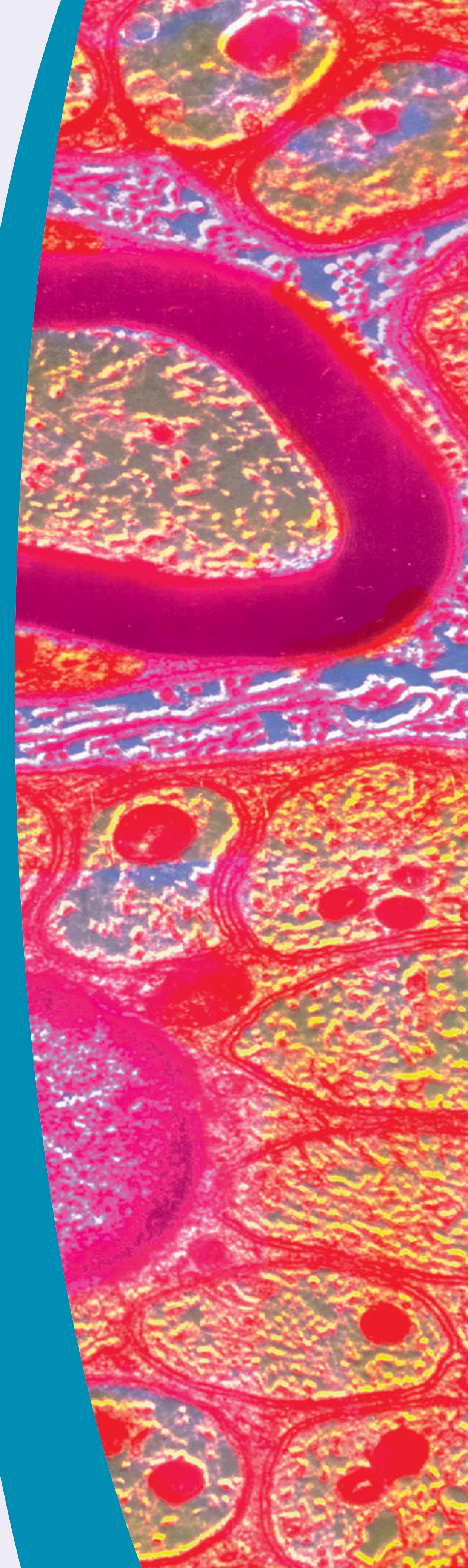
14 The Peripheral Nervous System

The human brain, for all its sophistication, would be useless without its sensory and motor connections to the outside world. Our very sanity depends on a continual flow of sensory information from the environment. When blindfolded volunteers were suspended in a tank of warm water (a sensory-deprivation tank), they began to hallucinate: One saw pink and purple elephants, another heard a singing chorus, and others had taste hallucinations. Our sense of well-being also depends on our ability to carry out motor instructions sent from the CNS. Many victims of spinal cord injuries experience despair at being unable to move or take care of their own needs. The **peripheral nervous system (PNS)**—the



Myelinated and non-myelinated axons from the human peripheral nervous system (colored TEM).

nervous system structures outside the brain and spinal cord—provides these vital links to the body and the outside world.

ORGANIZATION OF THE PERIPHERAL NERVOUS SYSTEM

➤ Define peripheral nervous system, and list its basic divisions.

Nerves thread through almost every part of the body, allowing the CNS to receive information and to initiate action. Figure 14.1 reviews the functional components of the PNS as presented in Chapter 12 (pp. 350–351). Recall that the sensory inputs and motor outputs carried by the PNS are categorized as either *somatic* (outer tube) or *visceral* (visceral organs or inner tube) and that sensory inputs are also classified as either *general* (widespread) or *special* (localized, i.e., the special senses). The visceral motor part of the PNS is the autonomic nervous system, which has *parasympathetic* and *sympathetic* divisions (see the bottom right side of Figure 14.1 and Chapter 15).

The following are the structures of the PNS:

1. The **sensory receptors.** Sensory receptors pick up stimuli (environmental changes) from inside and outside the body and then initiate impulses in sensory axons, which carry the impulse to the CNS.
2. The **nerves** and **ganglia.** As defined in Chapter 12, nerves are bundles of peripheral axons, and ganglia are clusters of peripheral cell bodies, such as the cell bodies of the sensory neurons. Most nerves contain both sensory and motor axons and are called *mixed nerves.* Some cranial nerves are purely sensory or purely motor in function.
3. The **motor endings.** The motor endings are the axon terminals of motor neurons that innervate the effector organs, muscles, and glands.

We begin this chapter by describing the peripheral sensory receptors. We then discuss the nerves of the body, starting with the *cranial nerves* (the nerves attached to the brain) and ending with the *spinal nerves* (the nerves attached to the spinal cord). Motor endings to the muscles and glands of the body are described elsewhere in the text with the appropriate organ system: skeletal muscle innervation in Chapter 10, cardiac muscle innervation in Chapter 19, and the innervation of smooth muscle and glands in Chapter 23. Although we mention the visceral part of the PNS, in this chapter we focus on somatic functions, deferring a more complete consideration of the visceral nervous system until Chapter 15.

check your understanding

1. List two examples of general somatic sensations. List one example of a special visceral sensation. (Refer to Table 12.1, p. 350, if needed.)
2. Do all nerves contain both sensory and motor fibers?

For answers, see Appendix B.

PERIPHERAL SENSORY RECEPTORS

➤ Classify sensory receptors according to body location, stimulus detected, and structure.

Peripheral sensory receptors are structures that pick up sensory stimuli and then initiate signals in the sensory axons. Most receptors fit into two main categories: (1) *free nerve endings of sensory neurons* and (2) complete *receptor cells,* which are specialized epithelial cells or small neurons that transfer

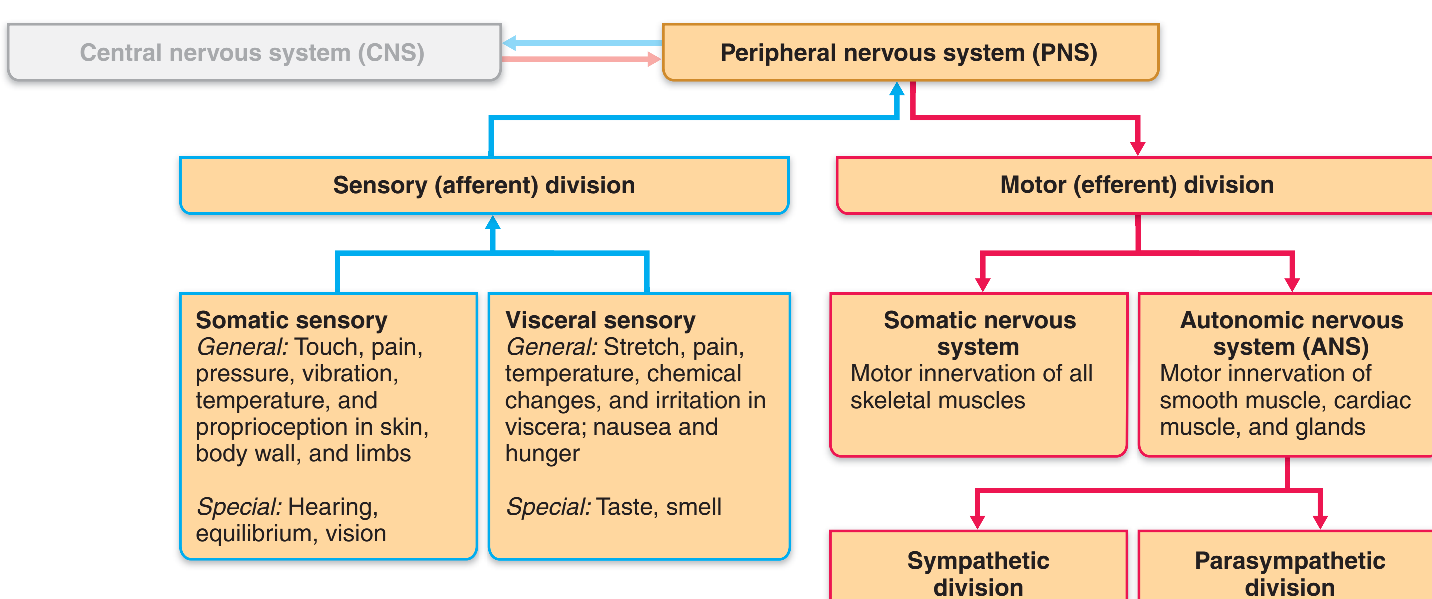


FIGURE 14.1 Functional organization of the peripheral nervous system (PNS) and its relation to central nervous system (CNS).

sensory information to sensory neurons. Free nerve endings monitor most types of general sensory information (such as touch, pain, pressure, temperature, and proprioception), whereas specialized receptor cells monitor most types of special sensory information (taste, vision, hearing, and equilibrium).

Sensory receptors may also be classified according to location, the type of stimulus they detect, and their structure. The next sections examine these different classification schemes in turn.

Classification by Location

Sensory receptors are divided into three classes based either on their location in the body or the location of the stimuli to which they respond.

1. **Exteroceptors** (eks″ter-o-sep′torz) are sensitive to stimuli arising outside the body. Accordingly, most exteroceptors are located at or near the body surface and include receptors for touch, pressure, pain, and temperature in the skin and most receptors of the special sense organs.
2. **Interoceptors** (in″ter-o-sep′torz), also called *visceroceptors,* receive stimuli from the internal viscera, such as the digestive tube, bladder, and lungs. Different interoceptors monitor a variety of stimuli, including changes in chemical concentration, taste stimuli, the stretching of tissues, and temperature. Their activation causes us to feel visceral pain, nausea, hunger, or fullness.
3. **Proprioceptors** are located in the musculoskeletal organs such as skeletal muscles, tendons, joints, and ligaments. Recall that proprioceptors monitor the degree of stretch of these locomotory organs and send input on body movements to the CNS (see p. 350).

Classification by Stimulus Detected

A second way to classify sensory receptors is by the kinds of stimuli that most readily activate them.

1. **Mechanoreceptors** respond to mechanical forces such as touch, pressure, stretch, vibrations, and itch. One type of mechanoreceptor, called a **baroreceptor,** monitors blood pressure.
2. **Thermoreceptors** respond to temperature changes.
3. **Chemoreceptors** respond to chemicals in solution (such as molecules tasted or smelled) and to changes in blood chemistry.
4. **Photoreceptors** in the eye respond to light.
5. **Nociceptors** (no″se-sep′torz) respond to harmful stimuli that result in pain (*noci* = harm).

Classification by Structure

The third way to classify sensory receptors is by their structure. The special senses are discussed in Chapter 16, so this section considers only the **general sensory receptors.** All these widely distributed receptors are nerve endings of sensory neurons that monitor touch, pressure, vibration, stretch, pain, temperature, and proprioception. Structurally, sensory receptors are divided into two broad groups: (1) *free* nerve endings and (2) *encapsulated* nerve endings surrounded by a capsule of connective tissue. These general sensory receptors are summarized in Table 14.1.

