative single-stance duration, improved swing symmetry, and ankle excursions. The decreased activity in the anterior tibialis continues to be a drawback.⁴² Use of a cane improves weight shift to prepare for the next step and results in decreased circumduction. Joint angles were more normal during the swing phase.⁵⁶

Control of spasticity and contractures by antispastic pattern positioning, range-of-motion exercise, stretching, and splinting has long been a part of the rehabilitation process. Maintaining soft tissue mobility in the distal extremities is a critical link to the performance of a motor activity. Traditionally it was thought that the activity of the spastic muscle should be limited to prevent further increase in tone; however, it has been shown that increased workload in a spastic muscle can be performed without increasing the spasticity.⁹

Cardiovascular endurance training is indicated for the stroke survivor; programs incorporating such activi-

ties should be part of rehabilitation programs. Treadmill training has been shown to reduce the energy expenditure and cardiovascular demands of gait within the stroke population.⁶³ Submaximal all-extremity exercise shows potential in the rehabilitation programs for stroke.⁶⁰ Research is ongoing to establish the parameters of cardiovascular training within the limits created by neurologic deficits.

Based on the theory of motor learning, the ability to learn a new motor program or a different way of moving does not follow a specific time frame following brain damage.⁵ It appears that the stroke-related sensorimotor deficits affect the processes underlying the control execution of motor skills but not the learning of those skills. Potential for adaptation based on learning goes beyond the time frame of spontaneous recovery.¹⁰⁹

Failure to maintain functional gains after the course of therapy is a concern for all individuals involved in the management of poststroke rehabilitation. Functional exercise done on a regular basis has been shown to have a positive impact on recovery.¹⁷ Early and consistent involvement of the family or primary caretakers is paramount, as is the follow-through of a home management program of activity and exercise. Compliance of stroke survivors and caregivers continues to be low despite efforts toward better education.⁸² The functional consequence of fatigue in physical, professional, and social activities should be considered.³⁶

The clinician and family should watch for symptoms related to angina, peripheral vascular disease, and deep vein thrombosis that may arise after stroke. Osteoporotic bone loss has been demonstrated with immobility of the upper extremity, especially in women, and should be addressed as a part of a standard protocol.¹⁵

References

To enhance this text and add value for the reader, all references are included on the companion Evolve site that accompanies this text. The reader can view the reference source and access it online whenever possible. There are a total of 114 cited references and other general references for this chapter.

CHAPTER 33

Traumatic Brain Injury

KENDA S. FULLER

TRAUMATIC BRAIN INJURY

Overview and Definition

Traumatic brain injury (TBI) is the negative effect on brain function resulting from external physical force. TBI has great influence on outcome from complex trauma. Almost half of the people sustaining a closed head injury die on site, and TBI is often the main cause of persistent morbidity, driving the need for discharge to long-term rehabilitation. Appropriate management of the brain injury results in improved outcome from trauma.³⁵

Typically there is, at least initially, a diminished or altered state of consciousness. Impairment of cognition and physical function are common and may be temporary or permanent. Changes are seen in behavior and emotional control. Functional disability or psychologic maladjustment can be persistent and can have a devastating impact on lifestyle. The long-term effects associated with closed head injury vary depending on the severity of the injury. Differences in recovery are seen in people who appear to have identical injuries.

One of the great challenges to the management of TBI is that the need to control cerebral perfusion or lower intracranial pressure (ICP) can collide with therapeutic goals focusing on problems with infection, ventilation, renal function, or even generalized perfusion. For this reason, integration of brain and systemic care is critical on all levels, from understanding the pathophysiologic principles to treatment through interdisciplinary communication.⁸

Incidence and Risk Factors

TBI accounts for a disproportionate share of morbidity and mortality in traumatized individuals. The past 2 decades have witnessed a significant decline, however, in overall TBI mortality from the mid-30% range in the 1970s to less than 20% in the 1990s. This improvement has paralleled an understanding of the secondary injury process and an appreciation that all neurologic damage does not occur at the moment of insult but evolves over the ensuing hours and days from various biochemical and molecular derangements.

TBI leads to 500,000 hospitalizations per year, resulting in over 175,000 deaths and significant disability.

Although the statistics are somewhat variable, it is estimated that the incidence of TBI currently approaches 222 in 100,000 population per year.¹⁸

The incidence of head injury appears to be close to 2 million persons per year. Many are left with lifelong disabilities that keep them from returning to their preinjury lifestyles. It is believed that there are now more than 5 million persons living with the effects of TBI. Men have twice the chance of sustaining head injury than women based on activities. The average age at the time of injury is 29 years. The incidence of TBI increases with declining income and with rising population density, suggesting that those most at risk for brain trauma are low-income inner-city dwellers.

TBI peaks at three different age levels. The first peak occurs in early childhood at age 1 to 2 years and is related most often to child abuse. The second occurs in late adolescence and early adulthood between ages 15 and 24 years and may be related to risk-taking behaviors. One of the most widespread causes of head injury among young people is bicycling. Wearing an appropriate helmet reduces the risk of severe head injury by 88%.²

Approximately 300,000 sports-related concussions occur annually. Actual incidence may be higher because of potential underreporting of concussion symptoms by athletes. Concussion may occur in sports and situations not typically thought to put the athlete at risk and not necessarily during games. A single concussion does not necessarily lead to long-term neuropsychologic or cognitive complications, but multiple concussions can cause long-term neuropsychologic abnormalities, particularly in executive functioning and information-processing speed. Athletes who have had previous concussions are more likely to have future concussions with longer recovery time.¹⁴

The third peak in TBI occurs in the elderly population and is related most often to falls. This group is the most likely to be hospitalized, and approximately 7% will die while hospitalized. Although elderly individuals account for less than 15% of trauma admissions due to falls, they account for half of deaths due to falls. Stretching of the bridging vessels over the surface of the brain results in increased susceptibility to tearing under shear forces. In addition, there seems to be a significant, age-related

decline in cerebrovascular autoregulation that may partially explain the worse outcomes seen in elderly individuals with TBI.¹

Of the severely brain-injured, approximately 60% of adults and 92% of children are injured in a motor vehicle accident. Pedestrians injured by automobiles represent some of the most seriously injured individuals in trauma. The elderly are at particular risk for being struck as pedestrians and make up a significant percentage of pedestrians who have been struck by a motor vehicle. Slow ambulation; impaired reflexes; misjudgment; and visual, auditory, and gait impairment appear to be involved, as elderly individuals are frequently struck within marked crosswalks or walk directly into the path of an oncoming vehicle. In the elderly there are significantly increased mortality rates, with a majority of deaths occurring at the scene or at the emergency department.¹ Motor vehicle accidents still account for the majority of injuries, but the increasing mandate for seatbelt use and availability of air bags appear to be reducing injuries. The incidence of penetrating TBI from gunshot wounds is increasing, and in some urban communities it is now the most common type of injury seen.¹⁸ Brain injury due to firearms is associated most often with attempted suicide.³²

Alcohol use and abuse are frequently associated with brain trauma. Fifty percent of people admitted into hospitals with head trauma are intoxicated at the time. Brain injury may be two to four times higher in alcoholics than in the general population.²³

Etiologic Factors

TBIs can come from open head injury or closed head injury. With an open head injury, the meninges have been breached, leaving the brain exposed. Penetrating missile injuries create localized, focal lesions that, when not fatal, cause limited damage to the brain. It is not the size of a missile but its velocity that generally determines the extent of damage. Penetrating injury also causes vascular injury, including disruption or the formation of aneurysms or pseudoaneurysms.³⁵ Fig. 33-1 shows the kind of damage that can occur from a gunshot wound.

A closed head injury occurs when there is no skull fracture or laceration of the brain. A closed head injury occurs when the soft tissue of the brain is forced into contact with the hard, bony, outer covering of the brain, the skull. The initial blow occurs under the point of impact; then, as the brain decelerates against the contralateral skull, injury occurs to tissue on the opposite side. Such contrecoup injury is frequently worse than the injury underlying the impact.

Actual loss of consciousness does not always occur, although there is generally an altered state of consciousness. Mild closed head injuries can occur after a severe neck injury without the head actually striking any surface. The symptoms are worse when there is a rotational component to the head injury in addition to the back-and-forth jarring.¹⁷ Both diffuse injury and rupture of veins bridging from the brain to the venous sinuses producing subdural and subarachnoid hemorrhage can occur. Rotational forces are the most likely forces to cause diffuse axonal injury, including damage to brainstem structures, such as the reticular activating system.

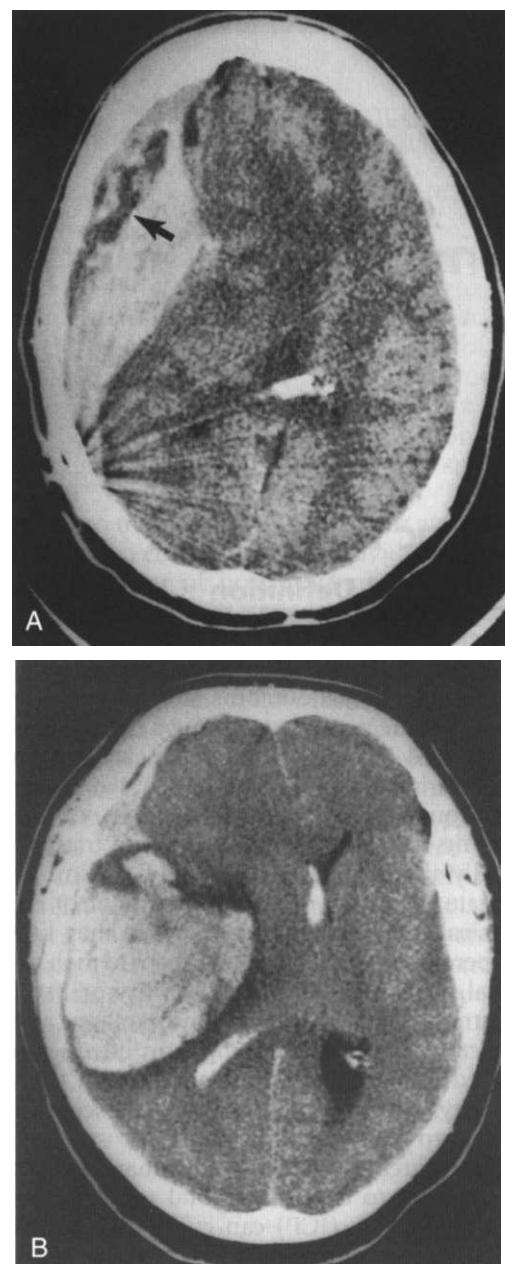
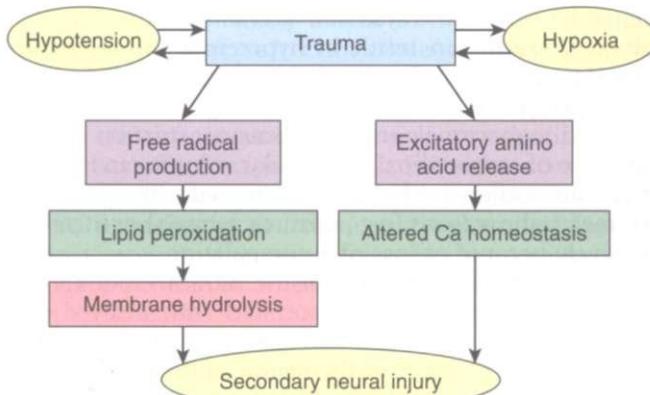


Figure 33-1

Gunshot wound resulting in both intracerebral and epidural hemorrhage. **A**, The bullet is shown on CT scan resting in a midline position with streaking effect of fragments also seen. The arrow points to area of decreased density thought to be epidural bleeding. **B**, Large intracerebral hemorrhage is noted with blood present in the ventricle. (Reprinted from Ramsey R: *Neuroradiology*, Philadelphia, 1994, WB Saunders, p 407.)

Severe head injuries result from significant bruising and bleeding within the brain. Approximately 25% of people with a normal initial computed tomographic (CT) scan will develop late hemorrhages. Contusions are usually more severe in persons with skull fracture than in those without fracture. Although contusion is the hallmark of TBI, severe or even fatal damage to the brain can occur without contusion.⁴

**Figure 33-2**

Biochemical and molecular substrates of the secondary injury cascade. (Reprinted from Salaman M: *Current techniques in neurosurgery*, ed 2, Philadelphia, 1993, Current Medicine.)

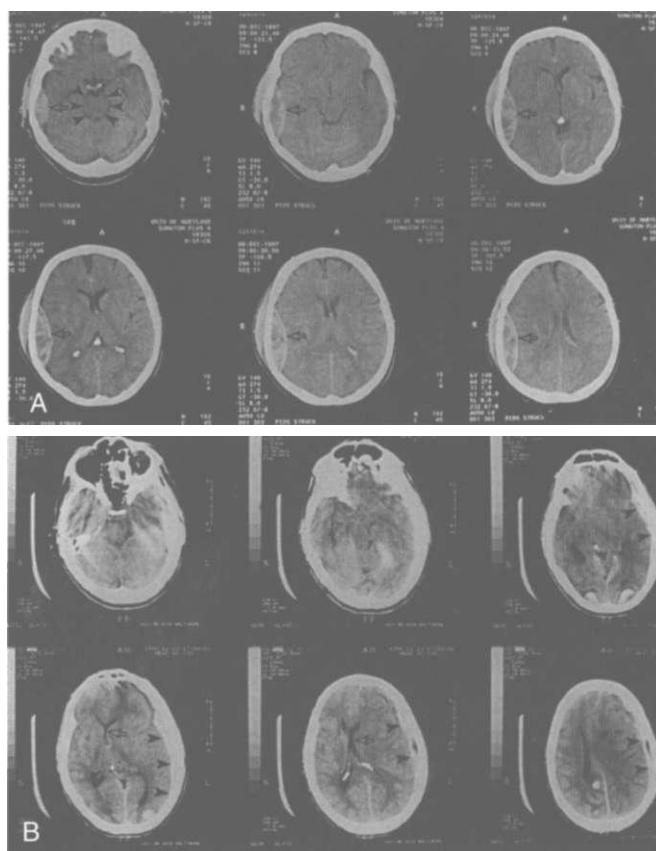
Pathogenesis

Primary damage is the result of forces exerted on the brain at the time of injury. Secondary damage refers to changes compromising brain function that result from the brain's reaction to trauma or other system failure. Causes of secondary damage include brain swelling and impaired cerebral perfusion (Fig. 33-2). Diffuse brain injury includes axonal injury, hypoxic damage, and edema. Multiple small hemorrhages may occur and are predictive of a poor outcome.⁷

Vascular Changes. Focal brain injuries usually result in cerebral contusions. Vascular damage is sustained at the moment of impact and leads to infarction within the cortical grey matter. Glial elements encapsulate the infarction, ultimately creating a residual cystic cavity.²⁶ Typically, contusions occur at the poles and on the inferior surfaces of the frontal and temporal lobes. Occipital blows are more likely to produce contusions than are frontal or lateral blows. Areas where the cranial vault is irregular, such as on the anterior poles, undersurface of the temporal lobes, and undersurface of the frontal lobes are commonly injured. With fracture of the cranial vault, there may be damage to the superficial epidural vessels and, particularly in the case of falls, there can be rupture of the bridging vessels between hemispheres.⁴² Fig. 33-3 shows CT scan images of changes seen after TBI.

TBI can be associated with other forms of vascular change. *Gliding contusions*, or hemorrhagic lesions in the cortex, may be the result of movement of the cortical grey matter in relation to the underlying white matter, causing shear strains to damage the penetrating vessels found at the grey and white matter interface.⁵⁷ Fig. 33-4 shows the effects of shearing injury as seen on CT scan. Subarachnoid hemorrhage is common due to the rupture of pial vessels within the subarachnoid space. This may trigger vasospasm that can lead to reduced regional blood flow. Injury to the vessels within the white matter can also cause significant neurologic consequences, especially if it is in the area of the basal ganglia.²⁶

The increase in blood volume is considered to be the most important cause of increased ICP after head trauma.

**Figure 33-3**

CT scans of two patients with closed head injury. **A**, This patient has a right temporal epidural hematoma (arrows). The mesencephalic cisterns are patent in the top left, indicating a lack of brainstem compression despite mass (arrowheads). **B**, This patient has suffered an acute left subdural hematoma (arrowheads) with midline shift (arrows). (Reprinted from Townsend CM: *Sabiston textbook of surgery*, ed 17, Philadelphia, 2004, Saunders.)

There can be bleeding into the epidural compartment, creating a mass effect that can displace the brain and increase ICP. The shear and tensile forces of traumatic injury can also create a subdural hematoma by disruption of the bridging veins. Acute hydrocephalus occurs when blood accumulates in the ventricular system, expanding the size of the ventricles and causing increased pressure on brain tissue being compressed between the skull and the fluid-filled ventricles.¹⁶ Vascular volume can increase if venous outflow is blocked or increased cerebral blood flow (CBF) increases passively because of loss of autoregulation. Cerebrospinal fluid (CSF) volume increases may be the result of blockage of outflow pathways or interference with reabsorption. When the volume of one compartment changes slowly, compensatory decreases in the volume of other compartments may prevent a rise in ICP. When the volume change is rapid or the compensatory mechanisms are exhausted or dysfunctional, the ICP goes up.⁸

The overall result of these vascular changes is the decreased ability of the cerebral vessels to maintain necessary homeostasis in the face of changing blood pressure or blood gas composition. Initially, within the first few

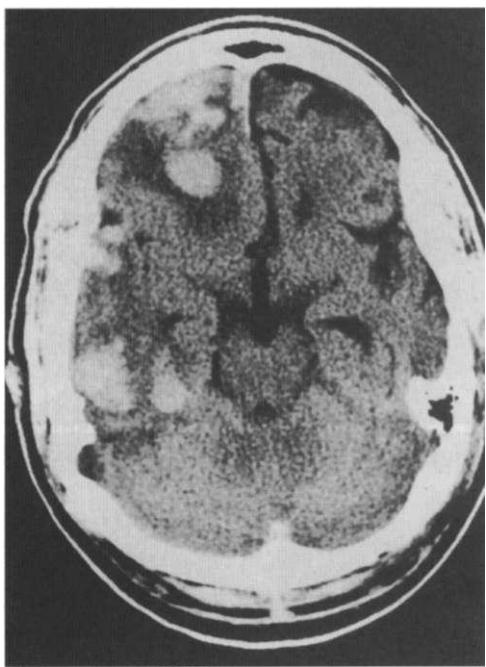


Figure 33-4

Contusion with shearing injury. CT scan shows multiple rounded areas of blood density with surrounding edema. Many of these areas are at the junction of grey and white matter consistent with shear injury. (Reprinted from Ramsey R: *Neuroradiology*, Philadelphia, 1994, WB Saunders, p 409.)

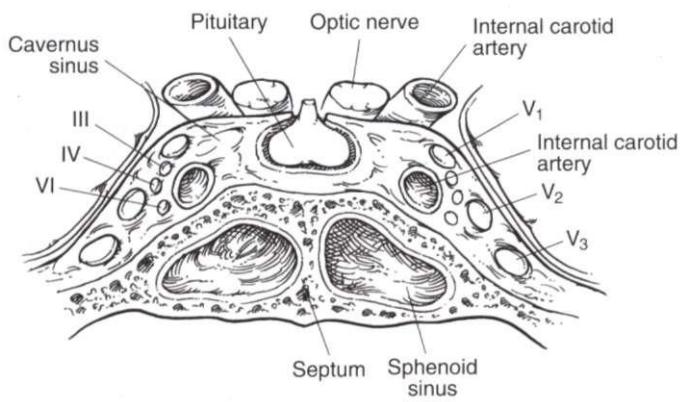


Figure 33-5

Diagram showing the close proximity of the intracavernous internal carotid artery and the sphenoid sinus. (Reprinted from Cummings CW, Haughey BH, Thomas R, et al: *Cummings otolaryngology: head and neck surgery*, ed 4, St Louis, 2004, Mosby.)

hours after severe injury, there is decreased CBF both globally and at the impact site, which can induce ischemia. Within 24 hours the blood flow can be at normal or above-normal levels.²⁶

The impairment of autoregulation of circulation has been described in the presence of moderate to severe head injury. This allows blood flow to the brain to become

dependent upon the systemic arterial pressure. Elevated blood pressure can result in hyperemia and decreased blood pressure, causing hypoperfusion. Impaired vascular responsiveness of blood gas changes in head injury results in abnormal arteriolar vasoconstriction in the presence of carbon dioxide. Vascular volume can increase if venous outflow is blocked or increased CBF is recruited for metabolic reasons (e.g., seizures, pyrexia) or increases passively because of loss of autoregulation.

Posttraumatic aneurysms of the intracavernous internal carotid artery can be associated with delayed and sometimes lethal massive epistaxis. This can be a result of basal skull fractures in the region of the carotid canal or cavernous sinus and/or orbital fractures and compromise of the optical nerves. Knowledge of these risk factors and early diagnosis can minimize the high mortality risk. Fig. 33-5 demonstrates this relationship. It can take from days to years for the artery weakening to develop, with an average time of 3 weeks. Because of the close anatomic relationship of the intracavernous portion of the internal cerebral artery (ICA) to the oculomotor, optic, abducens, trochlear, and trigeminal nerves, these structures may also be damaged during the aneurysm development, resulting in effects such as blindness, facial numbness, and/or oculomotor palsy.¹⁹

There appears to be a change in the endothelium, or walls, of the blood vessels following brain injury. In the normal brain, neurotransmitters such as acetylcholine induce dilation of the vessels through the release of endothelium-derived releasing factor, causing relaxation of the smooth muscle in the vessel wall. In the injured brain this reaction can be missing, resulting in abnormal vasoconstriction.¹⁵ Additional changes at the level of the endothelium result in a disturbed blood-brain barrier in the injured brain. This results in leakage of serum proteins and neurotransmitters into the parenchyma, causing edema. The effects of edema in the brain are described in Chapter 28.

Parenchymal Changes. Axonal injury is a consistent feature of the traumatic event. Shear and tensile forces most likely disrupt the axolemma, which impairs transport of proteins from the cell body and causes swelling of the axon. The distal axon segment detaches and undergoes *wallerian degeneration*. These reactive axonal swellings, or retraction balls, full of axon material develop and can be detected in the injured brain within 12 hours of injury. The myelin sheath pulls away from the axon. The axonal changes are seen throughout the brain regardless of site of impact. The damage is different from that of stroke or tumor, which produces a more complete but local deafferentation. Typically, with diffuse axonal injury, there remain intact axons interspersed with the damaged axons. There is evidence of the potential for recovery of function based on the possible sprouting of undamaged axons to reoccupy the areas left vacant by degenerating axons. Secondary cell death by necrosis of the cellular membrane can be a result of edema. Apoptosis, or programmed destruction from within the cell through changes in the DNA, can result in cell death that occurs days, weeks, or months after injury.⁴³

Study of excitotoxicity related to diffuse brain injury shows that the increase in extracellular neurotransmitters, resulting in increased potassium, causes a massive depolarization of the injured brain. There is a complex interaction of the various amino acids and neurotransmitters, which may affect the postsynaptic functions, resulting in secondary dysfunction of the neural mechanisms of the brain. The excitatory neurotransmitter glutamate appears to rise to abnormal amounts following brain injury. Glutamate is neurotoxic when concentrations increase. See Chapter 28 for information on the damage to the nervous system associated with glutamate.

Free radicals are generated by TBI. Extensive membrane depolarization, induced by trauma, allows for a nonselective opening of the voltage-sensitive calcium channels and an abnormal accumulation of calcium within neurons and glia. Such calcium shifts are associated with activation of lipolytic and proteolytic enzymes, protein kinases, protein phosphatases, dissolution of microtubules, and altered gene expression.¹⁸

Frank blood that moves into the parenchyma is possible and can cause extensive damage and infection of the tissue, especially with open wounds.

Compressive Damage. Intracranial hypertension can produce herniation. During trauma, the brain may shift from its normal symmetric position. The most common herniation is the lateral tentorial membrane separating the cerebral hemispheres from the posterior fossa. This shift may cause compression of the brainstem, the pituitary, or other delicate brain structures. Since the brainstem controls the body's major visceral functions, brainstem involvement may result in paralysis or death. In less severe situations, autonomic nervous system changes may include changes in pulse and respiratory rates and regularity, temperature elevations, blood pressure changes, excessive sweating, salivation, tearing, and sebum secretion. Because the brain is surrounded by the rigid skull, swelling of the brain, or pooling of blood, pushes tissue through openings in the base of the skull or through the other compartments of the brain, resulting in herniation through the foramen magnum. Fig. 33-6 shows the herniation possible with brain injury with epidural bleeding. Table 33-1 lists the possible signs of intracranial hypertension and associated herniation syndromes.

Hypoxia. Hypotension (systolic blood pressure less than 90 mm Hg) occurring between injury and resuscitation occurs in one third of severe TBI victims. It can be caused by blockages resulting in decreased blood in the brain or by decreased oxygen in the blood due to concomitant pulmonary insult. It is associated with doubling of mortality rate and a significant increase in morbidity. Early hypotension is also a strong predictor of poor outcome and can lead to intracranial hypertension in later stages.⁴⁴

Hypertension. Intracranial hypertension can interfere with perfusion by lowering the cerebral perfusion pressure (CPP). Under normal circumstances, cerebral pressure autoregulation maintains CBF constant over a CPP range of approximately 50 to 150 mm Hg. Following trauma, this relationship may be partially or totally dis-

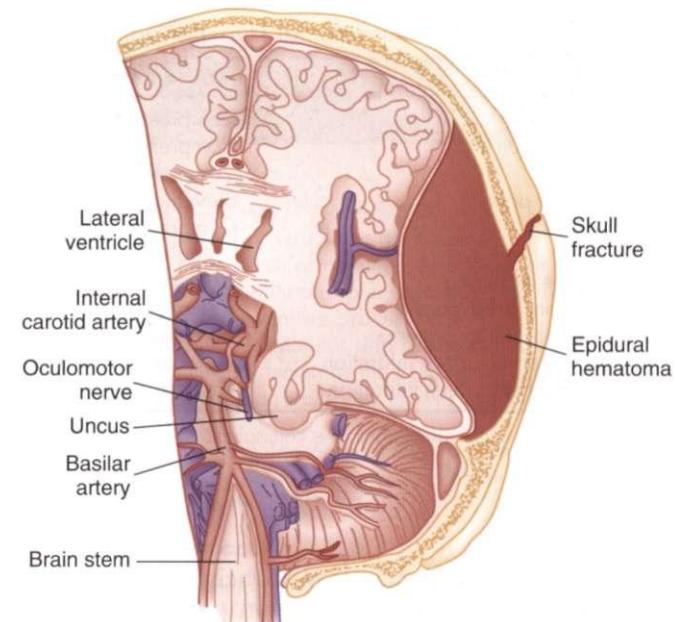


Figure 33-6

Anterior view of transtentorial herniation caused by large epidural hematoma. Skull fracture overlies hematoma. (Reprinted from Rockswold GL: Head injury. In Tintinalli JE et al, eds: *Emergency medicine*, New York, 1992, McGraw-Hill, p 915.)

rupted; the brain can weather limited changes in CPP without notable alterations of CBF.

Clinical Manifestations

Signs and Symptoms. Mild TBI is termed a *concussion*. Concussions are infrequently associated with structural brain injury and rarely lead to significant long-term sequelae. Moderate TBI may be associated with significant structural injury such as hemorrhage or contusion, but death is uncommon. Severe TBI generally results in some form of cognitive and/or physical disability or in death, especially with very low Glasgow Coma Scale (GCS) scores.¹⁸

Concussion. In minor head injury, or concussion, the loss of consciousness lasts a relatively short time, or there may be no loss of consciousness. The postconcussion syndrome is a distinct entity. Symptoms usually associated with concussion are dizziness, disorientation, nausea, and headache. The client may be irritable or distractible and have difficulty with reading and memory. There may be complaints of headache, fatigue, personality changes, and decreased control of emotions.

The symptoms generally reflect both the focal and the diffuse nature of the damage. Changes to neurons, axons, neurotransmitter metabolism, neuroendocrine system (pituitary gland), CBF, and reticular activating system are common. The shearing effects and coup/contrecoup can be responsible for dysfunction in frontal and temporal lobes. A right-sided cortical lesion could cause problems of visual-spatial processing, whereas a left-sided lesion could result in verbal processing deficits. Damage in the

Table 33-1 Signs of Intracranial Hypertension and Associated Herniation Syndromes

Sign	Mechanism	Type of Herniation
Coma	Compression of midbrain tegmentum	Uncal, central
Pupillary dilation	Compression of ipsilateral third nerve	Uncal
Miosis	Compression of the midbrain	Central
Lateral gaze palsy	Stretching of the sixth nerves	Central
Hemiparesis*	Compression of contralateral cerebral peduncle against tentorium	Uncal
Decerebrate posturing	Compression of the midbrain	Central, uncal
Hypertension, bradycardia	Compression of the medulla	Central, uncal, cerebellar (tonsillar)
Abnormal breathing patterns	Compression of the pons or medulla	Central, uncal, cerebellar (tonsillar)
Posterior cerebral artery infarction	Vascular compression	Uncal
Anterior cerebral artery infarction	Vascular compression	Subfalcine (cingulate)

*Hemiparesis will occur ipsilateral to the hemispheric lesion (false localizing sign).

area of the amygdala may lead to heightened arousal, which enhances sensory information processing and is linked to emotional responses. The function of the amygdala is essential to the learning process and understanding of the consequences of action. Divided attention deficit, a reduction in information processing capacity, speed, or amount of information that can be processed, is associated with acceleration and deceleration head injury. This may be related to the diffuse white matter lesion, brainstem dysfunction, or a disruption in the frontal-limbic reticular activating system.¹³ Neuropsychologic testing has shown significant cognitive disability following a concussion. Neuropsychologic testing has documented cognitive impairments, including a reduction in information processing speed, attention, reaction time, and memory for new information.¹⁸

Concussions in athletes can lead to symptoms as described above. A single concussion does not correlate with long-term neuropsychologic or cognitive complications, but multiple concussions can result in long-term neuropsychologic abnormalities, particularly in executive functioning and information-processing speed.