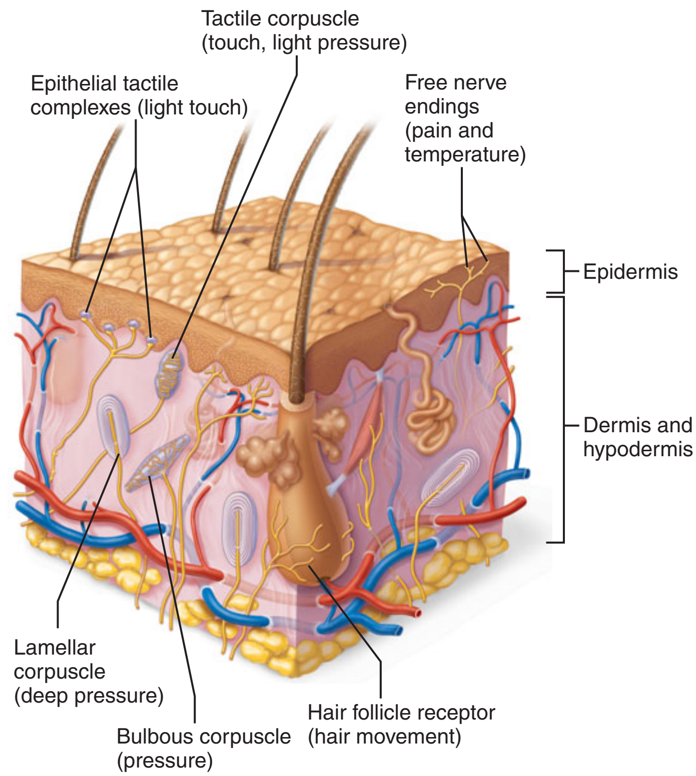


FIGURE 14.2 Structure of free and encapsulated general sensory receptors. Tactile corpuscles are not common in hairy skin but are included here for illustrative purposes.

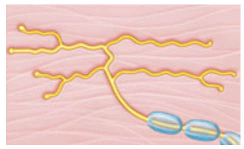
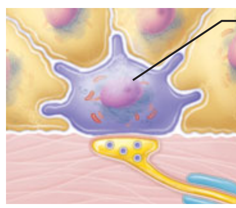
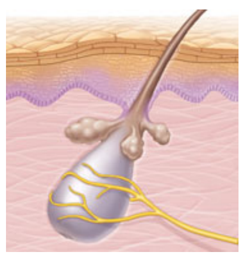
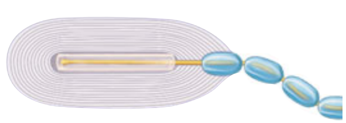
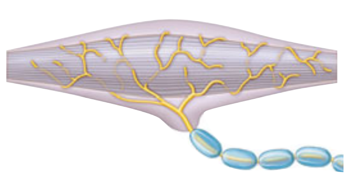
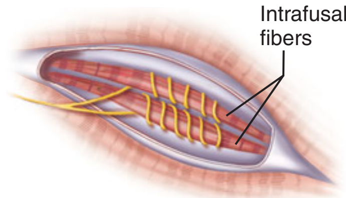
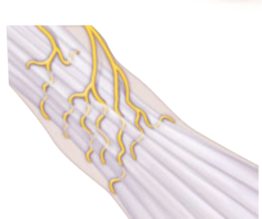
It is important to note that there is no perfect "one receptor–one function" relationship. Instead, one receptor type can respond to several different kinds of stimuli, and different receptor types can respond to similar stimuli.

Free Nerve Endings

Free nerve endings of sensory fibers invade almost all tissues of the body but are particularly abundant in epithelia and in the connective tissue that underlies epithelia (Figure 14.2). These receptors respond chiefly to pain and temperature (though some respond to tissue movements caused by pressure). One way to characterize free nerve endings functionally is to say that they monitor the *affective* senses, those to which people have an emotional response—and people certainly respond emotionally to pain!

Certain free nerve endings contribute to **epithelial tactile complexes** (*Merkel discs*), which lie in the epidermis of the skin. Each consists of a disc-shaped tactile epithelial cell (see p. 103) innervated by a sensory nerve ending. These complexes are **slowly adapting** receptors for light touch; that is, they continue to respond and send out action potentials even after a long period of continual stimulation. **Hair follicle receptors,** free nerve endings that wrap around hair follicles, are receptors for light touch that monitor the bending of hairs. Unlike epithelial tactile complexes, they are **rapidly adapting,**

TABLE 14.1 General Sensory Receptors Classified by Structure and Function

Structural Class	Illustration	Functional Class According to Location (L) and Stimulus Type (S)	Body Location
UNENCAPSULATED Free nerve endings of sensory neurons		L: Exteroceptors, interoceptors, and proprioceptors S: Nociceptors (pain), thermoreceptors (heat and cold), possibly mechanoreceptors (pressure), chemoreceptors	Most body tissues; densest in connective tissues (ligaments, tendons, dermis, joint capsules, periostea) and epithelia (epidermis, cornea, mucosae, and glands)
Modified free nerve endings: Epithelial tactile complexes (Merkel discs)		L: Exteroceptors S: Mechanoreceptors (light pressure)	Basal layer of epidermis
Hair follicle receptors		L: Exteroceptors S: Mechanoreceptors (hair deflection)	In and surrounding hair follicles
ENCAPSULATED Tactile (Meissner's) corpuscles		L: Exteroceptors S: Mechanoreceptors (light pressure, discriminative touch, vibration of low frequency)	Dermal papillae of hairless skin, particularly nipples, external genitalia, fingertips, eyelids
Lamellar (Pacinian) corpuscles		L: Exteroceptors, interoceptors, and some proprioceptors S: Mechanoreceptors (deep pressure, stretch, vibration of high frequency); rapidly adapting	Dermis and hypodermis; periostea, mesentery, tendons, ligaments, joint capsules, most abundant on fingers, soles of feet, external genitalia, nipples
Bulbous corpuscle (Ruffini endings)		L: Exteroceptors and proprioceptors S: Mechanoreceptors (deep pressure and stretch); slowly adapting	Deep in dermis, hypodermis, and joint capsules
PROPRIOCEPTORS Muscle spindles		L: Proprioceptors S: Mechanoreceptors (muscle stretch)	Skeletal muscles, particularly those of the extremities
Tendon organs		L: Proprioceptors S: Mechanoreceptors (tendon stretch)	Tendons
Joint kinesthetic receptors		L: Proprioceptors S: Mechanoreceptors and nociceptors	Joint capsules of synovial joints

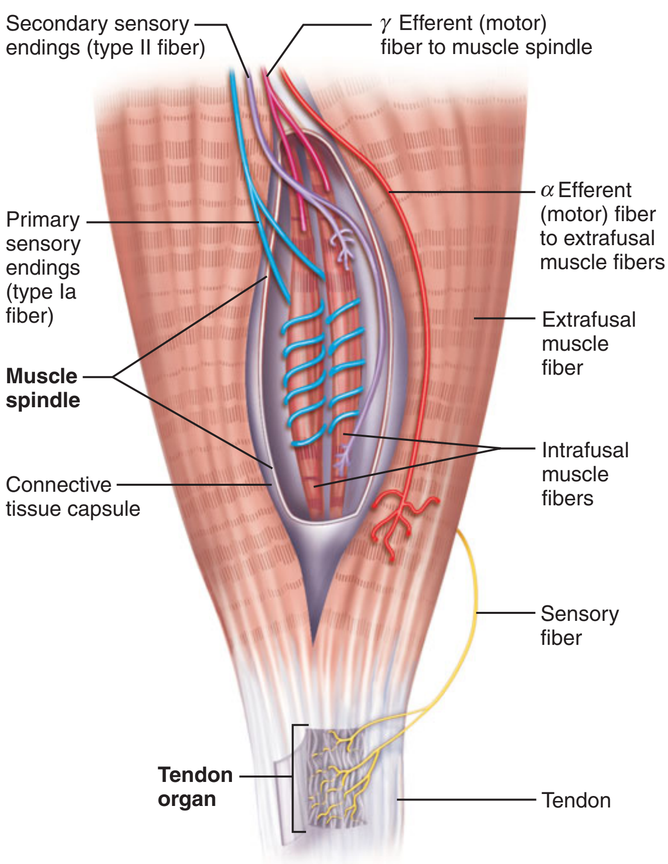


FIGURE 14.3 Structure of proprioceptors: muscle spindles and tendon organ. Myelin has been omitted from all nerve fibers for clarity.

meaning that the sensation disappears quickly even if the stimulus is maintained. The tickle of a mosquito landing on your forearm is mediated by hair follicle receptors.

Itch receptors consist of free nerve endings in the dermis. These receptors escaped detection until 1997 because of their thin diameter. Their discovery startled scientists, who had not realized that itch is a distinct sense but rather had believed it to be a mild form of pain.

Encapsulated Nerve Endings

All **encapsulated nerve endings** consist of one or more end fibers of sensory neurons enclosed in a capsule of connective tissue. All seem to be mechanoreceptors, and their capsules serve either to amplify the stimulus or to filter out the wrong types of stimuli. Encapsulated receptors vary widely in shape, size, and distribution in the body. The main types are *tactile (Meissner's) corpuscles, lamellar (Pacinian) corpuscles, bulbous corpuscles (Ruffini endings)* (see Figure 14.2), and *proprioceptors.*

Tactile Corpuscles In a **tactile corpuscle** (*Meissner's corpuscle*), a few spiraling nerve endings are surrounded by Schwann cells, which in turn are surrounded by an egg-shaped capsule of connective tissue. These corpuscles, which occur in the dermal papillae beneath the epidermis, are rapidly adapting receptors for fine, discriminative touch. They mainly occur in sensitive and hairless areas of the skin, such as the soles, palms, fingertips, nipples, and lips. Apparently, tactile corpuscles perform the same "light touch" function in hairless skin that hair follicle receptors perform in hairy skin. (See *A Brief Atlas of the Human Body,* Second Edition, Plate 37.)

Lamellar Corpuscles Scattered throughout the deep connective tissues of the body are **lamellar corpuscles** (*Pacinian corpuscles*). They occur, for example, in the hypodermis deep to the skin. Although they are sensitive to deep pressure, they respond only to the initial application of that pressure before they tire and stop firing. Therefore, lamellar corpuscles are rapidly adapting receptors that are best suited to monitor *vibration,* an on/off pressure stimulus. These corpuscles are large enough to be visible to the unaided eye—about 0.5–1 mm wide and 1–2 mm long. In section, a lamellar corpuscle resembles a cut onion: Its single nerve ending is surrounded by up to 60 layers of flattened Schwann cells, which in turn are covered by a capsule of connective tissue.

Bulbous Corpuscles Located in the dermis and elsewhere are **bulbous corpuscles** (*Ruffini endings*), which contain an array of nerve endings enclosed in a thin, flattened capsule. Like lamellar corpuscles, they respond to pressure and touch. However, they adapt slowly and thus can monitor *continuous pressure* placed on the skin.

Proprioceptors Virtually all proprioceptors are encapsulated nerve endings that monitor stretch in the locomotory organs. Proprioceptors include *muscle spindles, tendon organs,* and *joint kinesthetic receptors.*

Muscle spindles *(neuromuscular spindles)* measure the changing length of a muscle as that muscle contracts and is stretched back to its original length **(Figure 14.3)**. An average muscle contains some 50 to 100 muscle spindles, which are embedded in the perimysium between the fascicles. Structurally, each spindle contains several modified skeletal muscle fibers called **intrafusal muscle fibers** (*intra* = within; *fusal* = the spindle) surrounded by a connective tissue capsule. Intrafusal muscle fibers have fewer striations than the **extrafusal** (*extra* = outside) **muscle fibers,** that is, the ordinary muscle cells outside the spindles. The intrafusal fibers are innervated by two types of sensory endings: **Primary sensory endings** twirl around the noncontractile middle of the intrafusal fibers innervating the spindle center. These receptors are stimulated by the rate and degree of stretch of the muscle spindle. **Secondary sensory endings** monitor the spindle ends (the only contractile parts of the spindle) and respond only to degree of stretch.

Muscles are stretched by the contraction of antagonist muscles and also by the movements that occur as a person begins to lose balance. The muscle spindles sense this lengthening in the following way: When a whole muscle is stretched, its intrafusal fibers are also stretched. This stretching activates the primary and secondary sensory endings that innervate the spindle, causing them to fire off impulses to the spinal cord and brain. The CNS then activates spinal motor neurons called **α (alpha) efferent neurons** (Figure 14.3) that cause the entire muscle (extrafusal fibers) to generate contractile force and resist further stretching. This response can be initiated by a monosynaptic spinal reflex that rapidly prevents a fall; alternatively, the response can be controlled by the cerebellum regulating *muscle tone,* the steady force generated by noncontracting muscles to resist stretching.