Although cognitive impairment has been shown to resolve within about 7 days for most concussions, cognitive impairment has been shown to persist, particularly for athletes suffering multiple concussions. Epidural hematomas frequently result from skull fractures with subsequent laceration of the middle meningeal artery. Classically, epidural hematoma leads to an initial loss of consciousness, which is followed by recovery of consciousness and a lucid period. The athlete then progressively deteriorates neurologically, with development of headache, a decline in mental status, and focal neurologic findings such as contralateral weakness or numbness, pupillary reflex abnormalities, or facial asymmetry.

Migraine headaches with and without aura can develop in the hours to weeks after a mild concussion. Immediately after mild TBI in sports such as soccer, football, rugby, and boxing, children, adolescents, and young adults may have a first-time migraine with aura. This syndrome may be triggered multiple times after additional mild TBI and has been termed *footballer's migraine*. Cluster headaches can develop after mild TBI. Subdural

hematomas can result in headaches that are nonspecific and that can be mild to severe, paroxysmal or constant, and bilateral or unilateral.¹⁸

Nonspecific psychologic symptoms such as personality change, irritability, anxiety, and depression are reported by over one half of individuals within 3 months of mild TBI. Fatigue and disruption of sleep patterns are also often reported. Posttraumatic stress disorder, which has many symptoms similar to those of the postconcussion syndrome, may occur after mild TBI.

Levels of Consciousness. Altered level of consciousness is a state that can occur with both diffuse and focal head injuries. This can be a result of diffuse bilateral cerebral hemispheric damage or a smaller lesion that affects the brainstem. In many cases, it is probably a combination. In moderate or severe head injury, unconsciousness can be prolonged or persistent. Arousal is associated with wakefulness and depends on an intact reticular formation and upper brainstem.

Coma is regarded as the lowest level of consciousness and is characterized as not obeying commands, not uttering words, not opening the eyes, or a state of unresponsiveness. This indicates advanced brain failure, with bilateral cerebral hemispheric or direct involvement of the brainstem. Coma rarely lasts longer than 4 weeks. The GCS is the most widely used instrument for determining level of consciousness; it is used to determine current status and potential for improvement (Box 33-1).

Some individuals may continue to exhibit a reduced level of consciousness, a condition referred to as *persistent vegetative state*, or postcomatose unawareness, characterized by a wakeful, reduced responsiveness with no evident cerebral cortical function. This includes eye opening with sleep-wake cycles and tracking of the eyes, controlled at a subcortical level. The vegetative state (VS) is notable for preserved arousal mechanisms associated with a complete lack of self or environmental awareness. Individuals in a VS will open their eyes spontaneously, without visual tracking or gaze fixation. There is no purposeful movement and the individual remains mute. The VS can result from diffuse cerebral hypoxia or from severe, diffuse white matter impact damage. The brainstem is usually relatively intact.³

Box 33-1**GLASGOW COMA SCALE****Eye Opening (E)**

- Spontaneous: 4
- To speech: 3
- To pain: 2
- Nil: 1

Best Motor Response (M)

- Obeys: 6
- Localizes: 5
- Withdraws: 4
- Abnormal flexion: 3
- Extensor response: 2
- Nil: 1

Verbal Response (V)

- Oriented: 5
- Confused conversation: 4
- Inappropriate words: 3
- Incomprehensible sounds: 2
- Nil: 1

Coma score (E + M + V) = 3 to 15

Reprinted from Jennett B, Teasdale G: *Management of head injuries*, Philadelphia, 1981, FA Davis, p 78.

The locked-in syndrome consists of quadriplegia in the setting of preserved awareness and arousal. It is caused by injury to the ventral pons.¹⁸ It spares vertical eye movements and can be seen with disordered breathing patterns associated with injury to brainstem respiratory centers. *Cheyne-Stokes breathing* is a rhythmic pattern of alternating rapid breathing and momentary stopping of breathing. It often presents in individuals with hemispheric lesions that are bilateral or can be the result of lesions in the diencephalon. *Hyperventilation* is seen in individuals with pontine or midbrain lesions. *Apneustic breathing* is characterized by a prolonged pause at the end of inspiration and indicates lesions of the mid- and caudal portions of the pons. *Ataxic breathing*, seen with damage to the medulla, is irregular in both rate and tidal volume.

Cognitive and Behavioral Impairments. Cognitive impairments include problems with attention, memory, concentration, and executive functions. Residual cognitive and behavioral deficits often remain despite a return to full consciousness. Deficits, including disorders of learning, memory, and complex information processing and loss of abstract thinking and complex problem solving, reflect the frontal lobe pathology associated with TBI. Loss of executive functions is observed and there is often confusion and disorientation in addition to difficulty in problem solving delayed processing, and lack of initiation. Mood disturbances include depression and anxiety. Symptoms are related to the area of the brain injured.

When the damage is in the orbitofrontal area, behavior may be excessive and disinhibited. Inappropriate social

Box 33-2**COGNITIVE CHARACTERISTICS AND BEHAVIORAL DISTURBANCES ASSOCIATED WITH FRONTAL LOBE SYSTEM PATHOLOGY****Cognitive Characteristics**

- Loss of verbal fluency
- Loss of nonverbal or visual design fluency
- Decreased modulation of attention; specificity of attention
- Increased distractibility and pull toward interfering stimuli
- Slowed speed of cognitive processing
- Decreased ability to monitor and self-correct performance
- General intellectual functions may be within expectations
- Mental inflexibility and inability to shift cognitive set (the way a person thinks)
- Poor abstract reasoning and complex problem solving
- Inability to apply novel strategies in problem solving
- Loss of concrete thinking

Behavioral Disturbances

- Disordered planning and anticipation of events
- Lack of inhibition regarding social behaviors
- Psychomotor agitation
- Sexual inappropriateness
- Euphoria and inappropriate jocularity
- Irritability, emotional lability, depression
- Abulia, apathy, indifference, flat affect
- Paucity of spontaneous movement and gesture
- Motor, sensory, verbal perseveration
- Confabulation
- Echopraxis or imitation of gestures
- Anosognosia or explicit denial of illness or deficit
- Anosodiaphoria or lack of genuine concern about a deficit

Modified from Vomoto JM: Neuropsychological assessment and rehabilitation after brain injury. In Berrol S, ed: *Physical medicine and rehabilitation clinics of North America. Traumatic brain injury*, Philadelphia, 1992, WB Saunders, p 303.

and interpersonal behaviors, including inappropriate sexual behavior, occur with lesions in this area. Septal area lesions result in irritability and rage. Pseudobulbar injuries can result in emotional lability, including euphoria, involuntary laughing, or crying that is not associated with negative emotions.

Cognitive deficits are not always directly observable, but the observable behavior provides information regarding the ability to integrate cognitive processes. The observable behavior of a brain-injured person is directly related to the integrity of cognitive function. The behaviors reflect the inability to adjust to the environment. Typical behaviors include erratic wandering; motor, sensory, and verbal perseveration; imitation of gestures; restlessness; refusal to cooperate; and striking out in response to stimulus or in random fashion. Often the individual will attempt to run away from the institution or home. Deficits in attention are also common. Clients show impulsiveness, hyperactivity, and difficulty sustaining attention. Behavioral changes can be present without cognitive or physical deficits.⁵⁰ Box 33-2 describes some of the typical cognitive characteristics and the resulting behavioral disturbances seen in persons after TBI. A useful tool to assess behaviors

Table 33-2 Rancho Los Amigos Scale for Levels of Cognitive Functioning

Level	Behaviors Typically Demonstrated
I	No response: Client appears to be in a deep sleep and is completely unresponsive to any stimuli.
II	Generalized response: Client reacts inconsistently and nonpurposefully to stimuli in a nonspecific manner. Responses are limited and are often the same regardless of stimulus presented. Responses may be physiologic changes, gross body movements, or vocalization.
III	Localized response: Client reacts specifically but inconsistently to stimuli. Responses are directly related to the type of stimulus presented. May follow simple commands in an inconsistent, delayed manner, such as closing eyes or squeezing hand.
IV	Confused-agitated: Client is in heightened state of activity. Behavior is bizarre and nonpurposeful relative to immediate environment. Does not discriminate among persons or objects; is unable to cooperate directly with treatment efforts. Verbalizations frequently are incoherent or inappropriate to the environment; confabulation may be present. Gross attention to environment is very brief; selective attention is often nonexistent. Client lacks short-term and long-term recall.
V	Confused-inappropriate: Client is able to respond to simple commands fairly consistently. However, with increased complexity of commands or lack of any external structure, responses are nonpurposeful, random, or fragmented. Demonstrates gross attention to the environment, but is highly distractible and lacks ability to focus attention on a specific task. With structure, may be able to converse on a social-automatic level for short periods of time. Verbalization is often inappropriate and confabulatory. Memory is severely impaired, often shows inappropriate use of objects; may perform previously learned tasks with structure but is unable to learn new information.
VI	Confused-appropriate: Client shows goal-directed behavior but is dependent on external input for direction. Follows simple directions consistently and shows carryover for relearned tasks with little or no carryover for new tasks. Responses may be incorrect due to memory problems but appropriate to the situation; past memories show more depth and detail than recent memory.
VII	Automatic-appropriate: Client appears appropriate and oriented within hospital and home settings; goes through daily routine automatically, but frequently robot-like with minimal-to-absent confusion; has shallow recall of activities. Shows carryover for new learning, but at a decreased rate. With structure is able to initiate social or recreational activities; judgment remains impaired.
VIII	Purposeful-appropriate: Client is able to recall and integrate past and recent events and is aware of and responsive to environment. Shows carryover for new learning and needs no supervision once activities are learned. May continue to show a decreased ability relative to premorbid abilities, abstract reasoning, tolerance for stress, and judgment in emergencies or unusual circumstances.

Modified from Hagen C, Malkmus D, Durham P: Levels of cognitive functioning. In *Rehabilitation of the head injured adult: comprehensive physical management*, Downey, CA, 1979, Professional Staff Association of Rancho Los Amigos Hospital, pp 87-88.

as a function of cognitive recovery is the Rancho Los Amigos Scale (Table 33-2). Table 33-3 includes some of the behavioral disturbances and their manifestations in people with TBI.

Impairment of memory is common with head injury. *Retrograde amnesia* is the partial or total loss of ability to recall events that have occurred during the period immediately preceding head injury. *Posttraumatic amnesia* is the time lapse between the injury and the point at which functional memory returns.⁵ During this time there may be improvement in automatic activities, but there is no carryover of tasks requiring memory or learning. The duration of posttraumatic amnesia is considered a clinical indicator of the severity of the injury.³⁷

Anterograde memory is the ability to form new memory. Loss of anterograde memory is common and manifests as decreased attention or inaccurate perception. The capacity for anterograde memory is frequently the last function to return following recovery from loss of consciousness.

Memory disturbance is common with concussion and minor head injury. Memory function is disbursed throughout the brain (see Chapter 28), and there appears to be a lack of ability to use semantic organizational strategy to remember something by associating it with relevant cues. There is commonly difficulty with identifying nonverbal stimuli, reproducing visual stimuli, and

recalling verbal material. Complaints of memory problems are associated with poor performance on tests of speed, reaction time, attention tasks, and complex perceptual-motor abilities. Language deficits are often seen as word- and name-finding problems. However, recovery of language function appears to surpass that of memory in individuals with minor head injury.¹³

TBI is associated with several neuropsychiatric disturbances that can range from subtle deficits to severe disturbances including cognitive deficits, mood and anxiety disorders, psychosis, and behavioral problems. More than 50% of individuals with TBI develop psychiatric sequelae.⁴⁰

Pain. Pain is a common complaint after brain injury with complex interaction on both physical and neuropsychologic function. Even with a mild concussion there is some level of trauma associated. Head and neck pain is common with whiplash, and there is an increased incidence of physical trauma associated with the severity of head injury. Pain can cause a persistent distraction that pulls the individual's attention away from activity and can decrease the ability to concentrate. It can affect the ability to sleep, which leads to daytime lethargy, and it contributes to emotional reactions such as anxiety and depression.⁴⁵

Neuropathic pain can result from the aberrant somatosensory processing in the peripheral or central nervous

Table 33-3 Typology of Behavioral Disturbances after Traumatic Brain Injury

Symptom	Description
Behavioral Excesses	
Inappropriate abrupt physical action	Responds to a situation too quickly without thinking about the adequacy or consequences of the behavior: doing before thinking. Does not include verbal interruptions.
Tangential verbal output	Expresses one thought after another in disconnected or unrelated sequences: rambling speech, unable to get to the point.
Excessive verbal output	Provides too much information; content may be overly detailed or redundant; may be unaware of conversational turn exchange signals or unable to terminate conversation.
Verbal interruptions	Inserts comments that disrupt the flow of conversation or the task at hand; may force other person to relinquish conversational turn before completing the thought.
Inappropriate topic selection	Poor discrimination of appropriate topics for the social context. Revealing statements about personal matters, relationships, feelings that are inappropriate for the social context or level of relationship; excessive self-disclosure.
Inappropriate word choice	Use of profanity or emotionally charged words that are inappropriate for the social context. Overly explicit descriptions and explanations.
Physical proximity violation	Positions body within a spatial proximity of another person that is inappropriate for the level of relationship or social context; violates personal space.
Sexual inappropriateness	Acts with intent to develop intimate or sexual contacts or relationships inappropriate for the level of relationship or in violation of social mores (e.g., with adolescent minors); conversation contains sexual innuendos or lewd comments. May misinterpret others' expression of friendship as sexual advances and responds as above.
Poor social judgment	Unaware of or does not apply rules governing social behavior; does not consider personal safety or safety of others in social context; rude, immature, coarse, tactless. Violates rules of etiquette.
Irritability	Feelings of annoyance or impatience; may accompany restlessness; easily provoked but generally does not escalate into an anger outburst. Tends to be a constant state, usually neither improving nor worsening by a significant degree.
Lability of affect	Magnitude of affect displayed is disproportionate to the antecedent event or social context and does not necessarily reflect the true nature or extent of feelings.
Anxious affect and rumination	Feelings of worry, tenseness, fearfulness, uncertainty about the future. Complains or verbalizes concern over trivia.
Angry transition, verbal	An escalation of verbal output where pitch, volume, or speaking rate increases, dysfluency occurs, aggressive content is delivered. Still within the realm of appropriate. A building-up phase before an outburst.
Angry transition, behavioral	Facial flush; posture threatening; personal space may be violated, body positions exaggerated; agitation behavior is evident such as hair pulling, wringing of hands, clutching the fist.
Anger outburst, verbal	Explosive speech, screaming, abusive language, forceful or harmful content, self-deprecating content, or threats toward another person.
Anger outburst, behavioral	Hitting objects, striking out, exaggerated motions, forceful actions.
Behavioral Deficits	
Absence of or decrease in self-directed action	Decrease in spontaneous behaviors, requires prompts for behavioral action.
Depressed mood	Downcast facial expression, tearfulness, verbalizations of sadness, hopelessness, helplessness, low self-esteem; paucity of interest in pleasant events.
Restricted affect	Display of affect less than proportional to the event; face expressionless; voice monotonous; movement fails to reflect stated feelings.