Also innervating the intrafusal fibers of the muscle spindle are spinal *motor* neurons called **γ (gamma) efferent neurons** (Figure 14.3). These neurons preset the sensitivity of the spindle to stretch; that is, when the brain stimulates the gamma motor neurons to fire, the intrafusal muscle fibers contract and become tense so that very little stretch is needed to stimulate the sensory endings, making the spindles highly sensitive to applied stretch. Gamma motor neurons are most active when balance reflexes must be razor sharp, as for a gymnast on a balance beam or a rock climber on a vertical face.

Tendon organs (Golgi tendon organs) are proprioceptors located near the muscle-tendon junction, where they monitor tension within tendons (Figure 14.3). Each consists of an encapsulated bundle of tendon fibers (collagen fibers) within which sensory nerve endings are intertwined. When a contracting muscle pulls on its tendon, tendon organs are stimulated, and their sensory neurons send this information to the cerebellum. These receptors also induce a spinal reflex that both relaxes the contracting muscle and activates its antagonist. This relaxation reflex is important in motor activities that involve rapid alternation between flexion and extension, such as running.

Joint kinesthetic receptors (kin″es-thet′ik; "movement feeling") are proprioceptors that monitor stretch in the synovial joints. Specifically, they are sensory nerve endings within the joint capsules. Four types of joint kinesthetic receptors are present within each joint capsule:

1. *Lamellar (Pacinian) corpuscles:* These rapidly adapting stretch receptors are ideal for measuring acceleration and rapid movement of the joints.
2. *Bulbous corpuscles (Ruffini endings):* These slowly adapting stretch receptors are ideal for measuring the positions of nonmoving joints and the stretch of joints that undergo slow, sustained movements.
3. *Free nerve endings:* May be pain receptors.
4. Receptors resembling *tendon organs:* Their function in joints is not known.

Joint receptors, like the other two classes of proprioceptors, send information on body movements to the cerebellum and cerebrum, as well as to spinal reflex arcs.

PARESTHESIA An abnormal sensation of numbness, burning, or tingling is referred to as **paresthesia** (par″es-the′zha; "faulty sensation"). Temporary paresthesia commonly occurs in the foot, arm, or hand as a result of compression of the peripheral nerve serving the region. This is commonly referred to as a body part "going to sleep" or as the sensation of "pins and needles." Once nerve compression is relieved, normal sensation returns. Chronic paresthesia, ongoing numbness or tingling, can occur in any body region. It is usually symptomatic of some other neurological disease such as stroke, multiple sclerosis, a nerve entrapment syndrome such as carpal tunnel syndrome, or a traumatic nerve injury.

check your understanding

3. Name the type of sensory receptor that responds to painful stimuli. What is the structure of this receptor?
4. Are proprioceptors part of the somatic or visceral sensory system?
5. What type of stimulus do encapsulated receptors respond to?

For answers, see Appendix B.

CRANIAL NERVES

➤ Name the 12 pairs of cranial nerves, and describe the structures innervated by each.

The remainder of this chapter is devoted to the specific nerves of the body, beginning with the 12 pairs of **cranial nerves** that attach to the brain and pass through various foramina in the skull **(Figure 14.4)** (For a review of cranial foramina, see Figure 7.9, p. 156). These nerves are numbered from I through XII in a rostral to caudal direction. The first two pairs attach to the forebrain, the rest to the brain stem. Except for the vagus nerve (X), which extends into the abdomen, the cranial nerves innervate only head and neck structures.

This section introduces the cranial nerves, which are summarized in Figure 14.4b.

I. **Olfactory.** These are the sensory nerves of smell.

II. **Optic.** Because it develops as an outgrowth of the brain, this sensory nerve of vision is not a true nerve at all. It is more correctly called a brain tract.

III. **Oculomotor.** The name *oculomotor* means "eye mover." This nerve innervates four of the *extrinsic eye muscles*—muscles that move the eyeball in the orbit.

IV. **Trochlear.** The name *trochlear* means "pulley." This nerve innervates an extrinsic eye muscle that hooks through a pulley-shaped ligament in the orbit.

V. **Trigeminal.** The name *trigeminal* means "threefold," which refers to this nerve's three major branches. The trigeminal nerve provides general sensory innervation to the face and motor innervation to the chewing muscles.

VI. **Abducens.** This nerve was so named because it innervates the muscle that *abducts* the eyeball (turns the eye laterally).

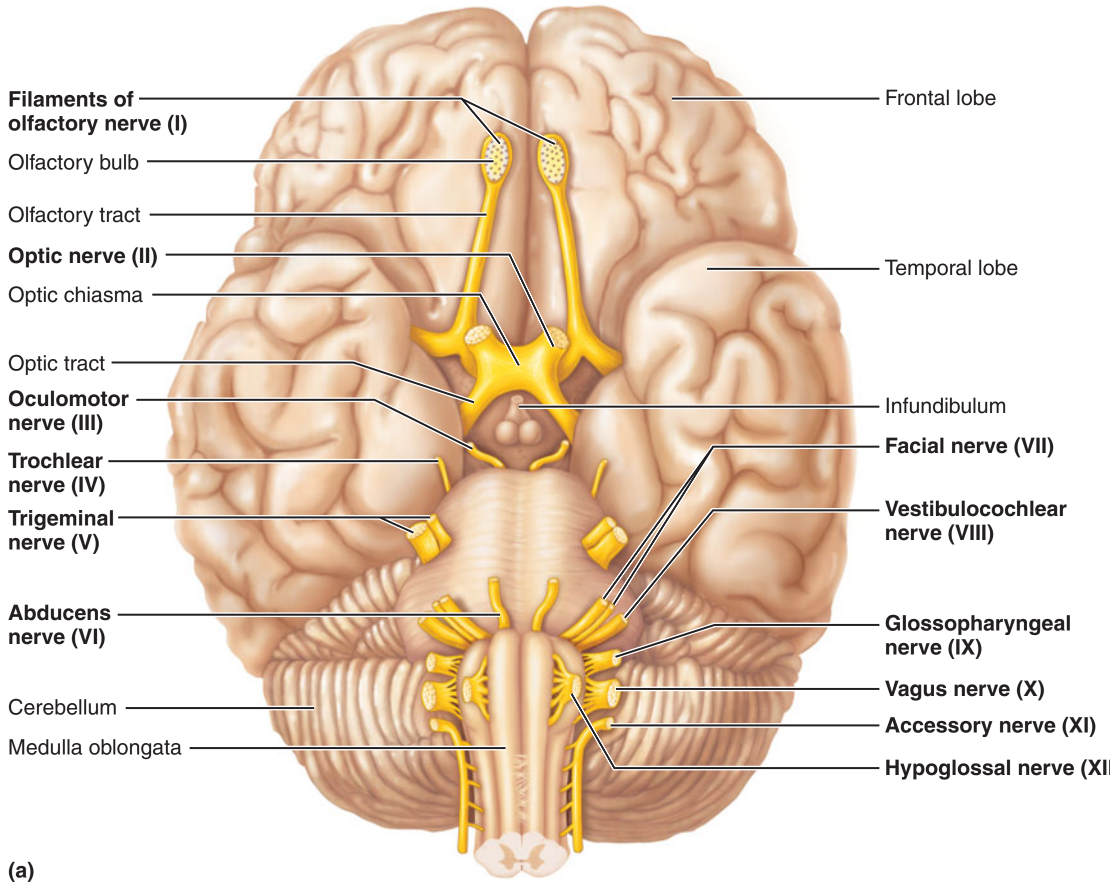
VII. **Facial.** This nerve innervates the muscles of facial expression as well as other structures.

VIII. **Vestibulocochlear.** This sensory nerve of hearing and equilibrium was once called the *auditory nerve.*

IX. **Glossopharyngeal.** The name *glossopharyngeal* means "tongue and pharynx," structures that this nerve helps to innervate.

X. **Vagus.** The name *vagus* means "vagabond" or "wanderer." This nerve "wanders" beyond the head into the thorax and abdomen.

XI. **Accessory.** This nerve was once called the *spinal accessory nerve.* It originates from the cervical region of



Cranial nerves	Sensory function		Motor function	
	Somatic sensory (SS)	Visceral sensory (VS)	Somatic motor (SM)	Visceral motor: parasympathetic (VM)
I Olfactory		Smell		
II Optic	Vision			
III Oculomotor			SM	VM
IV Trochlear			SM	
V Trigeminal	General		SM	
VI Abducens			SM	

Cranial nerves	Sensory function		Motor function	
	Somatic sensory (SS)	Visceral sensory (VS)	Somatic motor (SM)	Visceral motor: parasympathetic (VM)
VII Facial	General	General; taste	SM	VM
VIII Vestibulocochlear	Hearing; equilibrium		Some	
IX Glossopharyngeal	General	General; taste	SM	VM
X Vagus	General	General; taste	SM	VM
XI Accessory			SM	
XII Hypoglossal			SM	

(b)

FIGURE 14.4 The cranial nerves. (a) Ventral view of the human brain. **(b)** Summary of the cranial nerves by function. Cranial nerves that have somatic motor function also contain proprioceptive (sensory) fibers.

the spinal cord, enters the skull through the foramen magnum, and exits the skull with the vagus nerve. The accessory nerve carries motor innervation to the trapezius and sternocleidomastoid muscles.

XII. **Hypoglossal.** The name *hypoglossal* means "below the tongue." This nerve runs inferior to the tongue and innervates the tongue muscles.

The following phrase can help you remember the first letters of the names of the 12 cranial nerves in their proper order: "**O**h, **O**h, **O**h, **T**o **T**ouch **A**nd **F**eel **V**ery **G**ood **V**elvet, **AH**!"

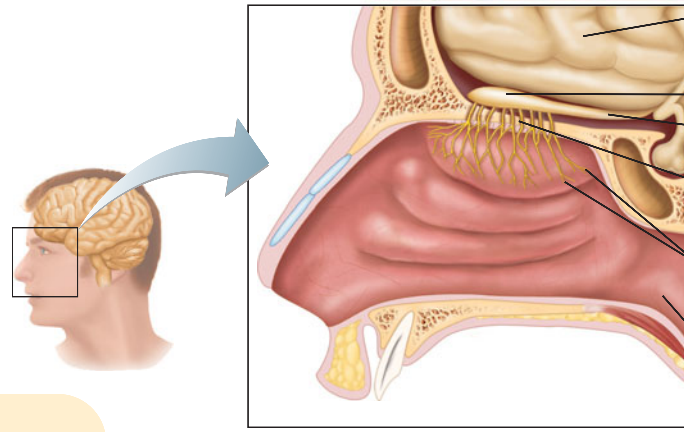
The cranial nerves contain the sensory and motor nerve fibers that innervate the head. The cell bodies of the *sensory* neurons lie either in receptor organs (e.g., the nose for smell, or the eye for vision) or within **cranial sensory ganglia,** which lie along some cranial nerves (V, VII–X) just external to the brain. The cranial sensory ganglia are directly comparable to the dorsal root ganglia on the spinal nerves (see p. 376).

TABLE 14.2 Cranial Nerves

I THE OLFACTORY (ol-fak′to-re) NERVES

Origin and course: Olfactory nerve fibers arise from olfactory receptor cells located in olfactory epithelium of nasal cavity and pass through cribriform plate of ethmoid bone to synapse in olfactory bulb. Fibers of olfactory bulb neurons extend posteriorly as olfactory tract, which runs beneath frontal lobe to enter cerebral hemispheres and terminates in primary olfactory cortex. See also Figure 16.3, p. 485.

Function: Purely sensory; carry special visceral afferent impulses for sense of smell.

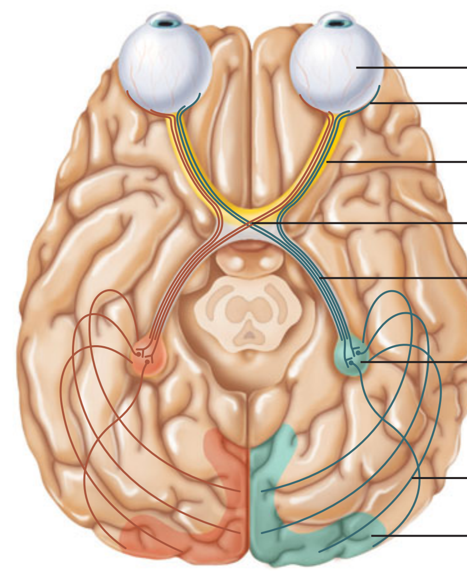


ANOSMIA Fracture of the ethmoid bone or lesions of olfactory fibers may result in partial or total loss of smell, a condition known as *anosmia* (an-oz′me-ah).

II THE OPTIC NERVES

Origin and course: Fibers arise from retina of eye to form optic nerve, which passes through optic canal of orbit. The optic nerves converge to form the optic chiasma (ki-az′mah), where fibers partially cross over, continue on as optic tracts, enter thalamus, and synapse there. Thalamic fibers run (as the optic radiation) to occipital (visual) cortex, where visual interpretation occurs. See also Figure 16.15, p. 497.

Function: Purely sensory; carry special somatic afferent impulses for vision.



OPTIC NERVE DAMAGE Damage to an optic nerve results in blindness in the eye served by the nerve; damage to the visual pathway distal to the optic chiasma results in partial visual losses; visual defects are called *anopsias* (an-op′se-as).

The cell bodies of most cranial *motor* neurons occur in cranial nerve nuclei in the ventral gray matter of the brain stem, as illustrated in Figure 13.12 (p. 386),—just as cell bodies of spinal motor neurons occur in the ventral gray matter of the spinal cord.

Based on the types of fibers they contain, the 12 cranial nerves can be classified into three functional groups (Figure 14.4b):

1. **Primarily or exclusively sensory nerves** (I, II, VIII) that contain *special sensory* fibers for smell (I), vision (II), and hearing and equilibrium (VIII).
2. **Primarily motor nerves** (III, IV, VI, XI, XII) that contain *somatic motor* fibers to skeletal muscles of the eye, neck, and tongue.
3. **Mixed (motor and sensory) nerves** (V, VII, IX, X). These mixed nerves supply sensory innervation to the face (through *general somatic sensory* fibers) and to the mouth and viscera *(general visceral sensory)*, including the taste buds for the sense of taste *(special visceral sensory)*. These nerves also innervate pharyngeal arch muscles *(somatic motor)*, such as the chewing muscles (V) and the muscles of facial expression (VII).

Additionally, four of the cranial nerves (III, VII, IX, X) contain *visceral motor* fibers that regulate visceral muscle and glands throughout much of the body. These motor fibers belong to the parasympathetic division of the autonomic nervous system (ANS) (see Figure 14.1). The ANS is discussed in Chapter 15, but note for now that the ANS innervates body structures through chains of two motor neurons and that the cell bodies of the second neurons occupy *autonomic motor ganglia* in the PNS.

Now that you have read this overview, study the detailed coverage of the individual cranial nerves in **Table 14.2**. In Table 14.2, the foramina of the skull through which each cranial nerve passes are indicated in blue text for emphasis.

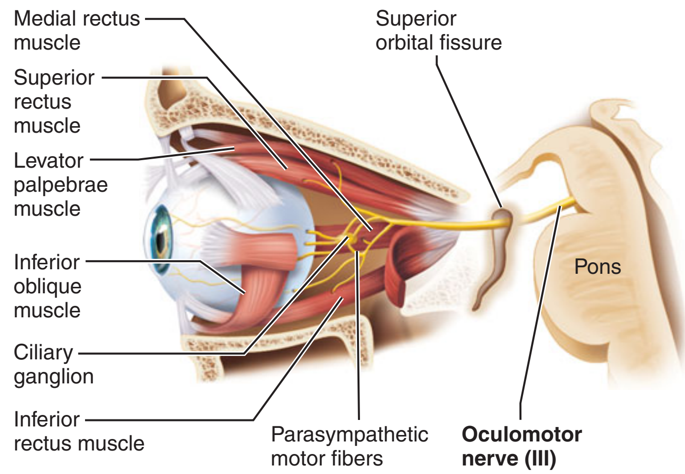
TABLE 14.2 Cranial Nerves *continued*

III THE OCULOMOTOR (ok″u-lo-mo′ter) NERVES

Origin and course: Fibers extend from ventral midbrain (near its junction with pons) and pass through bony orbit, via superior orbital fissure, to eye.

Function: Primarily motor (*oculomotor* = motor to the eye); contain a few proprioceptive afferents. Each nerve includes:

- Somatic motor fibers to four of the six extrinsic eye muscles (inferior oblique and superior, inferior, and medial rectus muscles) that help direct eyeball, and to levator palpebrae superioris muscle, which raises upper eyelid (p. 486).
- Parasympathetic (autonomic) motor fibers to constrictor muscles of iris, which cause pupil to constrict, and to ciliary muscle, which controls lens shape for focusing. Cell bodies of ganglionic parasympathetic neurons are in the ciliary ganglion.
- Sensory (proprioceptor) afferents, which run from same four extrinsic eye muscles to midbrain.



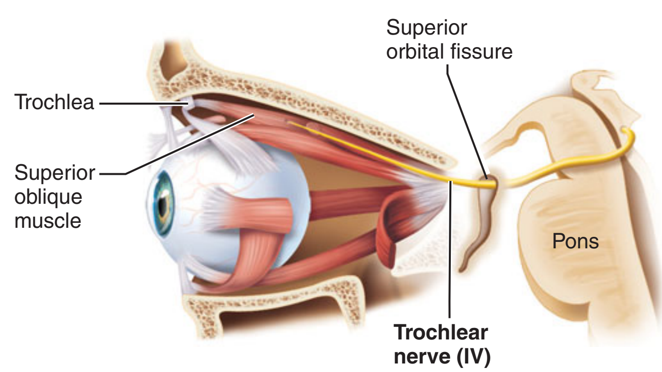
OCULOMOTOR NERVE PARALYSIS In oculomotor nerve paralysis, the eye cannot be moved up or inward, and at rest the eye turns laterally (*external strabismus* [strah-biz′mus]) because the actions of the two extrinsic eye muscles not served by cranial nerve III are unopposed. The upper eyelid droops *(ptosis)*, and the person has double vision and trouble focusing on close objects.

IV THE TROCHLEAR (trok′le-ar) NERVES

Origin and course: Fibers emerge from dorsal midbrain and course ventrally around midbrain to enter orbit through superior orbital fissure along with oculomotor nerve.

Function: Primarily motor; supply somatic motor fibers to, and carry proprioceptor fibers from, one of the extrinsic eye muscles, the superior oblique muscle.

TROCHLEAR NERVE DAMAGE Damage to a trochlear nerve results in double vision and reduced ability to rotate the eye inferolaterally.



V THE TRIGEMINAL NERVES

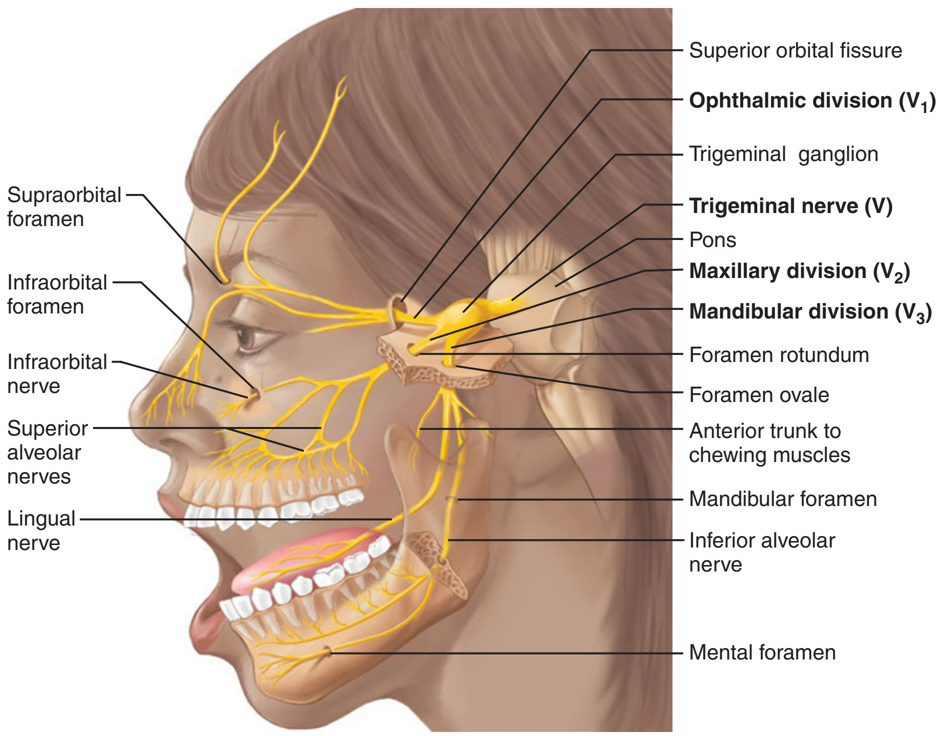
Largest of cranial nerves; fibers extend from pons to face, and form three divisions (*trigemina* = threefold): ophthalmic, maxillary, and mandibular divisions. As major general somatic sensory nerves of face, transmit afferent impulses from touch, temperature, and pain receptors. Cell bodies of sensory neurons of all three divisions are located in large *trigeminal ganglion.* The mandibular division also contains motor fibers that innervate chewing muscles.

	Ophthalmic Division (V_1)	Maxillary Division (V_2)	Mandibular Division (V_3)
Origin and course	Fibers run from face to pons via superior orbital fissure; cutaneous branch passes through supraorbital foramen	Fibers run from face to pons via foramen rotundum; cutaneous branch passes through infraorbital foramen	Fibers pass through skull via foramen ovale; enters mandible through mandibular foramen; cutaneous branch passes through mental foramen
Function	Sensory fibers from skin of anterior scalp, upper eyelid, and nose, and from nasal cavity mucosa, cornea, and lacrimal gland	Sensory fibers from nasal cavity mucosa, palate, upper teeth, skin of cheek, upper lip, lower eyelid	General sensory fibers from anterior tongue, lower teeth, skin of chin, temporal region of scalp; motor fibers to, and proprioceptor fibers from, muscles of mastication

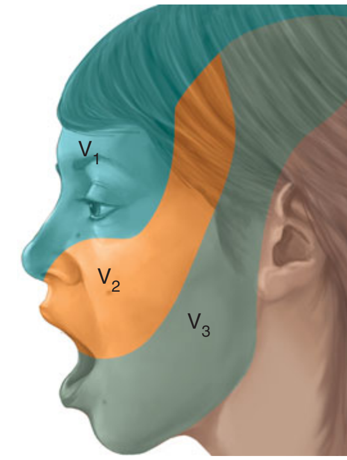
TABLE 14.2 *continued*

V THE TRIGEMINAL NERVES (*continued*)

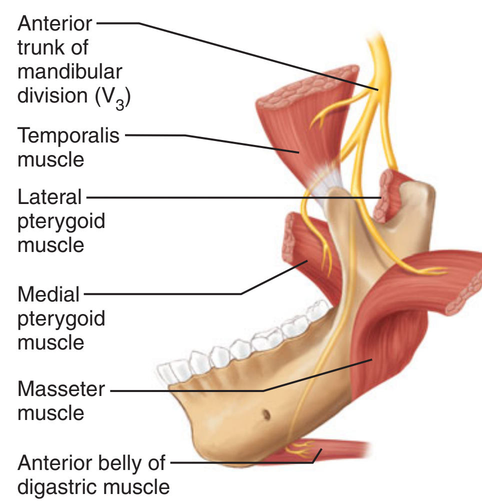
ANESTHESIA FOR UPPER AND LOWER JAWS Dentists desensitize upper and lower jaws by injecting local anesthetic (such as Novocain) into alveolar branches of the maxillary and mandibular divisions of the trigeminal nerve, respectively. This blocks pain-transmitting fibers from the teeth, and the surrounding tissues become numb.