Modified from Vomoto JM: Neuropsychological assessment and rehabilitation after brain injury. In Berrol S, ed: *Physical medicine and rehabilitation clinics of North America. Traumatic brain injury*. Philadelphia, 1992, WB Saunders, p 307.

system, most common with damage in the area of the thalamus. Myofascial pain is common with trigger points, stiffness, and weakness. A deep, burning pain followed by persistent, involuntary, and irregular movements of the toes and feet, termed *painful legs and moving toes*, can be associated with minor foot and ankle injuries. Fibromyalgia can develop, as it is related to sleep disturbances, anxiety, and depression. Another component of pain is suffering, in which the intensity is dependent on the person's mood, life experience, and level of social support.

The result can often be that the cycle of pain and limitation of central processing can lead to a condition that mimics chronic pain syndrome. Chronic pain can have an impact on the neuropsychologic function as part of a vicious cycle. Managing this syndrome in the individual with head injury can be challenging and warrants good decisions regarding both the pharmacologic and neuropsychologic approaches.¹³

Cranial Nerve Damage. Focal damage in the brainstem can be reflected in the loss of cranial nerve function.

Table 33-4 Brainstem Reflexes in the Comatose Patient

	Examination Technique	Normal Response	Afferent Pathway	Brainstem	Efferent Pathway
Pupils	Response to light	Direct and consensual pupillary constriction	Retina, optic nerve, chiasm, optic tract	Edinger-Westphal nucleus (midbrain)	Oculomotor nerve, sympathetic fibers
Oculocephalic	Turn head from side to side	Eyes move conjugately in direction opposite to head	Semicircular canals, vestibular nerve	Vestibular nucleus, Medial longitudinal fasciculus, parapontine reticular formation (pons)	Oculomotor and abducens nerves
Vestibulo-oculocephalic	Irrigate external auditory canal with cold water	Nystagmus with fast component beating away from stimulus	Semicircular canals, vestibular nerve	Vestibular nucleus, medial longitudinal fasciculus, parapontine reticular formation (pons)	Oculomotor and abducens nerves
Corneal reflex	Stimulation of cornea	Eyelid closure	Trigeminal nerve	Trigeminal and facial nuclei (pons)	Facial nerve
Cough reflex	Stimulation of carina	Cough	Glossopharyngeal and vagus nerves	Medullary cough center	Glossopharyngeal and vagus nerves
Gag reflex	Stimulation of soft palate	Symmetric elevation of soft palate	Glossopharyngeal and vagus nerves	Medulla	Glossopharyngeal and vagus nerves

The following are signs of specific cranial nerve deficits.^{21,46} Examination of the eyes may yield valuable information about the level of brainstem disease causing coma, given the proximity of centers governing eye movement, pupillary function, and elements of the ARAS. Completely normal pupillary function and eye movements suggest that the lesion causing coma is rostral to the midbrain. Table 33-4 lists brainstem reflexes in the comatose individual.

The olfactory nerve is well protected in the cribriform plate, but shearing of the fibers to the extent of damage occurs in about 7% of head injuries. In about 50% of those cases, this is a temporary condition.

The optic nerve is not a true cranial nerve but rather a direct extension of the brain. The most vulnerable component of the optic nerve in people with head injury is the portion of the nerve located within the optic canal. Damage to this portion can result in monocular blindness, a dilated pupil with an absent direct pupillary response, and a brisk consensual response to light. Partial visual defects may take the form of scotomata, sector defects, and upper or lower hemianopia.

The oculomotor nerve works in conjunction with the trochlear and abducens nerves to move the eyeball in the orbit to maintain gaze stability and scanning. Damage is often due to direct insult to the musculature, but it can also be due to cerebral herniation. This nerve is damaged in less than 3% of people with head injury. In some cases there is development of misdirection of regeneration, resulting in constriction of the pupil when any one of the extraocular muscles supplied by the third nerve is acti-

vated. Also, because of misdirection of the growing axons, the levator muscle of the lid may receive fibers destined for other muscles. When the person affected attempts to look down, instead of the globe moving down, the lid becomes elevated.

It is important to understand the difference between peripheral damage to the oculomotor system and the abnormal movement that represents damage of a central nature that affects eye movements. Conjugate lateral deviation of the eyes is a sign either of an ipsilateral hemisphere lesion, a contralateral hemisphere seizure focus, or damage involving the contralateral pontine horizontal gaze center. Lateral gaze palsy may signal central herniation with compression of bilateral sixth nerves. Tonic downward deviation of gaze is suggestive of injury or compression involving the thalamus or dorsal midbrain, such as may occur with acute obstructive hydrocephalus or midline thalamic hemorrhage. Tonic upward gaze has been associated with bilateral hemispheric damage. Ocular bobbing, a rapid downward jerk followed by a slow return to mid-position, is indicative of pontine lesions. Rapid intermittent horizontal eye movements suggest seizure activity.¹⁸

The fourth cranial nerve is the least frequently injured oculomotor nerve. Damage is usually in the form of contusion or stretching. With severe frontal blows, there can be direct damage to the fourth nerve or hemorrhage of the tentorial incisura. There can be a vertical diplopia mimicking a third nerve palsy. The prognosis for recovery in fourth nerve palsy is poor because the nerve is so slender that it is often avulsed by the trauma.

The most common form of trigeminal nerve injury after head trauma involves the supraorbital and supratrochlear nerves as they emerge from the orbit. Damage results in anesthesia of a portion of the nose, eyebrow, and forehead. Facial trauma may extend the sensory deficits to the cheek, upper lip, gums, teeth, and hard palate. In deep coma, the eyelids can be opened easily, and the corneal reflex (indicating fifth nerve palsy) is often absent.

The abducens nerve is often injured when the head is crushed in an anteroposterior plane with resultant lateral expansion and distortion of the skull. It can also be damaged in fractures of the petrous bone. Vertical movement of the brainstem may severely stretch the sixth nerve as it leaves the pons. There can also be damage in relation to the third and fourth nerves in the orbital fissure. There is failure of the eye to abduct when the head is passively turned away from the side of the lesion. Abnormal wandering movements are present in midbrain lesions, and they usually disappear when the person regains consciousness.

Trauma to the facial nerve is common in head injury. With injury to the temporal bone or swelling of the nerve, external compression caused by hematoma symptoms of facial nerve palsy may occur. Loss of tear production, saliva secretion, and taste in the anterior two thirds of the tongue and loss of stapedius muscle function may be noted. Muscles controlling facial expressions become weak.

Hearing and vestibular dysfunction occur in head injuries. Transverse fractures of the temporal bone may cause disruption of the auditory and vestibular end organs or transient eighth nerve dysfunction. A blow to the head creates a pressure wave that is transmitted through the petrous bone to the cochlea, resulting in hair cell damage and degeneration of cochlear nerves. For further information on dizziness and vertigo, see Chapter 38.

The glossopharyngeal, vagus, spinal accessory, and hypoglossal cranial nerves pass through the jugular foramen at the base of the skull. The twelfth nerve passes through the hypoglossal foramen nearby. Injury is most often from a missile wound, but fractures of the occipital condyle can also produce lower cranial nerve palsies. Symptoms include cardiac irregularities, excessive salivation, loss of sensation and gag reflex of the palate, loss of taste on the posterior third of the tongue, hoarse voice, dysphagia, and deviation of the tongue to the side of the lesion.

Motor Deficits. Abnormalities of movement include monoplegia, hemiparesis, and abnormal reflexes. Often there is *flaccidity*, the absence of motor responses, at the onset, which is gradually replaced by increased tone, spasticity, and rigidity. *Decorticate posturing*, or hyperactive flexor reflexes in the upper extremities and hyperactive extensor response in the lower extremities, is common initially and reflects the loss of cortical control. *Decerebrate posturing*, or hyperactive extensor reflexes in both the upper and lower extremities, reflects injury at the superior border of the pons resulting in the loss of inhibitory control of the cortex and basal ganglia.^{2,34}

The specific manifestations of hemiparesis may include loss of selective motor control, abnormal balance reac-

tions, and sensory loss. Cerebellar and basal ganglia dysfunction can result in ataxia, dysmetria, and tremor or bradykinesia. See Chapter 32 for further information regarding focal damage to the brain associated with the area of infarct.

Direct trauma to subcortical and substantia nigra neurons can result in movement disorders occurring shortly after an injury. Movement disorders occurring months following the injury have been hypothesized to be related to sprouting, remyelination, inflammatory changes, oxidative reactions, and central synaptic reorganization. Peripheral trauma that precedes the development of a movement disorder may alter sensory input, leading to central cortical and subcortical reorganization.

Postural and kinetic tremor can be due to direct traumatic lesions of the dentatothalamic circuit. Postural-kinetic tremors of the arms, legs, or head may occur within weeks of mild TBI even without loss of consciousness. Peripheral trauma can induce tremor, which can occur along with reflex sympathetic dystrophy, dystonia, and myoclonus. Myoclonus, dystonia, and athetosis may be present in individuals with posttraumatic tremors.

Contralateral dystonia can be due to a lesion in the striatum, particularly the putamen. The onset of dystonia may have a latency period from 1 month to 9 years. Spastic dystonia due to pyramidal and extrapyramidal injury and paroxysmal nocturnal dystonia are variants of posttraumatic dystonia. Often individuals develop posttraumatic dystonia as a delayed sequela of severe TBI, initially characterized by coma and quadriplegia. After the individual awakens and the plegia improves, severe action dystonia develops.¹⁸

Heterotopic Ossification. Another complication associated with head injury is the formation of *heterotopic ossification* (HO), or abnormal bone growth around a joint. The cause and pathogenesis of HO is unknown, but bone scans show evidence of increased uptake, and there is also elevation of alkaline phosphatase.

The onset of HO is usually 4 to 12 weeks after the head injury, and it is first represented as a loss of range of motion. Local tenderness and a palpable mass can be detected, and there can be erythema, swelling, and pain with movement. HO in the hip area can mimic deep vein thrombosis. Peripheral nerve compression will sometimes develop, especially if the HO is in the elbow. HO can also result in vascular compression and possible lymphedema.⁵³

Medical Complications. Multiple medical complications can also occur after TBI. Cardiovascular effects of TBI include neurogenic hypertension and cardiac dysrhythmias. Respiratory complications such as neurogenic pulmonary edema, aspiration pneumonia, and pulmonary emboli usually caused by deep venous thrombosis are common. Other complications include disseminated intravascular coagulation, hyponatremia, diabetes insipidus, and stress gastritis. Iatrogenic infections are common.

MEDICAL MANAGEMENT

DIAGNOSIS. The diagnosis of brain injury starts at the level of concussion, and the American Academy of

Neurology guidelines include three levels of concussion. The *second impact syndrome* should be addressed as a diagnostic entity, as the cumulative damage from multiple concussions can lead to long-term brain damage and disability. Every possible concussion should therefore be reported and maintained as part of an individual's medical record. Athletic injury, falls, and minor auto accidents can result in concussions that are often not reported to health care providers. In general, people who have lost consciousness for 2 minutes or more following head injury should be observed medically from the time of the impact.

When the person sustains a severe head injury, the GCS is used to assess level of consciousness. Using this scale, three aspects of coma are observed independently: eye opening, best motor response, and verbal response. A score of 8 or less indicates coma. Reflex responses tested by applying a noxious stimulus, such as pressure on a nail bed, fall into three categories: appropriate, inappropriate, or absent.

There is some controversy over including motor responses to describe the depth of coma because neural structures regulating consciousness differ from and are more anatomically distant from those regulating motor function.⁴¹

Oculomotor and pupillary signs are valuable in assisting with the diagnosis, localizing brainstem damage, and determining the depth of coma. Pupillary examination should document size and reactivity to light. Greater than 1 mm difference in size or asymmetry should be considered abnormal. Once the baseline neurologic status has been determined, repeated evaluations are critical to monitor improvement, provide prognostic data, or detect deterioration, which should be addressed immediately. Symptoms of focal neurologic deficits, lethargy, or skull fractures should be monitored. A mental status examination is important in all head-injured individuals. Subtle abnormalities may be a guide to significant intracranial injury.

Higher GCS is associated with greater than normal cardiac index responses and better tissue oxygenation. Poor outcomes are related to low GCS, hypertension, mild tachycardia, normal pulmonary function, and reduced tissue oxygenation.³⁹

Diagnostic imaging can provide significant information, which can guide the intervention and allow a more accurate prognosis. CT is the primary imaging modality for the initial diagnosis and management of the head-injured person. CT scanning of the head reveals the presence of hemorrhage, swelling, or infarction. In individuals with traumatic coma, patterns on CT that have been associated with worse neurologic outcome include lesions in the brainstem, encroachment of the basal cisterns, and diffuse axonal injury (Fig. 33-7).⁵¹ An initially normal CT scan, however, is no assurance that hemorrhagic lesions will not occur.

Diffuse axonal injury (DAI) is a frequent CT and pathologic correlate of severe TBI, accounting for about 50% of primary brain injuries. DAI is usually associated with a poor outcome. DAI is readily identifiable on CT as multiple punctate hemorrhages, typically in the deep white matter and corpus callosum and occasionally in the

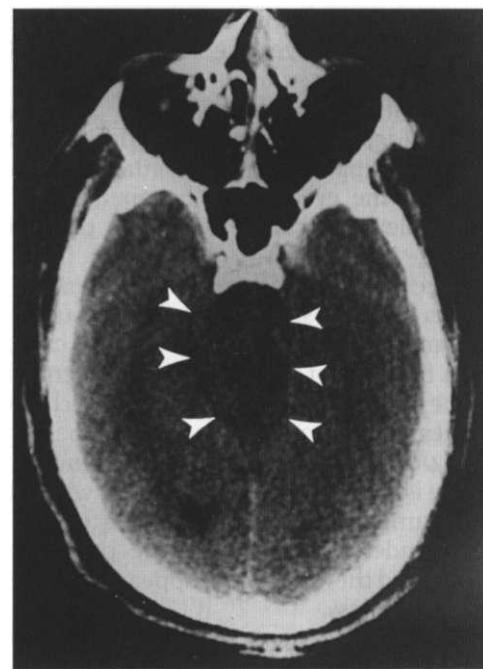


Figure 33-7

CT scan of the head in a patient with a closed head injury. Severe compression of mesencephalic cisterns is seen, indicating midbrain compression. [Reprinted from Townsend CM: *Sabiston textbook of surgery*, ed 17, Philadelphia, 2004, Saunders.]

brainstem. DAI may also occur as a result of mild TBI and may culminate in subtle types of cognitive deficits. Approximately 10% to 15% of individuals with clinically severe TBI have a normal CT scan. In such situations, the possibility of extracranial or intracranial vascular disruptions may exist, and angiography should be considered.¹⁸

Current imaging with CT or magnetic resonance imaging (MRI) does not permit quantification of neural injury that occurs after a traumatic brain concussion. Proton magnetic resonance spectroscopic imaging can be used to assess the neurochemical damage derived from a cerebral concussion by monitoring N-acetyl-L-aspartate (NAA) levels over time. Current research indicates that NAA diminution appears to be linked to a general mitochondrial dysfunction, and therefore NAA restoration can be considered a surrogate marker of metabolic recovery. The ability to identify postconcussive individuals who are in a vulnerable cellular state is important as there can be a catastrophic deterioration in individuals even with a simple head injury. The combination of metabolic data, physiologic data, and clinical observations satisfactorily addresses the complete recovery from concussion.³⁶

CT and Doppler measurements could be combined to detect individuals at risk for secondary neurologic deterioration on admission to improve their initial disposition.³⁰

Clinical examination is of no diagnostic value in predicting head CT scan findings and should not be used as a means of avoiding head CT scans in pediatric practice. If clinical examination alone is used to evaluate children with loss of consciousness or amnesia and minor TBI,

intracranial injuries will be missed. Due to possible implications for learning, return to athletic activity, parent education, and potential medicolegal issues, in all children with observed loss of consciousness or amnesia a head CT scan should be considered as part of the evaluation. Warning signs that may portend need for urgent intervention include any vomiting, restlessness, any GCS score decrease, severe headache, confusion, and focal temporal blow.¹⁰ Vomiting may also represent an individual who is predisposed due to migraine familial characteristics, so this should also be considered.¹¹

MRI is complementary to CT and is used in conjunction with, not as a replacement for, CT. The multiplanar capabilities of MRI are important to better demonstrate extra-axial hemorrhage located subfrontally, subtemporally, or along the tentorium. Lesions in the posterior fossa, as well as shear injury, are better demonstrated on MRI than on CT. MRI can also detect small hemorrhages in the corpus callosum, intraventricular hemorrhages, or effacement of basal cisternal structures in the absence of brain shift or mass lesions. This can lead to the diagnosis of increasing ICP, a significant risk in brain injury.²⁵

MRI offers a sensitive window of detection for neuropathology from mild TBI. MRI is more sensitive than CT to DAI. Anatomic distribution of tissue damage and precise indications of the volume of lesions seen on MRI can predict recovery of the brain in the subacute phase. Prediction of outcome should not be based on CT scanning or MRI alone.²² Positron emission tomography (PET) can be used to identify both structural and functional consequences and is especially valuable for mild head injury.²⁹

Electrophysiologic tests that have been used for predicting coma outcomes include somatosensory evoked potentials, transcranial motor evoked potentials, brain-stem auditory evoked potentials, and event-related potentials. Visual, auditory, and somatosensory evoked potentials make it possible to observe changes in a lesion, and therefore may aid in prognosis, but are not routinely used in isolation.

Neuropsychologic evaluation is valuable in identifying the extent of the cognitive deficits. The evaluation consists of a series of cognitive challenges given to the individual, including assessment of sensorimotor status, attention span, memory, language, sequencing, problem solving, and verbal and spatial integration tasks. Comparisons of normal and brain-injured persons have been well documented. Previous tests of intellectual function, including IQ tests and achievement tests, can be helpful for comparison, especially in mildly brain-injured clients. Cognitive impairment is the primary contributor to disability with moderate to severe brain injury.²⁸ Language and cognitive problems are examined by speech pathologists and can include neuropsychologic testing with naming tests, aphasia examinations, as well as tests of auditory comprehension and speed of comprehension.

Athletes should undergo formal neuropsychologic evaluations when injury is suspected because this may unmask subtle continued deficits when compared with baseline testing. Such deficits have been shown to correlate with duration of symptoms. This has become an increasingly important tool in concussion evaluation.



Figure 33-8

Intubating an acute trauma patient with an uncertain cervical spine. A hypnotic and a relaxant have been administered. One assistant maintains in-line axial stabilization with the occiput held firmly to the backboard; a second applies cricothyroid pressure. The posterior portion of the cervical collar remains in place to "discourage" atlanto-axial extension. (Reprinted from Stene JD: Anesthesia for the critically ill trauma patient. In Siegel JH, ed: *Trauma: emergency surgery and critical care*, Melbourne, Australia, 1987, Churchill Livingstone, p 843.)

Postural stability testing may also be undertaken for adjunctive data in determination of concussion severity.

Cognitive and behavioral dysfunctions caused by brain injury are similar to posttraumatic stress syndrome, conversion or hysterical reactions, malingering, depression, and anxiety. Therefore careful evaluation of each individual should be performed to determine cause of symptoms. It can be considered as well that the trauma occurring at the time of the injury may trigger posttraumatic syndrome or other psychoses in susceptible individuals with history of prior trauma.

Approximately 5% to 10% of individuals with severe TBI have an associated spine and/or spinal cord injury. Initial head injury evaluation and management thus require simultaneous evaluation and management for potential spinal injuries. The majority of individuals with severe TBI have multisystem injury. Possibility of other significant and potentially life-threatening injuries should be evaluated and the proper treatment priorities accordingly established. Fig. 33-9 represents the levels of care that are utilized in the course of treatment. Note that primary prevention is the first step, and it is only when prevention is not provided that the client must begin the acute medical phase.

TREATMENT

Acute. Treatment of TBI requires coordinated care and service from the onset of injury through the person's lifetime. Fig. 33-9 represents the levels of care that are utilized in the course of treatment. Note that primary prevention is the first step, and it is only when prevention is not provided that the client must begin the acute medical phase.

Prehospital management of the severely head-injured person includes rapid triage, resuscitation, and efficient transport. Survival and medical management with the goal of stabilization and prevention of secondary com-

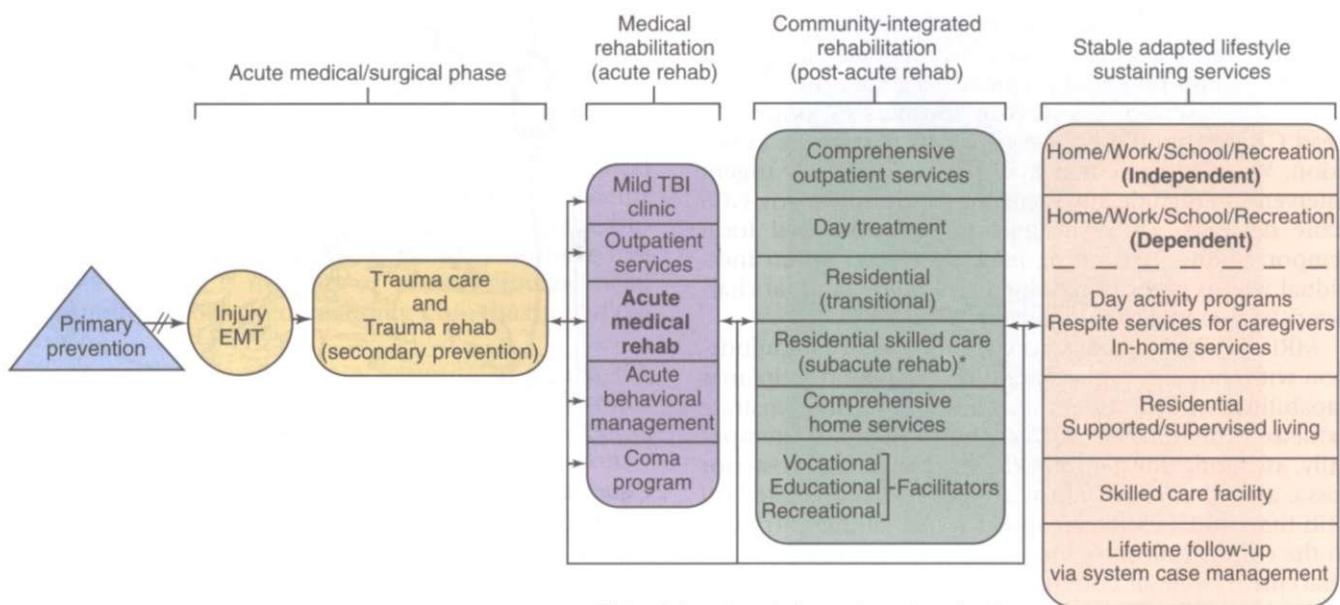


Figure 33-9

System of care for the person with TBI showing the components that should be considered in each phase. (Reprinted from Horn J: Systems of care for the person with traumatic brain injury. In Berrol S, ed: *Physical medicine and rehabilitation clinics of North America. Traumatic brain injury*, Philadelphia, 1992, WB Saunders, p 479.)

plications are the primary medical focus. Hypoxia is a frequent secondary insult; often the upper airway is obstructed, and clearing the airway is the first treatment administered. Intubation and ventilation are critical, with positive-pressure breathing techniques supplemented by 100% oxygen and early intervention.²⁵ Hypotension (systolic blood pressure less than 90 mm Hg) and hypoxia (PaO_2 less than 60 mm Hg) should be avoided if possible and corrected if present.

Emergency department treatment includes determination of head injury severity, identification of persons at risk of deterioration, and control of hypoxia and hypotension. Prevention of secondary brain damage caused by edema, increased ICP, or bleeding should be addressed. Treatment of the medical complications of the trauma are paramount but is not discussed here; the focus of this chapter is on the control and treatment of neurologic sequelae. Close clinical observation remains the best tool for neurologic monitoring in the early stages of head injury.

Surgical intervention is critical in the presence of hemorrhage to prevent neurologic compromise and can improve both short- and long-term outcomes. Uncal, transtentorial, or tonsillar herniations can occur with hematomas. In some cases, the individual may be lucid after the injury and then, in the presence of undetected hematoma, lapse into coma and die.

Injury to the dural sinus can occur with a depressed fracture over a major sinus and requires evacuation. Decompression of the skull, often using burr holes, is warranted in the presence of significant cerebral edema or subdural hematoma. Decompressive craniectomy for

intractable brain swelling is an older treatment that has recently received renewed attention. A number of operations have been developed for or applied to decompression of the brain at risk for the sequelae of uncontrollable intracranial hypertension.

Individuals with a CCS score of less than 8, or individuals whose neurologic status cannot be assessed because of administration of sedative drugs or neuromuscular blocking agents, should be monitored for ICP increases. The institution of ICP monitoring remains somewhat controversial; however, ICP monitors provide the most reliable guide to treatment of the underlying brain injury. Elevation of ICP more than 20 mm Hg is a significant predictor of a poor outcome. Monitoring of ICP can be accomplished in a number of ways. The ventriculostomy catheter allows monitoring and drainage of CSF but it is the most invasive method and is associated with risk of infection. The epidural catheter, hollow subarachnoid bolt, and subarachnoid fiberoptic catheter are other options. All must be surgically placed. The noninvasive Doppler waveform can also provide information regarding ICP. If an ICP monitor is in place, the drainage of CSF may have significant therapeutic benefits.

CPP is determined by subtracting the ICP value from mean arterial blood pressure and represents the pressure driving CBF. Thus CPP and CBF can be positively affected by either lowering ICP or elevating systemic blood pressure. It is generally believed that active attempts to maintain CPP above 70 mm Hg improve outcome; however, there are no systematic scientific studies to validate this.¹⁸

Table 33-5 When to Return to Play after Removal from Contest

Grade of Concussion	Time Until Return to Play*
Multiple grade 1 concussions	1 week
Grade 2 concussion	1 week
Multiple grade 2 concussions	2 weeks
Grade 3: brief loss of consciousness (seconds)	1 week
Grade 3: prolonged loss of consciousness (minutes)	2 weeks
Multiple grade 3 concussions	1 month or longer; based on clinical decision of evaluating physician

Reprinted from Practice parameter: the management of concussion in sports (summary statement). Report of the Quality Standards Subcommittee, *Neurology* 48:584, 1997.

*Only after being asymptomatic with normal neurologic assessment at rest and with exercise.

Cerebral fluid volume can be reduced pharmacologically. Mannitol is used to control blood volume. Hyperventilation has been used as mechanism for controlling cerebral blood volume by increasing in blood pCO_2 , resulting in vasoconstriction of the central vessels and reduced CBF. This must be considered a short-term procedure to be used judiciously because the cerebral vasoconstriction induced may produce ischemia. There remains debate on its usefulness in the light of possibility for worse outcome.³⁷ High-dose barbiturate therapy is generally reserved for those situations in which ICP changes becomes refractory to other available therapies.

Blood pressure control is important in brain-injured clients, and systolic blood pressure should be kept at a minimum of 90 mm Hg. If fluid management cannot keep the blood pressure at an adequate level, then vasoconstrictor drugs are used. Phenylephrine is effective at maintaining stability. CSF can also play a role in ICP. This can be controlled by the use of hypertonic saline or mannitol. Removal of CSF can be accomplished by ventriculostomy. In clinical studies, the use of mild hypothermia appears to reduce neuronal injury by decreasing the amount of glutamate released.