(a) Distribution of the trigeminal nerve



(b) Distribution of sensory fibers of each division



(c) Motor branches of the mandibular division (V_3)

VI THE ABDUCENS (ab-du′senz) NERVES

Origin and course: Fibers leave inferior pons and enter orbit via superior orbital fissure to run to eye.

Function: Primarily motor; supplies somatic motor fibers to lateral rectus muscle, an extrinsic muscle of the eye; conveys proprioceptor impulses from same muscle to brain.

ABDUCENS NERVE PARALYSIS In abducens nerve paralysis, the eye cannot be moved laterally; at rest, affected eyeball turns medially *(internal strabismus).*

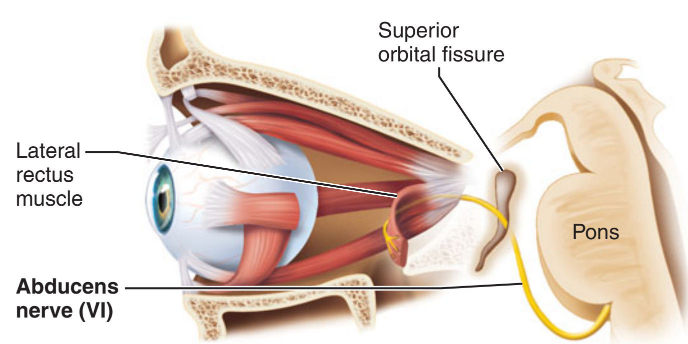


TABLE 14.2 Cranial Nerves *continued*

VII THE FACIAL NERVES

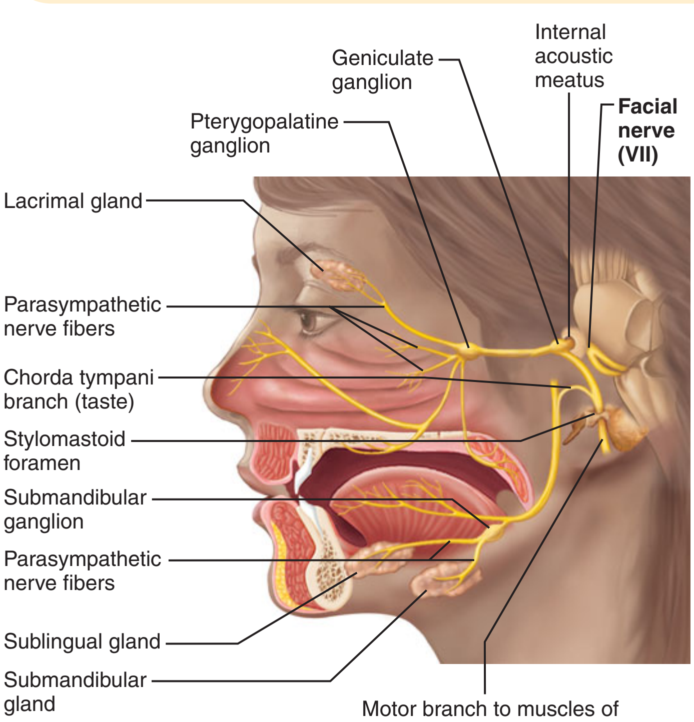
Origin and course: Fibers issue from pons, just lateral to abducens nerves (see Figure 14.4), enter temporal bone via internal acoustic meatus, and run within that bone. Chorda tympani branches off to two salivary glands and tongue. Nerve emerges through stylomastoid foramen, then courses to lateral aspect of face.

Function: Mixed nerves that are the chief motor nerves of face; have five major branches on face: temporal, zygomatic, buccal, mandibular, and cervical; see (a) and (c).

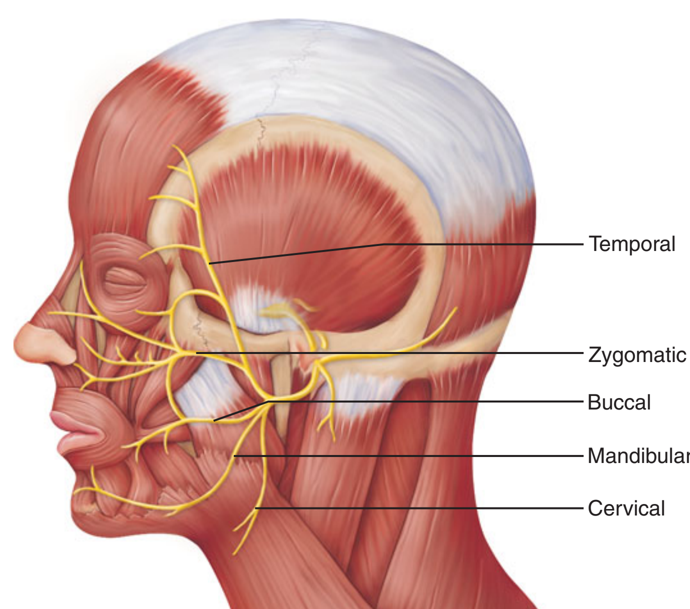
- Convey somatic motor impulses to skeletal muscles of face (muscles of facial expression), except for chewing muscles served by trigeminal nerves, and transmit proprioceptor impulses from same muscles to pons; see (c).
- Transmit parasympathetic (autonomic) motor impulses to lacrimal (tear) glands, nasal and palatine glands, and submandibular and sublingual salivary glands. Cell bodies of ganglionic parasympathetic motor neurons are in *pterygopalatine* (ter″ĭ-go-pal′ah-tin) and *submandibular ganglia* on the trigeminal nerve; see (b).
- Convey special sensory impulses from taste buds of anterior two-thirds of tongue and general sensory impulses from a tiny patch of skin on the ear; cell bodies of these sensory neurons are in *geniculate ganglion;* see (b).

(a) A simple method of remembering the courses of the five major motor branches of the facial nerve

BELL'S PALSY *Bell's palsy*, characterized by paralysis of facial muscles on affected side and partial loss of taste sensation, may develop rapidly (often overnight). It is caused by herpes simplex (viral) infection, which produces inflammation and swelling of the facial nerve. The lower eyelid droops, the corner of the mouth sags (making it difficult to eat or speak normally), and the eye constantly drips tears and cannot be completely closed. The condition may disappear spontaneously without treatment.



(b) Parasympathetic efferents and sensory afferents



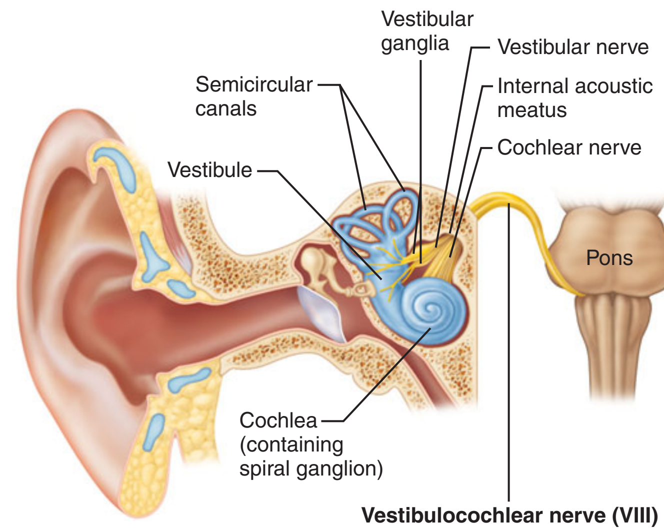
(c) Motor branches to muscles of facial expression and scalp muscles (see p. 278)

TABLE 14.2 *continued*

VIII THE VESTIBULOCOCHLEAR (ves-tib″u-lo-kok′le-ar) NERVES

Origin and course: Fibers arise from hearing and equilibrium apparatus located within inner ear of temporal bone and pass through internal acoustic meatus to enter brain stem at pons medulla border. Afferent fibers from hearing receptors in cochlea form *cochlear division*; those from equilibrium receptors in semicircular canals and vestibule form *vestibular division*. The two divisions merge to form vestibulocochlear nerve; see also Figure 16.19, p. 503.

Function: Primarily sensory. Vestibular branch transmits special somatic sensory impulses for sense of equilibrium, and sensory nerve cell bodies are located in *vestibular ganglia*. Cochlear branch transmits special somatic sensory impulses for sense of hearing, and sensory nerve cell bodies are located in *spiral ganglion* within cochlea. Small motor component adjusts the sensitivity of sensory receptors.



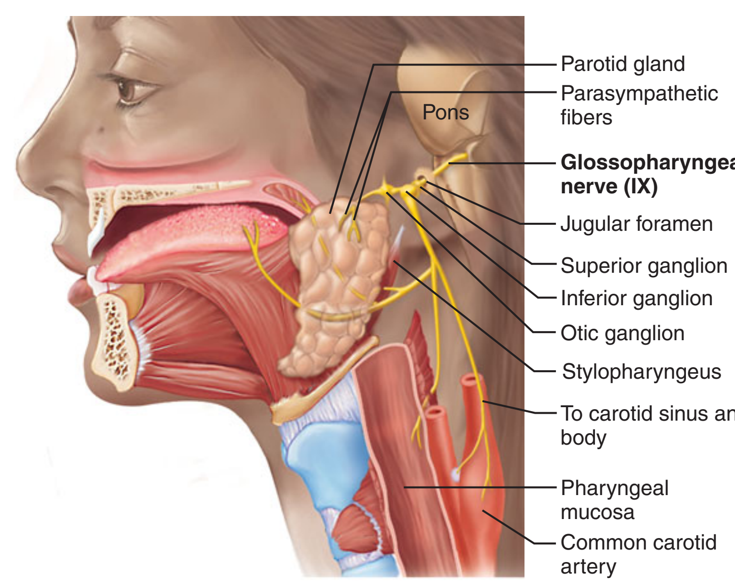
VESTIBULOCOCHLEAR NERVE DAMAGE
Lesions of cochlear nerve or cochlear receptors result in *central* or *nerve deafness*, whereas damage to vestibular division produces dizziness, rapid involuntary eye movements, loss of balance, nausea, and vomiting.

IX THE GLOSSOPHARYNGEAL (glos″o-fah-rin′je-al) NERVES

Origin and course: Fibers emerge from medulla and leave skull via jugular foramen to run to throat.

Function: Mixed nerves that innervate part of tongue and pharynx. Provide somatic motor fibers to, and carry proprioceptor fibers from, a superior pharyngeal muscle called the stylopharyngeus, which elevates the pharynx during swallowing. Provide parasympathetic motor fibers to parotid salivary gland. (Cell bodies of these ganglionic parasympathetic motor neurons are located in the *otic ganglion* on the trigeminal nerve.)

Visceral sensory fibers conduct taste and general sensory (touch, pressure, pain) impulses from pharyngeal mucosa and posterior tongue, from chemoreceptors in the carotid body (which monitor O_2 and CO_2 tension in the blood and help regulate respiratory rate and depth), and from baroreceptors of carotid sinus (which help to regulate blood pressure by providing feedback information). General somatic sensory fibers innervate a small area of skin on the external ear and some of the membrane lining the middle ear cavity. Sensory neuron cell bodies are located in *superior* and *inferior ganglia.*



GLOSSOPHARYNGEAL NERVE DAMAGE Injury or inflammation of glossopharyngeal nerves impairs swallowing and taste on the posterior third of the tongue.