Glucocorticoids have been used to treat cerebral edema, but there appears to be little long-term effect.¹² They are still used to reduce brain swelling and neuronal injury in select cases. They may be used counter the negative effects of TBI on the stress response to systemic trauma, then are rapidly withdrawn once a individual's failure to improve neurologically clearly identifies him or her as a nonresponder. This usually becomes apparent in the first 48 hours.⁴⁷

Management of secondary injury is as critical in TBI as it is in other brain disorders. Control of free radicals through use of vitamin E appears to show some effect. Study of neurotrophic agents has not yet proved to be effective in clinical studies, although they show effect in animals. The most active area of research in TBI today is in the field of molecular genetics. It has been noted that certain genes are upregulated, whereas others are downregulated, after both trauma and ischemia. Particular attention has been focused on the apolipoprotein E gene and its various alleles. Certain alleles have been associated with an increased susceptibility and severity of brain injury, and others have been linked to improved recoveries after TBI.

Because of the intense sympathetic stimulation seen with head injury, hypertension and tachycardia are preva-

lent. Cushing's phenomenon, or a rise in blood pressure in the presence of an acute rise in ICP (most often caused by brainstem compression), may be present. Moderate increases in blood pressure can be tolerated, but extreme hypertension should be treated because it could lead to increased blood volume.²⁵

For sports-related minor TBI, the American Academy of Neurology has defined three grades of concussion and recommended guidelines for return to play. For grades 1 and 2, there is transient confusion and no loss of consciousness. Resolution of concussion symptoms or mental status abnormalities occurs in less than 15 minutes in grade 1 and more than 15 minutes in grade 2. Grade 3 concussion is any loss of consciousness. Players with grade 1 concussion may return to play the same day if they have a normal sideline neurologic assessment, including a detailed mental status examination. Players with grade 2 and 3 concussions should not return to play the same day. Guidelines for return to play are necessary because of concern over the cumulative effects of even mild TBI. See Table 33-5 for current guidelines.^{14,18}

Subacute. In addition to attempting to maintain homeostasis in the brain, management of the other sequela of brain injury is important. Spasticity is controlled by the administration of baclofen, diazepam, or dantrolene. These medications must be used carefully because of their side effects, which include increased weakness, lethargy, and drowsiness. Intrathecal baclofen can be used selectively to decrease tone with a baclofen pump, and the overall side effects are decreased. Abnormal muscle tone can also be controlled by nerve and motor point blocks or by the administration of botulinum toxin directly into the muscle belly.²⁵

Control of seizures is provided by the use of medication such as divalproex sodium (Depakote). If the thalamus is affected, there can be abnormal sensations or intractable pain. The use of antiseizure medications is effective but carries high side effects and is often not tolerated by the individual whose system is already compromised. Attempts to control aggressive behavior through use of carbamazepine (Tegretol) and propranolol (Inderal) have had limited success. The nontricyclic antidepressants seem to be the most effective when the person is depressed.²⁰

Rehabilitation. Rehabilitation of the head-injured person and return to optimal function are the goals once the medical status is stabilized. Highly skilled, specially trained interdisciplinary teams provide an organized

approach to the complex deficits encountered after head injury. Rehabilitation management of the individual is dependent on the cognitive and behavioral level of function of the individual. The Rancho Los Amigos Scale (see Table 33-2), which assesses components of cerebral function, is widely used. Treatment protocols are established according to the level at which the individual is functioning.

Psychotherapy is critical in posttraumatic stress disorder and can be helpful to establish coping mechanisms to address the cognitive deficits and problem solving in relationship to daily activity.

Restoration of mobility, self-care, employment, and recreational activities depends on the level of sensorimotor impairment as well as cognitive status. See Special Implications for the Therapist: Traumatic Brain Injury, in this chapter.

Community Reentry. Community reentry programs for the head-injured person enhance the transition from rehabilitation unit to independent living. Therapists play a significant role in such programs.

In order to return to a lifestyle that may include work and school, the person with TBI needs to learn how to cope with the multiple demands on his or her attention that are part of that lifestyle. The person with TBI will have difficulty with executive functions such as organizing time and information, self-monitoring, and self-correcting. Self-motivation is often lacking, and structuring is necessary to ensure follow-through on assigned activities. Extensive use of checklists and environmental cues is helpful when attempting to reintegrate the client into the community.

The therapist working with brain-injured individuals must understand the interaction between the deficits related to cognitive and social behaviors and the ability to learn to move.⁵⁴ Cognitive rehabilitation and physical rehabilitation are closely related. Functional outcomes are limited by the cognitive status, and the understanding of the techniques that foster behavioral modification and learning in the head-injured should be used by the therapist while motor skill acquisition is being attempted.⁵⁰ For further explanation regarding this motor control and for information specific to learning, see Chapter 28. For information regarding working on mobility in individuals with focal brain injury, see Special Implications for the Therapist: Traumatic Brain Injury, in this chapter.

Individuals with higher level physical skills and moderate- or low-level cognition skills are often the most difficult to reintegrate into the family and society. Therefore they may have higher levels of handicaps remaining after rehabilitation because family and coworker expectations are high based on motor function. Generally it is the cognitive functions that make one more successful in society. Aggressive counseling should start as soon as the behavioral and cognitive impairments are identified. Neuropsychologists and counselors can suggest interventions that help with cognitive functions, especially techniques to deal with memory loss, decreased attention span, and inappropriate behavior.

Significant deficits in motor skills but higher levels of cognitive skills generally lead to a higher quality of life. There are numerous upper and lower extremity adaptive

devices to help perform activities of daily living. Electric wheelchairs controlled by the head, mouth, or hand and electric lifts for vans as well as hand controls for driving can assist with mobility. Computerized communications systems can improve interactions when speech is disrupted and cognition is still present.

The lack of motivation associated with TBI becomes a challenge for the therapist. Lack of internal initiation and decreased ability to learn may persist despite cues from the external environment. Determining goals that are meaningful to the client even though they may seem to be unrealistic is the first step in establishing motivation.

Alterations in attention span can be detrimental to progress in therapy. Reducing distracting stimuli can be helpful initially; distractions can be reintroduced as the ability to manage multiple input improves. In most cases the family of the survivor needs help understanding their family member's social and behavioral changes.⁴⁹

PROGNOSIS. Because of the complex nature of the injury, predicting outcomes in brain injury is difficult at best. One major problem is with the consistency of the tests performed and interpretation of those tests. However, there are some indicators that can be considered broadly.⁵² The probability of having persistent symptoms and neuropsychologic deficits is the same whether an individual is only dazed or loses consciousness for less than 1 hour. The effects of repeated concussions are cumulative because the ability of the brain to accommodate the damage is compromised by previous trauma. Individuals with moderate TBI usually experience both cognitive and physical disabilities and typically require rehabilitation services after acute hospitalization. Nevertheless, the incidence of severe long-term disability is small.¹⁸

Injury severity is one of the main factors determining outcome. The depth of impaired responsiveness and the duration of altered consciousness have been related to outcome.^{31,55} The current gold standard for assessing those mental states in the head-injured person is the Glasgow Outcome Scale (Box 33-3). In addition, the duration of posttraumatic amnesia has been used as a predictor of severity of the head injury. Other aspects of neurologic functioning are predictive of outcome. Loss of pupillary light reflexes following head injury reflects significant damage to the brainstem and portends a poor prognosis. Oculomotor deficits often signal concomitant cerebral damage resulting in severe cognitive deficits. The degree of hypoxemia and hypotension encountered in the early stages can also have an effect on the long-term prognosis.⁴⁸

CT has increased the ability to predict outcome in the head-injured person with a lesion of the brain parenchyma, intracranial hematoma, subdural hematoma, or massive hemispheric swelling. Acute hemispheric swelling with an extracerebral hematoma is associated with the worst prognosis. Unilateral brain contusion and DAI also carry a poor prognosis. A midline shift of brain structures, absent or compressed basal cisterns (indicating rising ICP), and subarachnoid hemorrhage will increase the risk of death or remaining in a VS.⁵¹

Epilepsy occurring within 7 days is often related to severe injury, depressed fracture, or intracranial hemor-

Box 33-3**GLASGOW OUTCOME SCALE****Vegetative State**

The client is in a state of nonsentient survival with reduced responsiveness associated with wakefulness. There is no evidence of psychologically meaningful activity, although there may be local motor activity.

Severe Disability

The client is conscious but dependent. There is often spastic paralysis of three or four limbs. Dysphasia that limits communication may be the reason for the dependency, or it may be due to severely restricted mental activity.

Moderate Disability

The client is independent but disabled. The limitations to normal functional levels may be memory deficits and personality changes. Focal brain damage can be evidenced by cranial nerve involvement, posttraumatic epilepsy, hemiparesis, or movement disorders.

Good Recovery

Although there is not restoration of all normal function, the client is able to participate in normal social life and may be able to return to work.

Modified from Jennett B, Teasdale G: *Management of head injuries*, Philadelphia, 1981, FA Davis, pp 304-305.

rhage. Posttraumatic epilepsy may emerge months or years following brain trauma and is more common after severe brain injury. Late epilepsy occurs most often as grand mal seizures or temporal lobe seizures.²³ For further information on seizures, see Chapter 36.

Dementia has been long recognized as a sequela of multiple head injuries in boxing, as evidenced by the term "punch drunk." Neuropathologic studies of brains of boxers with dementia demonstrate β-amyloid protein-containing diffuse plaques and neurofibrillary tangles, which are pathologic features of Alzheimer's disease.

Neuropsychologic dysfunction appears greater in people over the age of 30 years and those with less education. Social outcomes may be related to the premorbid status of the individual. History of substance abuse, low educational level, and psychiatric disorders can also limit success. Social and family problems are common and can cause isolation and poor quality of life.³³

Cognitive deficits that affect motivation, attention, emotion, memory, or learning will slow progress. Lack of social skills has been reported to affect an individual's ability to reintegrate into the community. Often it becomes difficult to sustain relationships that were stable before the injury. Working with professionals who recognize these deficits and are trained to treat them will improve the chances of increasing quality of life after head injury.

A compensation case or lawsuit is often filed in circumstances in which another party may be responsible for the TBI, such as a motor vehicle accident or on-the-job injury. In this circumstance, when individuals have persistent complaints, many physicians are appropriately concerned about compensation neurosis or malingering

Box 33-4**CHILDREN'S COMA SCALE****Ocular response (O)**

Pursuit: 4
Extraocular movement intact, reactive pupils: 3
Fixed pupils or extraocular movement impaired: 2
Fixed pupils and extraocular movement paralyzed: 1

Verbal response (V)

Cries: 3
Spontaneous respirations: 2
Apneic: 1

Motor response (M)

Flexes and extends: 4
Withdraws from painful stimuli: 3
Hypertonic: 2
Flaccid: 1

Infants (younger than 1 year) may have a worse outcome (with scores <6) than toddlers. A score <6 relates to a poor outcome for toddlers. Reprinted from Raimondi AJ, Hirschauer J: Head injury in the infant and toddler, *Child Nerv Syst* 11:12-35, 1984.

being the cause. Individuals with claims, however, have similar symptoms that improve with time and similar cognitive test results as those without claims. For many claimants, the end of litigation does not mean the end of symptoms or return to work. They are not cured by a verdict.¹⁸

TRAUMATIC BRAIN INJURY IN CHILDREN

TBI is one of the leading causes of death and disability in children of all ages.³⁸ Nonaccidental injury is a common cause of head injury in infants and toddlers and is often the result of the battered child syndrome. The head injury is often caused by shaking or striking the child.

Although the pathology of the brain injury in the child reflects damage similar to that in the adult, there are differences. Infants typically have tears in the white matter of the temporal and orbitofrontal lobes. The infant will more often sustain a subdural or epidural hemorrhage than an older child but is less likely to have skull fracture because of the pliancy of the skull.

Drowning is the third leading cause of death in children aged 1 to 4 years. Peak incidences occur in 1- to 4-year-olds and in adolescent boys. Boys are three times more likely to be injured. Rapid resuscitation leads to better outcomes. As in adults, the motor activity return and pupillary light response are prognosticators of outcome (see Chapter 15).

A children's coma scale has been developed for use in children under the age of 3 years (Box 33-4). The highest level of ocular response is eye tracking. The verbal response is rated highest by crying, then by spontaneous respirations, with the lowest score given for apneic breathing. The motor response has a highest score for flexing and extending the extremities.

Early management of the infant or child with TBI follows that of the adult, with some difference in the child's ability to tolerate the medications used. Late seizures are less common with children than with adults, so the need to be maintained on seizure medication is less.

Rehabilitation goals for the child are similar to those of the adult, although play is used during therapy. Orthotic and assistive devices are used frequently but for a shorter time than for adults. Agitation is common and is often difficult for the parents and siblings to handle. Aggression, decreased attention span, hyperactivity, and socially inappropriate behavior are seen. These children often require a great deal of behavior modification.

Community reintegration can be as difficult for the child as it is for the adult. Schools are better prepared to handle cognitive delays than abnormal behaviors. Cognitive status may return in one area and remain defective in another. Attention and memory deficits may produce the greatest obstacles to learning.

SPECIAL IMPLICATIONS FOR THE THERAPIST 33-1

Traumatic Brain Injury

Rehabilitation of the head-injured person involves the therapist at many different levels and in different settings. Understanding the deficits common in acute injury and the natural recovery patterns of the brain dependent on the site and type of injury is paramount for the therapist treating head injury.

Often the therapist will be involved in a dedicated head injury unit or in a community reentry program. Even in a more general setting, the therapist is often responsible for intervention with individuals sustaining head injury, often acutely, or when an individual has been through a rehabilitation setting and is referred for follow-up based on residual deficits. Provision of therapy in the long-term care setting involves care for individuals in a persistent VS or with behavioral deficits precluding independent living.⁵

Acute Management

In the acute care setting, the therapist is responsible for the evaluation of neurologic function in conjunction with physicians and nurses. One role may be consistent monitoring of cranial nerve function. In addition, the therapist is involved in monitoring reflexive and voluntary motor behaviors. The treatment plan often includes pulmonary care, positioning, range-of-motion exercises, and relaxation techniques. Movement facilitation begins early in the treatment and continues throughout rehabilitation in many cases. Because treatment starts while the individual is still in the intensive care unit, a discussion of life-sustaining equipment follows.

Chest tubes are common with a pneumothorax or hemothorax. The drainage tube should be kept below the level of the chest at all times. Upper extremity movement should be monitored so as not to interfere

with the tube. Nasogastric tube feeding is also common initially, and when a tube is in place, the head of the bed should be placed at 30 degrees to avoid aspiration. It is important that cerebral venous blood volume be controlled in head injury. Maintaining the head at a 20- to 40-degree tilt will usually provide adequate drainage. However, compression of venous drainage from tracheal ties and collars and extreme neck flexion or extension can occur if precautions are not followed. Lines such as central venous pressure catheters, pulmonary or arterial lines, and ICP monitors can be compromised during movement, and often the movement will trigger an alarm that can be upsetting for the client and family. Close communication with the nursing staff will give the therapist confidence in moving the person in the intensive care setting.