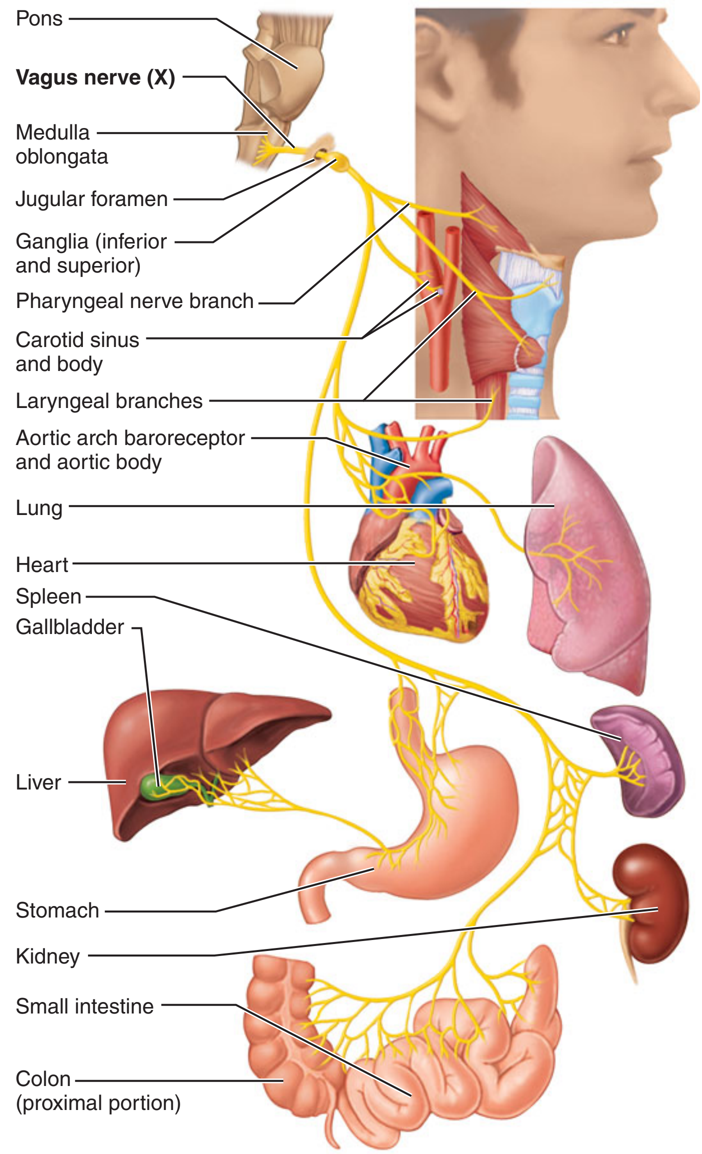
TABLE 14.2 Cranial Nerves *continued*

X THE VAGUS (va′gus) NERVES

Origin and course: The only cranial nerves to extend beyond head and neck region. Fibers emerge from medulla, pass through skull via jugular foramen, and descend through neck region into thorax and abdomen. See also Figure 15.5, p. 468.

Function: Mixed nerves. Somatic motor fibers innervate skeletal muscles of pharynx and larynx (involved in swallowing and vocalization). Parasympathetic motor fibers supply heart, lungs, and abdominal viscera and are involved in regulation of heart rate, breathing, and digestive system activity. General visceral sensory fibers return from thoracic and abdominal viscera, from the mucosa of larynx and pharynx, from the carotid sinus (baroreceptor for blood pressure), and from the carotid and aortic bodies (chemoreceptors for respiration). Special visceral sensory fibers return from taste buds on the epiglottis. Also carries general somatic sensory impulses from a tiny area of skin on the external ear and some of the membrane lining the middle ear cavity. Carry proprioceptor fibers from muscles of larynx and pharynx.

VAGUS NERVE DAMAGE Because most muscles of the larynx ("voice box") are innervated by laryngeal branches of the vagus, vagal nerve paralysis can lead to hoarseness or loss of voice; other symptoms are difficulty swallowing and impaired digestive system motility. Total destruction of both vagus nerves is incompatible with life, because these parasympathetic nerves are crucial in maintaining the normal state of visceral organ activity; without their influence, the activity of the sympathetic nerves, which mobilize and accelerate vital body processes (and shut down digestion), would be unopposed.



XI THE ACCESSORY NERVES

Origin and course: Unique in that they are formed from ventral rootlets that emerge from the spinal cord, not the brain stem. These rootlets arise from superior region ($C_1 – C_5$) of spinal cord, pass upward along the spinal cord, and enter the skull as the accessory nerve via foramen magnum. The accessory nerves exit the skull through the jugular foramen together with the vagus nerves and innervate the trapezius and sternocleidomastoid muscles. Long considered to have both a cranial and spinal portion, the cranial rootlets have been shown to be part of the vagus nerves. Although currently still classified as cranial nerves, this nomenclature may be reconsidered.

Function: Primarily motor. Supply somatic motor fibers to trapezius and sternocleidomastoid muscles, which together move head and neck, and convey proprioceptor impulses from same muscles.

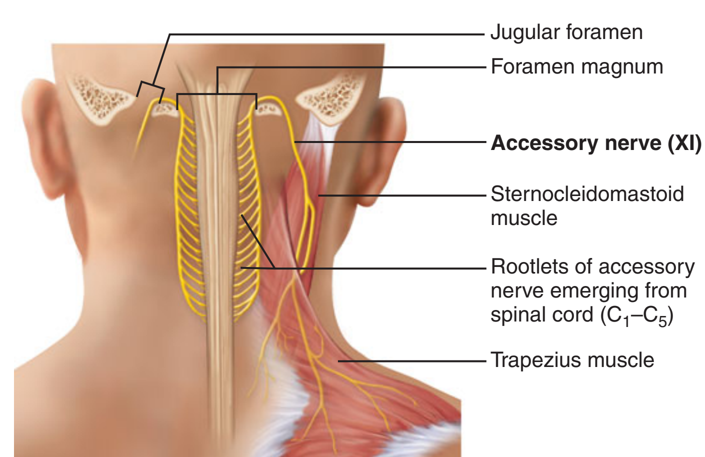


TABLE 14.2 *continued*

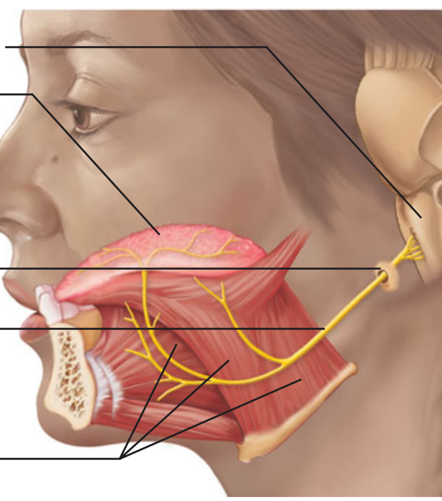
XI THE ACCESSORY NERVES *(continued)*

DAMAGE TO ACCESSORY NERVES Injury to the spinal root of one accessory nerve causes the head to turn toward the side of the injury as result of sternocleidomastoid muscle paralysis; shrugging of that shoulder (role of trapezius muscle) becomes difficult.

XII THE HYPOGLOSSAL (hi″po-glos′al) NERVES

Origin and course: As their name implies (*hypo* = below; *glossal* = tongue), hypoglossal nerves mainly serve the tongue. Fibers arise by a series of roots from medulla and exit from skull via hypoglossal canal to travel to tongue. See also Figure 14.4.

Function: Primarily motor. Carry somatic motor fibers to intrinsic and extrinsic muscles of tongue and proprioceptor fibers from same muscles to the brain stem. Hypoglossal nerve control allows not only food mixing and manipulation by tongue during chewing, but also tongue movements that contribute to swallowing and speech.



HYPOGLOSSAL NERVE DAMAGE Damage to hypoglossal nerves causes difficulties in speech and swallowing. If both nerves are impaired, the person cannot protrude the tongue; if only one side is affected, the tongue deviates (leans) toward affected side. Eventually the paralyzed side begins to atrophy.

check your understanding

6. Which cranial nerves pass through the jugular foramen?
7. Which nerves contain special somatic sensory fibers? What is the special sensation carried in each?
8. Which nerve is the "great sensory nerve of the face"? Which nerve innervates the muscles of facial expression?

For answers, see Appendix B.

SPINAL NERVES

- Describe the location of a spinal nerve, and distinguish spinal roots from rami.
- Describe the somatic innervation of the back, trunk, and limbs.
- Define nerve plexus. Name the four main plexuses formed by ventral rami, and the body region innervated by each. Describe the major nerves originating from each plexus.
- Define dermatomes, and explain Hilton's law of the innervation of joints.

Thirty-one pairs of **spinal nerves,** each containing thousands of nerve fibers, attach to the spinal cord **(Figure 14.5)**. These nerves are named according to their point of issue from the vertebral column: There are 8 pairs of cervical nerves (C_1–C_8), 12 pairs of thoracic nerves (T_1–T_{12}), 5 pairs of lumbar nerves (L_1–L_5), 5 pairs of sacral nerves (S_1–S_5), and 1 pair of coccygeal nerves (designated Co_1). Notice that there are eight pairs of cervical nerves but only seven cervical vertebrae. This discrepancy is easily explained: The first cervical spinal nerve (C_1) lies *superior* to the first vertebra, whereas the last cervical nerve (C_8) exits *inferior* to the seventh cervical vertebra, leaving six nerves in between. Below the cervical region, every spinal nerve exits *inferior* to the vertebra of the same number. Each spinal nerve has long branches that supply most of the body inferior to the head.

As mentioned in Chapter 13, each spinal nerve connects to the spinal cord by a **dorsal root** and a **ventral root (Figure 14.6)**. Each root forms from a series of **rootlets** that attach along the whole length of the corresponding spinal cord segment. The dorsal root contains the axonal processes of sensory neurons arising from cell bodies in the **dorsal root ganglion.** The ventral root contains the axonal processes of

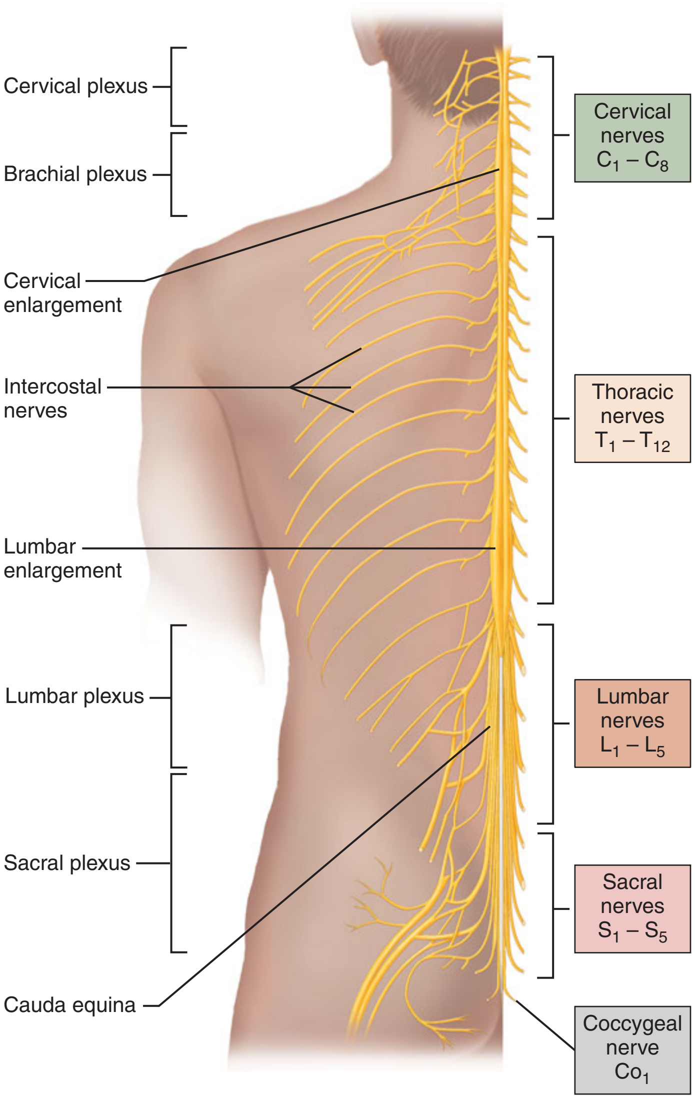


FIGURE 14.5 Spinal nerves, posterior view. The spinal nerves are shown on the right; their ventral rami are shown on the left. Most ventral rami form nerve plexuses (cervical, brachial, lumbar, and sacral). The long, horizontal nerves in the region of the ribs are the intercostal nerves.

motor neurons whose cell bodies are located in the ventral gray column of the spinal cord. The spinal nerve lies at the junction of the dorsal and ventral roots, just lateral to the dorsal root ganglion. The spinal nerves and dorsal root ganglia lie within the intervertebral foramina, against the bony pedicles of the vertebral arches (Figure 14.7a).