Pulmonary management is another critical area. Normal levels of partial pressure oxygen are between 80 and 100 mm Hg. Normal oxygen saturation is between 95% and 100%. Techniques such as percussion, vibration, and suctioning are used to keep the airway clear but must be done with caution and may be contraindicated in the presence of increased ICP. Monitoring blood gases and oxygen saturation is critical in some clients, because movement may alter these values. Weaning from the ventilator is an individual endeavor. Some clients are able to continue to incorporate activity during weaning, but for others it may mean a decrease in tolerance to movement.²⁴

Management of decreased range of motion from spasticity or HO is another intervention provided by therapists. Joint contractures are a secondary problem produced by inability of the muscle to return to its normal resting length. Serial casting and dynamic splinting are used to maintain joint motion in the presence of spasticity, rigidity, or HO.⁴ Managing excessive muscle and reflex activity through movement and positioning begins in the acute phase and often must still be addressed in the rehabilitative phase.

Similar concepts apply to decisions for wheelchair seating and positioning in the nonambulatory individual. Prevention of secondary joint disorders, pain, and disfigurement is facilitated by provision of support in the anatomically proper position. Materials and equipment that are lightweight and provide total contact provide the most comfortable support.⁹

Swallowing deficits and related problems with respiration or coughing occur in approximately one third of persons with head injury. Head, neck, and trunk control affect the ability to swallow. Intervention based on lack of strength and mobility of the perioral structures often starts in the acute phase. Sensation, dentition, tongue control, and laryngeal control are assessed to determine the level of impairment relating to disability of speech and swallowing.⁵⁶

Hemiplegia often persists and is seen in over 50% of individuals with head injury 6 months after onset. Diffuse damage to the central white matter tracts and midbrain with loss of integration of reflexes can have a devastating effect on function. See Chapter 32 for further information on hemiplegia.

Long-Term Management

Because all three of the mechanisms that can lead to dizziness and imbalance can be affected after TBI, all components should be evaluated carefully. Intervention can be effective if the appropriate program is established. Too often, the individual is referred for vestibular therapy because of the complaint of dizziness or imbalance, but the clinicians lack knowledge of brain injury and the individual is often overstimulated, complains of excessive fatigue, or is noncompliant due to other issues related to the TBI. The therapist is often frustrated by the lack of progress, and often the client is blamed for failure to proceed forward. Visual stimulation is often disorienting and the client prefers to maintain an environment without peripheral visual stimulus, has difficulty reading, and avoids situations with fluorescent lighting. Often the individual is hypervigilant in regard to the vestibular input and is already overstimulated by the time he or she reaches the therapist. Often there is a sensation of moving when at rest that is uncovered by sitting with the eyes closed. This can be an indication of maladaptation of the vestibular system. Settling techniques, such as putting weights on the shoulders, or pressing down on the top of the head can increase the somatosensory input. Sensitivity to vestibular input can be decreased with therapy.

The individual with TBI will have complex movement disorders related to force production, timing, reaction time, and fatigue, and movements may be too slow for function. Sensory disturbances are significant, and the therapist should be adequately trained to evaluate and understand the sensory contributions to function. Learning new tasks is difficult, as described above in relation to central dysfunction, and lack of motivation can limit progress.

The therapist should understand, however, that with repetition of appropriate activities, these individuals can make significant gains in all areas. There are excellent resources available to assist the therapist in treatment. Many therapists have special expertise, and institutions are focused on management of the individual with brain injury.

References

To enhance this text and add value for the reader, all references are included on the companion Evolve site that accompanies this text book. The reader can view the reference source and access it online whenever possible. There are a total of 57 cited references and other general references for this chapter.

CHAPTER 34

Traumatic Spinal Cord Injury

KENDA S. FULLER

SPINAL CORD INJURY

Spinal cord injury (SCI) is a catastrophic event of low incidence and high cost. It is most often highly active persons who incur the types of accidents that cause severe SCI. Within a matter of seconds, the person sustaining a traumatic SCI will become dependent on others or on assistive devices to perform even the most basic activities of self-care. SCI rarely occurs in isolation, and over 75% of these individuals have some other systemic injury. In 10% to 15%, there is an associated head injury. This concern has led to the widely quoted clinical maxim that all traumatized patients or any patient with a severe head injury should be presumed to have a spine injury or SCI until proven otherwise.³⁰

Incidence and Risk Factors

Males account for more than 80% of all cases of traumatic SCI. Most of the injured have traditionally been young people, but the mean age of SCI increased in the 1990s and is now recorded as the early thirties.^{11,12} It is postulated that there is now a higher survival rate in the older population; in addition, the mean age of the general population also has increased. It is estimated that there are approximately 30 to 40 cases per 1 million persons on an annual basis, with an additional 6 to 8 deaths (per 1 million) occurring before hospitalization; however, the number of deaths occurring before hospitalization is decreasing. The number of individuals living with SCI is probably between 183,000 and 230,000 persons, with approximately 10,000 new cases each year.

The primary cause of SCI is motor vehicle accidents, accounting for 40% of SCIs. The overall incidence of SCI associated with automobile accidents has decreased in the 1990s because of mandatory seat belt laws and installation of air bags in cars manufactured after 1990. Still, drivers aged 16 to 20 have an annual rate of involvement in fatal crashes of 62 per 100,000 licensed drivers, compared with 29 per 100,000 for the general public.

In some urban areas the incidence of gunshot-related SCI is increasing. Approximately 15% of SCIs are caused by gunshot wounds; these include job-related injuries to security guards, policeman, workers shot during robberies, and others. The likelihood of SCI from a gunshot wound appears to be higher among those who have had previous gunshot wounds (30%) or who have

had prior involvement in the criminal justice system (52%). Unlike sports injuries, which peak nationwide during the summer months, the incidence of penetrating wounds of the spine remains the same throughout the year, and 40% of them occur on a Saturday or Sunday.²⁵

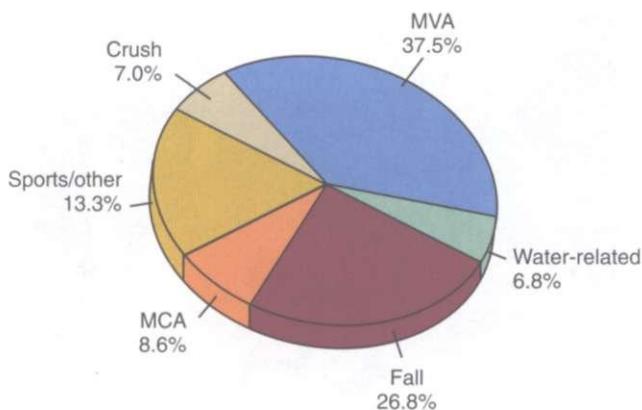
Sports-related injuries account for less than 7% of the total. Accidents resulting in SCI are most prevalent in the contact sports of football and wrestling, high-speed sports such as snow skiing and surfing, and sports in which injuries can involve a fall from a height, such as a trampoline or a horse. The most preventable cause of SCI is diving. The injury occurs most often in water 4 to 6 feet deep. Fig. 34-1 shows a breakdown of the typical incidence of injury types.

Approximately 47% of all persons with SCIs have paraplegia, and 53% have tetraplegia. Twenty-six percent of all thoracic and lumbar cord injuries are complete lesions, as are 18% of cervical injuries. For penetrating wounds of the spine, however, a significantly greater proportion are complete, and there is a much greater shift toward thoracic spinal injuries as compared with injuries of the neck or lumbar spine.⁷²

The incidence of traumatic SCI in small children is low, and they represent less than 10% of the traumatic SCI population. In children, SCI is most often related to an automobile accident. After 45 years of age, falls become the most common cause of SCI.

In most high-income countries today SCI is the leading cause of death between the ages of 1 year and 44 years. Similar trends are seen in today's low- and middle-income countries, with increases in many injury-related causes of death, especially road traffic. Because of recent increases in the use of motorized transport globally, road traffic crashes have now become a leading cause of death among young, working-aged adults in almost every country. In the age group 15 to 44 years, road traffic deaths are second only to human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS) as a cause of death.

All too often, injury prevention is misconstrued as merely admonitions to be careful. In reality, injury prevention is a scientific field that seeks to understand the extent and characteristics of injury through surveillance and research. There is a need to identify risk factors and target these risk factors through well-developed and

**Figure 34-1**

Epidemiology of spinal cord injury. MCA, Motorcycle accident; MVA, motor vehicle accident. (From Goetz CG, ed: *Textbook of clinical neurology*, ed 2, Philadelphia, 2003, Saunders.)

scientifically based prevention efforts. Recent developments to improve road safety in the United States have included graduated licensing and strengthened efforts to combat drunk driving, including wider adoption of a blood alcohol concentration of 80 mg/dl as the criterion for drunk driving.⁵⁵

Definition and Etiologic Factors

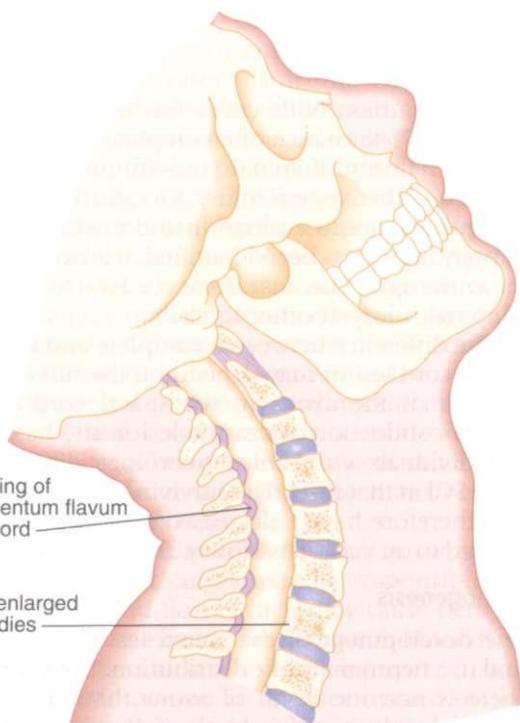
SCI is classified as concussion, contusion, or laceration. A *concussion* is an injury caused by a blow or violent shaking and results in temporary loss of function, similar to the cerebral concussion associated with head injury. In *contusion* injury the glial tissue and spinal cord surface remain intact. There may be a loss of central grey and white matter, which creates a cavity that is surrounded by a rim of intact white matter at the periphery of the spinal cord. *Laceration* or *maceration* of the cord occurs with more severe injuries in which the glia is disrupted and the spinal cord tissue may be torn. Occasionally this can result in complete transection of the cord. Gunshot wounds, knife wounds, and puncture injuries fall into this category.

Hemorrhages into the dura are common, although they rarely become large enough to compromise the spinal cord. Subarachnoid hemorrhages, caused by contusion and laceration of the cord, are frequent and can cause further compression of the cord.

The mechanism of injury influences the type and degree of the spinal cord lesion. Fig. 34-2 shows the flexion damage that is referred to as the hangman's fracture, related to excessive flexion. Approximately 50% of injuries come from excessive flexion of the spinal column that results in a severe neurologic disorder.¹⁸ Fig. 34-3 shows how extension can cause SCI in the elderly population. Fig. 34-4 shows vascular changes that may result from displacement of spinal components. The spinal cord is often violently displaced or compressed momentarily during an injury with forceful flexion, extension, and rotation of the spine. The vertebral body can burst and cause pressure or scatter bone fragments into the spinal cord. Fig. 34-5 illustrates this phenomenon. Complete spinal cord lesions occur in about one third of

**Figure 34-2**

Fracture of C2 (hangman's fracture). (From Green NB, Swionkowski MF, eds: *Skeletal trauma in children*, ed 3, Philadelphia, 2003, Saunders.)

**Figure 34-3**

Elderly patients subjected to extension forces can sustain cervical spinal cord injury as a result of compression of the spinal cord between the posterior hypertrophic ligamentum flavum and the arthrictically enlarged anterior vertebral bodies. (From Marx JA, ed: *Rosen's emergency medicine: concepts and clinical practice*, ed 6, Philadelphia, 2006, Mosby.)

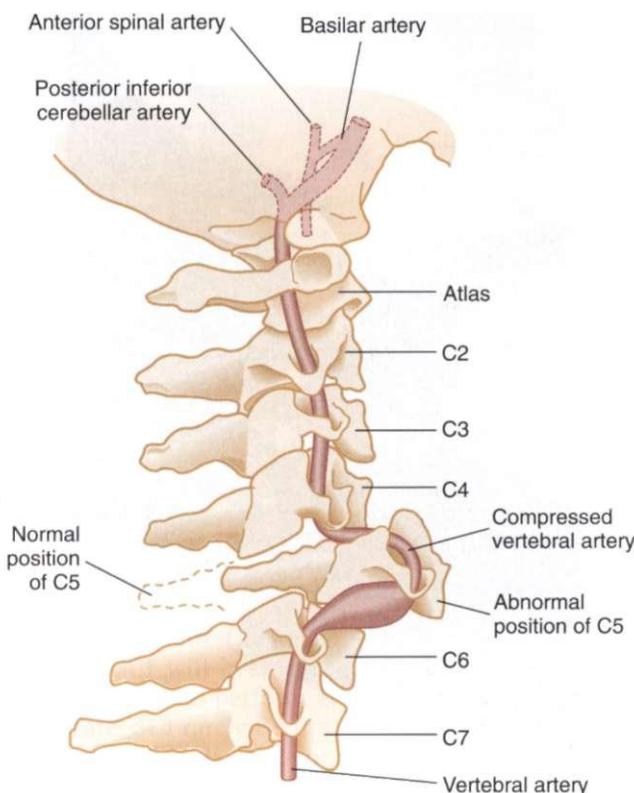


Figure 34-4

Mechanism of vascular injury of the spinal cord resulting from cervical vertebral injury. (From Marx JA, ed: *Rosen's emergency medicine: concepts and clinical practice*, ed 6, Philadelphia, 2006, Mosby.)

flexion injuries. With crush fractures of the vertebrae, there is a 75% chance of a complete spinal cord lesion.

The majority of spinal cord-injured patients have at least one other system injury. Occasionally these injuries take precedence in evaluation and treatment. If one level of bony injury has been identified, it is necessary to survey the entire spine, because there is a 10% to 15% incidence of spinal injury at other levels.³⁰

The difference between a complete and an incomplete spinal cord lesion may depend on the survival of a small fraction of the axons in the spinal cord. Evidence of axonal conduction across the lesion site has been found in individuals with clinical neurologic diagnoses of complete SCI at that level. The surviving axons may be injured and therefore have a decreased response to stimuli. The injured axon conducts slowly and fatigues rapidly.³⁰

Pathogenesis

The development of the spinal lesion occurs over time and in a neuroanatomic distribution. In the first 18 hours, there is necrotic death of axons that were directly disrupted by the trauma. In the following weeks, there is further progression of tissue injury in both directions from the lesion. The immune system probably plays a major role during this phase. It appears that immune cells, such as monocytes and macrophages, emit chemical signals, such as cytokines and chemokines, that trigger apoptosis, or programmed cell death. This breakdown of

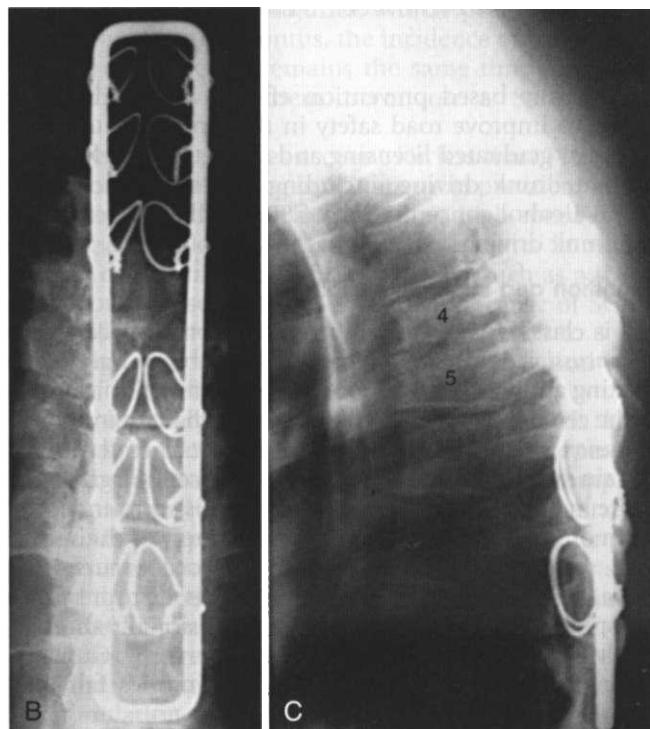
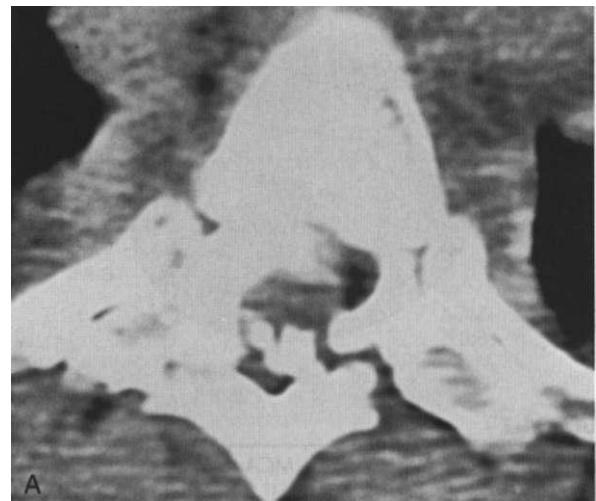


Figure 34-5

A T4-T5 fracture-dislocation resulted in a complete spinal cord injury in a 30-year-old man. **A**, A computed tomographic scan through the injured level demonstrates marked displacement and comminution at T4-T5, with multiple bone fragments within the canal. **B**, A postoperative anteroposterior radiograph shows stabilization with a Luque rectangle and sublaminar wires. This instrumentation provided rigid fixation and allowed early mobilization with minimal external support. The strength of fixation could have been improved with the use of double wires around the lamina bilaterally. **C**, Postoperative lateral radiograph. (From Browner BD, Jupiter JB, Levine AM, et al: *Skeletal trauma: basic science, management, and reconstruction*, ed 3, Philadelphia, 2003, Saunders.)

cell function can occur away from the lesion site, often by as far as four spinal segments.¹⁷

The pathophysiology of SCI may be divided into phases. *Primary injury* refers to the structural damage occurring instantly after the traumatic event. Trauma to the spinal cord results in primary destruction of neurons

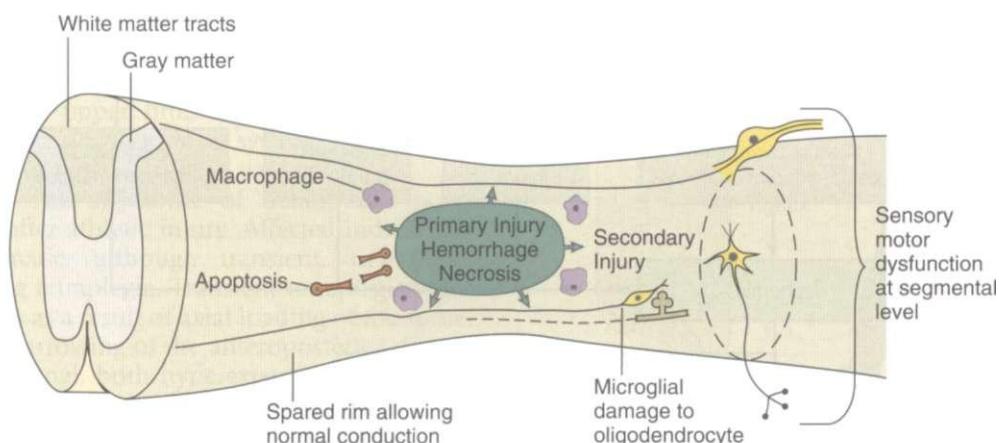


Figure 34-6

Spinal cord contusion lesions are characterized by a primary area created by hemorrhage of blood vessels causing necrosis of cells. This area eventually spreads because of secondary injury associated with apoptosis (programmed cell death), macrophages acting as immune mediators, and microglia causing damage to oligodendrocytes. The secondary damage may continue for days to weeks and move along the segmental levels, causing sensory and motor dysfunction. The spared rim may allow normal processing and preservation of function.

at the level of the injury by disruption of the membrane, hemorrhage, and vascular damage. More extensive primary injury may occur, however, if an injured spine is not adequately immobilized. A critical aspect of these lesions is that even after severe injuries, a small peripheral rim of spared tissue and axons often remains. Spared descending systems play an important role in recovery. In paraplegia, the amount of spared rim correlates with the level of locomotor function.^{5,70}

Secondary injury refers to a pathophysiologic cascade initiated shortly after injury, including such insults as ischemia, hypoxia, edema, and various harmful biochemical events. The spread of damage is thought to be due to initiation of biochemical events leading to necrosis and excitotoxic damage and can continue for hours, days, or weeks.³ Fig. 34-6 shows the changes that can result from SCI. Because it is extremely rare for the primary injury to cause transection of the spinal cord, and it has been shown that less than 10% of the cross-sectional area of the spinal cord supports locomotion, it is very important to focus clinical attention on the secondary injury process.

Electrolyte disturbances following SCI include increased intracellular calcium level, increased extracellular potassium level, and increased sodium permeability. The route of calcium entry rather than the amount may be the critical component. The influx of calcium ions in the neuronal cell can then lead to activation of various secondary processes resulting in cellular death. Excitatory neurotransmitter accumulation, arachidonic acid release, endogenous opiate activation, and prostaglandin production can cause damage as part of the postinjury cascade. Free radical production and lipid oxidation play a central role in this process. See Chapter 28 for information regarding the effects of these disturbances. This results in ischemia, edema formation, membrane destruction, cell death, and eventually permanent neurologic deficits.³⁰

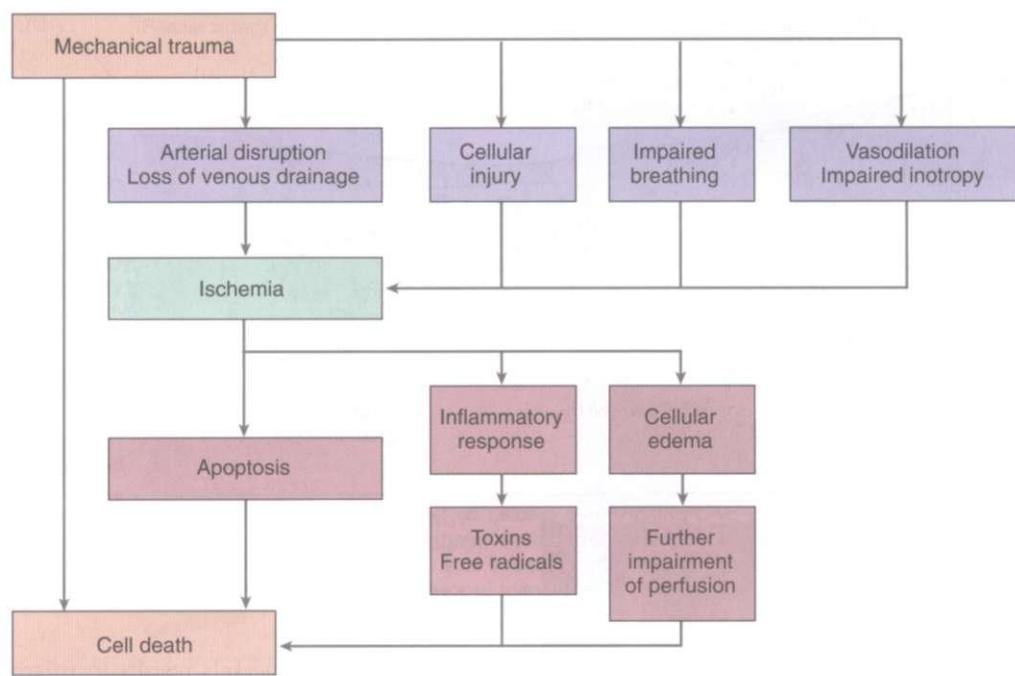
Blood Flow Changes. Ischemia related to reduced blood flow is a very prominent feature of post-SCI events.

Damage to blood vessels results in microhemorrhage in the central grey matter, which spreads radially and axially. The resulting hypoxic and ischemic events deprive grey and white matter of oxygen and nutrients necessary for neural cell survival and function. Within 2 hours of injury there is a significant reduction in spinal cord blood flow. Swelling rapidly occurs at the injury level, and because the bony spinal canal has a fixed diameter, pressure on the cord climbs higher than venous blood pressure. Ischemia in the area of injury may be due to the presence of norepinephrine, serotonin, histamine, and prostaglandins, all of which cause vasoconstriction. This ischemia may be compounded by loss of the normal autoregulatory response of the spinal cord vasculature.

Changes in blood flow, represented by small hemorrhages, begin soon after the SCI. After several hours there appear to be gross hemorrhages present, preceded by endothelial breakdown and pathologic coagulation products in the blood vessels. Ischemia and necrosis occur primarily in the grey matter, presumably because of the richer blood supply. Macrophages enter the lesion and begin to digest the necrotic debris, converting the complex myelin lipids to neutral fat. Axonal swelling and increased permeability of blood vessels result in a visibly swollen spinal cord.⁷⁷ Glial cells become active after about 6 days, and astrocytic fibers form scarlike tissue that lines the cavities created by the necrosis.

Autoregulation of circulation is disabled at the injury site. Systemic pressure changes may be responsible for changes in spinal blood flow, which may cause nervous tissue damage by direct effects. The changes in blood flow may reflect rather than cause secondary injury.³⁴

Edema. Edema formation is another feature of the secondary injury process. Edema develops first at the injury site and subsequently spreads into adjacent and sometimes distant segments of the cord. The relationship between this edema and worsening of neurologic function is not well understood. The relationship of mechanisms of damage leading to cell death is shown in Fig. 34-7.

**Figure 34-7**

Mechanisms of spinal cord injury. Mechanical trauma to the spinal cord is exacerbated by systemic hypoperfusion or hypoxia. (From Miller RD, ed: *Miller's anesthesia*, ed 6, New York, 2005, Churchill Livingstone. Redrawn from Dutton RP: Spinal cord injury, *Int Anesthesiol Clin* 40:109, 2002.)

Demyelination. Demyelination results in reduced rate of firing in the injured spinal cord. The demyelination is due to direct trauma to the oligodendroglial cells that produce myelin. Unlike neuronal excitotoxicity, which is mediated predominantly by N-methyl-D-aspartate (NMDA) receptors, mature oligodendrocytes are sensitive to excitotoxicity mediated by non-NMDA receptors. Lymphocytes and macrophages invade the lesion site by way of the disrupted blood-brain barrier as part of the inflammatory response. The myelin sheath becomes thin between the nodes, and this is responsible for a decrease in the peak currents along the axon. Loss of a single segment of myelin renders an axon dysfunctional; therefore, a large subset of axons crossing the lesion eventually become nonfunctional despite the axon's remaining physically intact.

Changes in white matter begin with Wallerian degeneration in the ascending posterior columns above the level of the lesion and in the descending corticospinal tracts. Wallerian degeneration may be triggered by microglial activation and by the destruction of the oligodendrocytes via the release of cytokines or other neurotropic factors.⁴⁴ The immune system appears also to trigger the release of nerve growth factor, which can be neuroprotective to some cells while it is toxic to other cells in the spinal cord.

A prominent feature of subchronic SCI is the maturation of a scar around the lesion. This scar tissue forms a cellular and molecular barrier to axonal regeneration. By the chronic injury phase, the scar is well formed and consists of several cell types, such as the reactive astrocytes, fibroblasts, Schwann cells, microglia, and macrophages that have invaded the scar.

Grey Matter. Typically, the loss of central grey matter is confined to between one and one and one-half segmental levels of the spinal cord, causing central cavitation. The result is a fluid-filled cyst or syrinx (see later), or the cord collapses around the loss of tissue in an hour-glass shape with the minimal diameter located at the spinal segment of the original injury.

Dural Scarring. Scarring of the dura can cause a permanent connection of the cord to the overlying dura. Because the cord is normally freely mobile within the spinal canal, restricted motion attributable to dural scarring produces unusual forces on the cord when the neck is bent or with normal breathing or the cardiac cycle. These forces can produce microscopic injury, which may limit optimal regeneration and recovery.

Neural Function. Neural activity below the injury level is related to passive and active limb movements and sensory stimuli from the moving limbs. Substantial reduction of neural activity limits the body's ability to maintain the cellular functions of the spinal cord circuitry. Slow progressive loss of function is normal in chronic SCI. It is believed that the injured central nervous system (CNS) undergoes accelerated aging, with abnormal cell production and impairments in mechanisms of cellular repair. The cellular mechanisms important for regeneration may be lost as a part of this process.

Animal models of SCI suggest that areas of the brain involved in sensorimotor control undergo atrophic changes after spinal cord transection. A significant decrease in the size and number of corticospinal neurons has been demonstrated in the rat brain. Atrophy may occur in the subacute phase (5 to 10 weeks), with cell