Directly lateral to its intervertebral foramen, each spinal nerve branches into a **dorsal ramus** (ra′mus; "branch") and a **ventral ramus.** Connecting to the base of the ventral ramus are *rami communicantes* leading to *sympathetic trunk ganglia*—visceral structures discussed in Chapter 15. Each of the branches of the spinal nerve, like the spinal nerve itself, contains both motor and sensory fibers (Figure 14.6).

The rest of this chapter focuses on the dorsal and ventral rami and their branches (Figure 14.7b). These rami supply the entire *somatic* region of the body, the outer tube (skeletal musculature and skin), from the neck inferiorly. The dorsal rami supply the dorsum of the neck and the back. The much thicker ventral rami supply a larger area: the anterior and lateral regions of the neck and trunk, and all regions of the limbs.

It is important to review the difference between the *roots* and *rami* (Figure 14.6). The roots lie medial to the spinal nerves and are either strictly sensory (dorsal root) or strictly motor (ventral root). The rami, by contrast, are lateral branches of the spinal nerves, and each contains both sensory fibers and motor fibers. Do not confuse the roots with the rami!

The following sections explore how the rami and their branches innervate various regions of the body. We will first consider the innervation of the back and the anterior thoracic and abdominal wall. Then we discuss the anatomy and roles of the structures called *nerve plexuses.* Finally, we will examine the innervation of the neck, the upper limbs, the lower limbs, the joints, and the skin. The text throughout refers to the innervation of major muscle groups; for more specific information on muscle innervation, see Tables 11.3–11.17 on pp. 278–328.

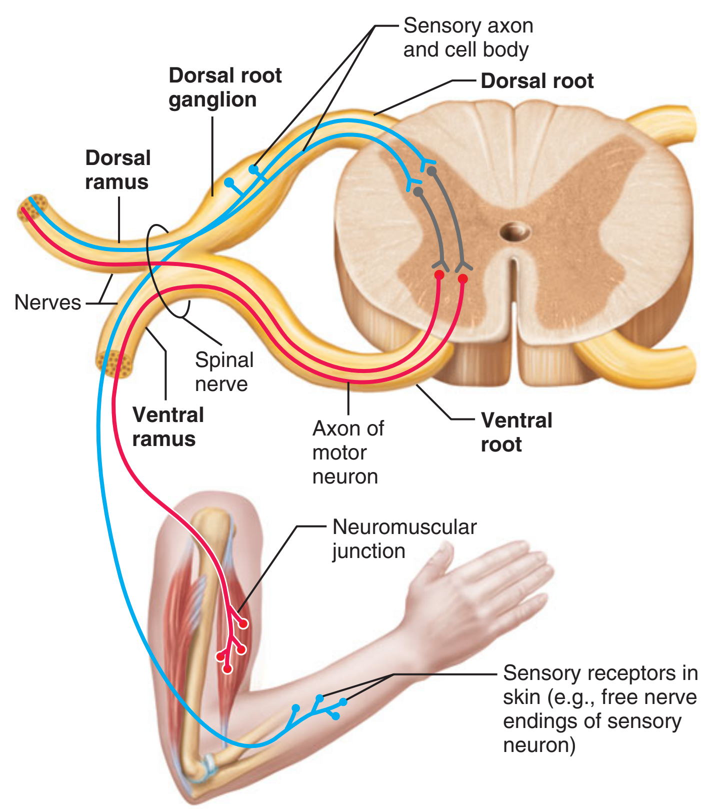
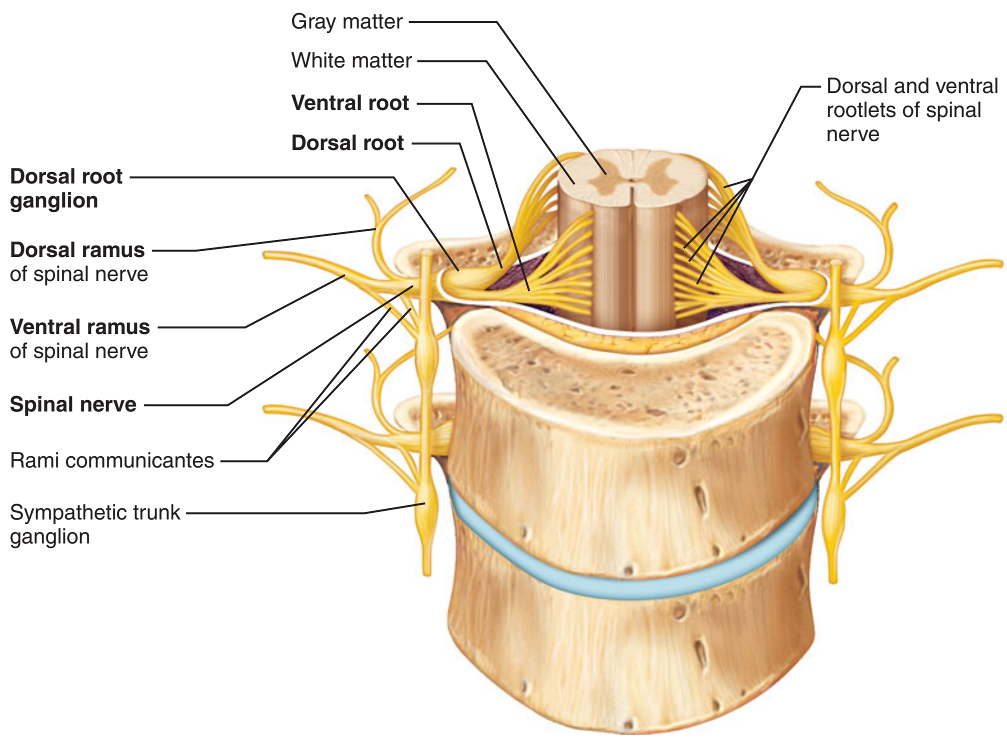
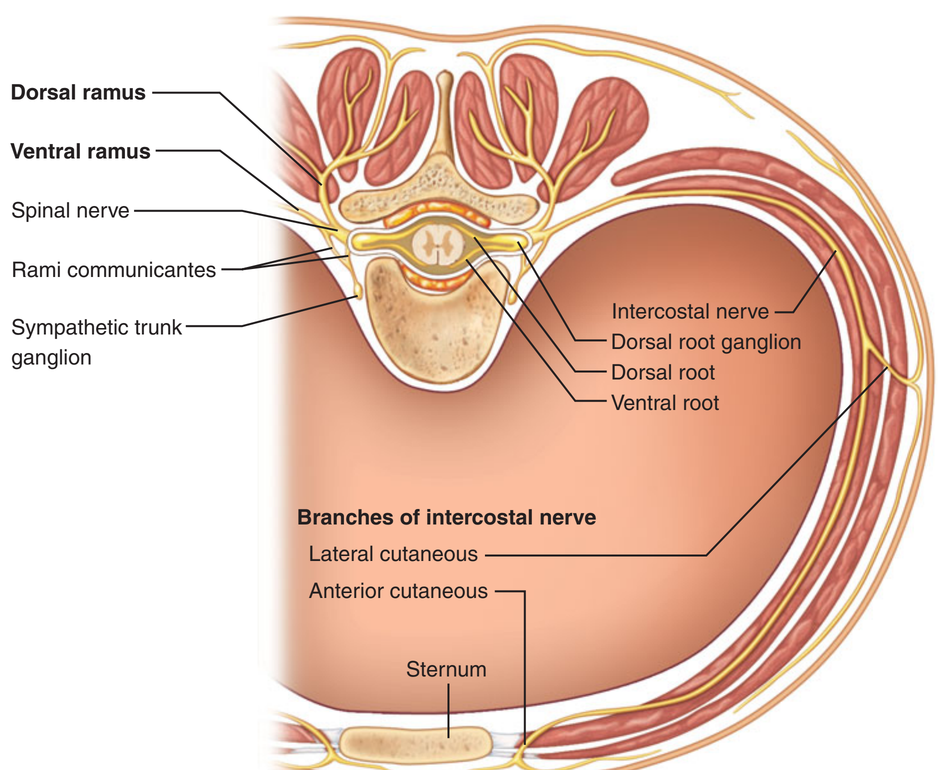


FIGURE 14.6 The functional components of a spinal nerve, anterior view. The branches and connections to the spinal cord are illustrated.



(a) Anterior view showing spinal cord, associated nerves, and vertebrae. The dorsal and ventral roots arise medially as rootlets and join laterally to form the spinal nerve.



(b) Cross section of thorax showing the main roots and branches of a spinal nerve.

FIGURE 14.7 Formation of spinal nerves and rami distribution. Notice in (b) the distribution of the dorsal and ventral rami. In the thorax, each ventral ramus continues as an intercostal nerve.

Innervation of the Back

The innervation of the back (posterior part of the trunk and neck) by the dorsal rami follows a neat, segmented pattern. Each dorsal ramus branches to innervate a horizontal strip of muscle and skin in line with its emergence point from the vertebral column (Figure 14.7b). This pattern of innervation is far simpler than the innervation of the rest of the body by the ventral rami.

Innervation of the Anterior Thoracic and Abdominal Wall

Only in the thorax are the ventral rami arranged in a simple and segmented pattern. The thoracic ventral rami run anteriorly, one deep to each rib, as the **intercostal nerves** (Figures 14.5 and 14.7b). These nerves supply the intercostal muscles, the skin of the anterior and lateral thorax, and most of the abdominal wall inferior to the rib cage. Along its course, each intercostal nerve gives off **lateral** and **anterior cutaneous branches** to the adjacent skin (Figure 14.7b).

Two nerves in this thoracic series are unusual. The last (T_{12}) lies inferior to the twelfth rib and thus is called a *subcostal* ("below the ribs") *nerve* rather than an intercostal nerve. The first (most superior) intercostal nerve is exceptionally small because most fibers of T_1 enter the brachial plexus (discussed shortly).

check your understanding

9. What deficits would result from a lesion that damaged the dorsal root of spinal nerve T_4? What deficits would occur if a lesion damaged the dorsal ramus of T_4?
10. Below which vertebra does each of the following nerves exit: (a) cervical nerve C_5; (b) lumbar nerve L_3?

For answers, see Appendix B.

Introduction to Nerve Plexuses

A **nerve plexus** is a network of nerves. The ventral rami of all spinal nerves except T_2–T_{12} branch and join one another lateral to the vertebral column, forming nerve plexuses (see Figure 14.5). These interlacing networks occur in the cervical, brachial, lumbar, and sacral regions and primarily serve the limbs. Note that these plexuses are formed by *ventral* rami only. Within the plexuses, fibers from the different ventral rami crisscross each other and redistribute so that (1) each end branch of the plexus contains fibers from several different spinal nerves, and (2) fibers from each ventral ramus travel to the body periphery via several different routes or branches. Therefore, each muscle in a limb receives its nerve supply from more than one spinal nerve. As a result of this arrangement, the destruction of a single spinal nerve cannot completely paralyze any limb muscle.

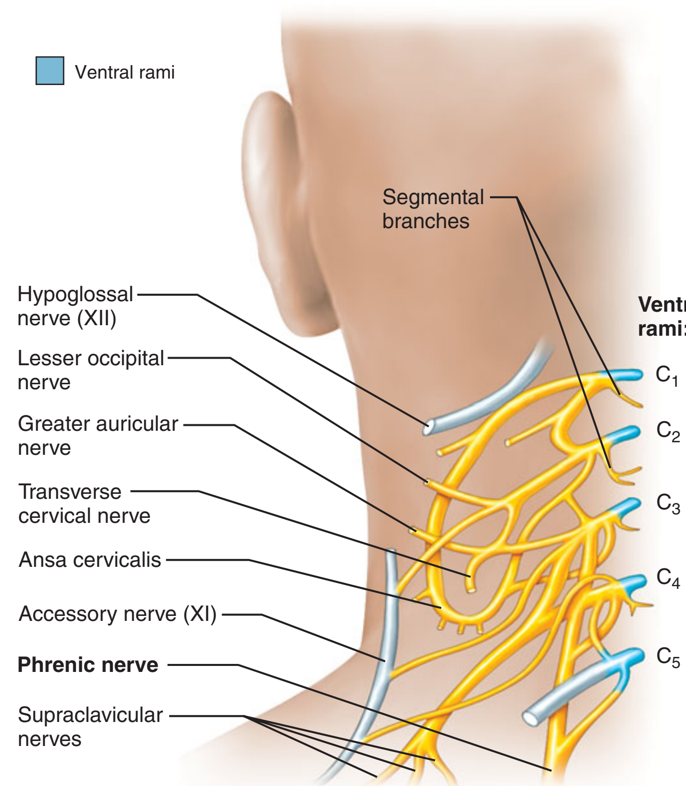


FIGURE 14.8 The cervical plexus, posterior view. The nerves that are depicted in gray connect to the cervical plexus but do not belong to it. See Table 14.3 for areas of innervation.

The Cervical Plexus and Innervation of the Neck

The **cervical plexus** is buried deep in the neck, under the sternocleidomastoid muscle, and extends into the posterior triangle of the neck (shown in Figure 11.30, p. 332). It is formed by the ventral rami of the first four cervical nerves **(Figure 14.8)**. The plexus forms an irregular series of interconnecting loops from which branches arise. The structures these branches serve are listed in **Table 14.3**. Most branches of the cervical plexus are **cutaneous nerves** (*cutane* = skin) that carry sensory impulses from the skin of the neck, the back of the head, and the most superior part of the shoulder. Other branches carry motor innervation to muscles in the anterior neck region.

The most important nerve from this plexus is the **phrenic** (fren′ik) **nerve,** which receives fibers from C_3, C_4, and C_5. The phrenic nerve courses inferiorly through the thorax and innervates the diaphragm (*phren* = diaphragm), providing somatic motor and sensory innervation to this most vital respiratory muscle. If both phrenic nerves are cut (or if the spinal cord is damaged superior to C_3–C_5), respiratory arrest will occur.

Hiccups result when the phrenic nerve induces abrupt, rhythmic contractions of the diaphragm. This reflexive response commonly originates from sensory irritation of the diaphragm or stomach. Swallowing spicy food or acidic soda

TABLE 14.3 Branches of the Cervical Plexus (Figure 14.8)

Nerves	Ventral Rami	Structures Innervated
CUTANEOUS BRANCHES (SUPERFICIAL)		
Lesser occipital	C_2, C_3	Skin on posterolateral aspect of neck
Greater auricular	C_2, C_3	Skin of ear, skin over parotid gland
Transverse cervical	C_2, C_3	Skin on anterior and lateral aspect of neck
Supraclavicular (anterior, middle, and posterior)	C_3, C_4	Skin of shoulder and clavicular region
MOTOR BRANCHES (DEEP)		
Ansa cervicalis (superior and inferior roots)	C_1–C_3	Infrahyoid muscles of neck (omohyoid, sternohyoid, and sternothyroid)
Segmental and other muscular branches	C_1–C_5	Deep muscles of neck (geniohyoid and thyrohyoid) and portions of scalenes, levator scapulae, trapezius, and sternocleidomastoid muscles
Phrenic	C_3–C_5	Diaphragm (sole motor nerve supply)

pop can lead to hiccups via this reflex. Painful stimuli from the diaphragm, carried on the somatic sensory fibers of the phrenic nerve, are perceived as coming from the skin of the shoulder area, which is innervated by the same spinal segments (see Figure 14.16).

The Brachial Plexus and Innervation of the Upper Limb

The **brachial plexus** **(Figure 14.9a)** lies partly in the neck and partly in the axilla (armpit) and gives rise to almost all of the nerves that supply the upper limb. The brachial plexus can sometimes be felt in the posterior triangle of the neck just superior to the clavicle at the lateral border of the sternocleidomastoid muscle (refer to Figure 11.30, p. 332). (Note that the name is "brachial," referring to the arm, not "branchial," referring to the pharynx or "bronchial," referring to the airways in the lung.)

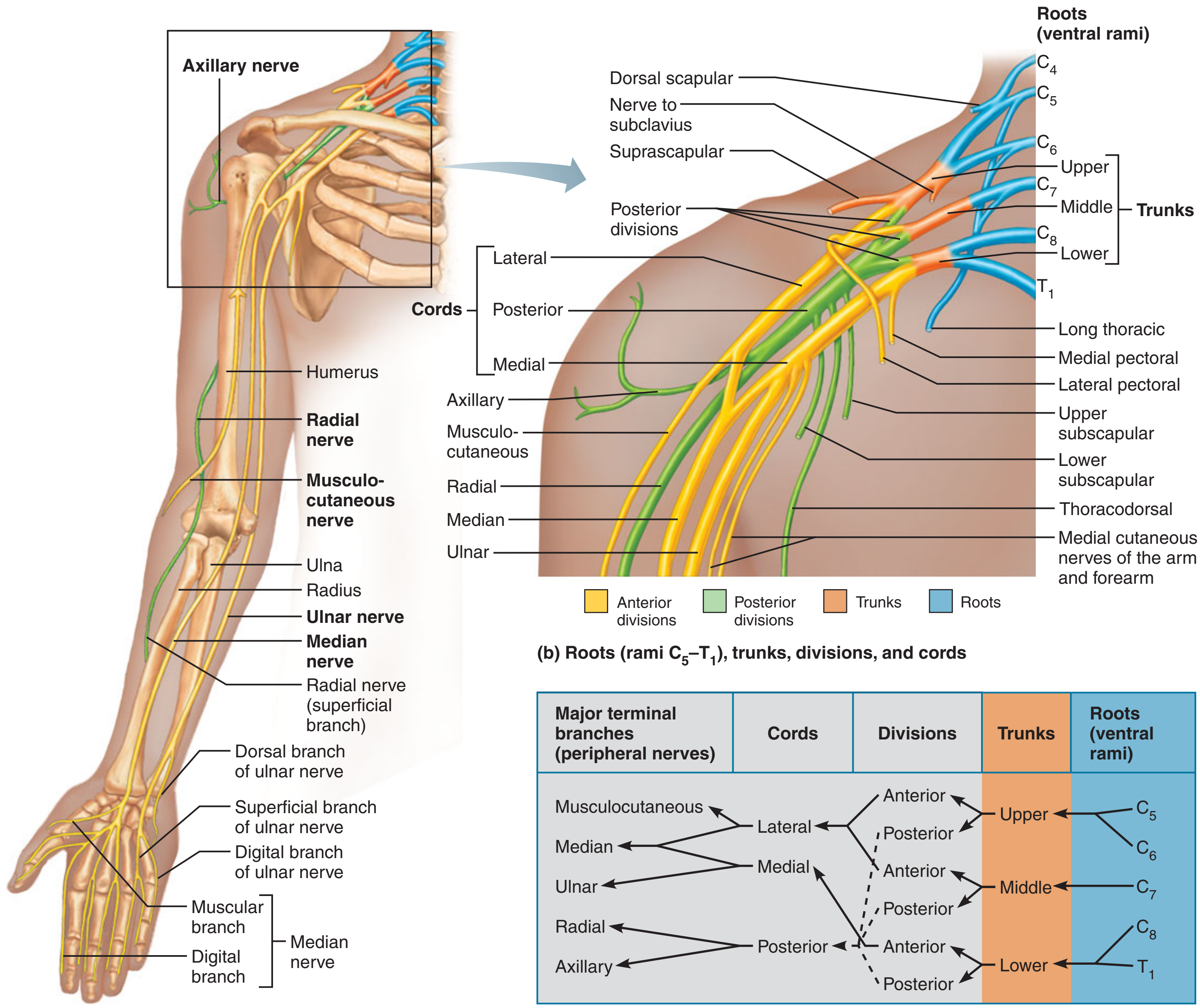
The brachial plexus is formed by the intermixing of the ventral rami of cervical nerves C_5–C_8 and most of the ventral ramus of T_1. Additionally, it may receive small contributions from C_4 or T_2.

Because the brachial plexus is very complex, some consider it the anatomy student's nightmare, yet its arrangement reflects the functional organization of the structures it innervates. The components of the brachial plexus, from medial to lateral, are the ventral rami (misleadingly called *roots**), which merge to form three *trunks.* Each trunk splits into two *divisions,* anterior and posterior. These six divisions then converge to form three *cords.* The phrase "**R**eally **T**ired? **D**rink **C**offee" can help you remember the sequence of roots, trunks, divisions, and cords. Refer to Figure 14.9b and c as you work through the description of these components.

The five **roots** of the brachial plexus, ventral rami C_5–T_1, lie deep to the sternocleidomastoid. At the lateral border of this muscle, these rami unite to form the **upper, middle,** and **lower trunks,** each of which branches into an **anterior** and **posterior division.** The anterior divisions (colored yellow in Figure 14.9) give rise to nerves that innervate the anterior compartment muscles in the upper limb (flexor muscles) and skin on the anterior surface. The nerves from the posterior divisions (colored green in Figure 14.9) serve the limb's posterior compartment muscles (extensor muscles) and skin on the posterior surface. The divisions pass deep to the clavicle and enter the axilla. The anterior divisions from the upper and middle trunks give rise to the **lateral cord,** and the anterior division from the lower trunk forms the **medial cord.** The **posterior cord** is composed of the posterior divisions of all three trunks. The cords are named for their position in reference to the axillary artery. Some nerves branch off the brachial plexus here to supply muscles of the superior thorax and shoulder (and some skin of the shoulder as well) (Figure 14.9b).

BRACHIAL PLEXUS INJURIES Injuries to the brachial plexus are common and can be serious. These injuries usually result from stretching the plexus, as can occur in football when a tackler yanks the arm of a ball carrier, or when a blow depresses a shoulder and laterally flexes the head away from that shoulder. Falls, as from a horse or motorcycle, or carrying a heavy backpack can result in overstretching or crushing the brachial plexus and can lead to weakness or even paralysis of the upper limb. Transient injuries to this plexus eventually heal.

*Do not confuse these roots of the brachial plexus with the dorsal and ventral roots of spinal nerves.



(a) **The major nerves of the upper limb**

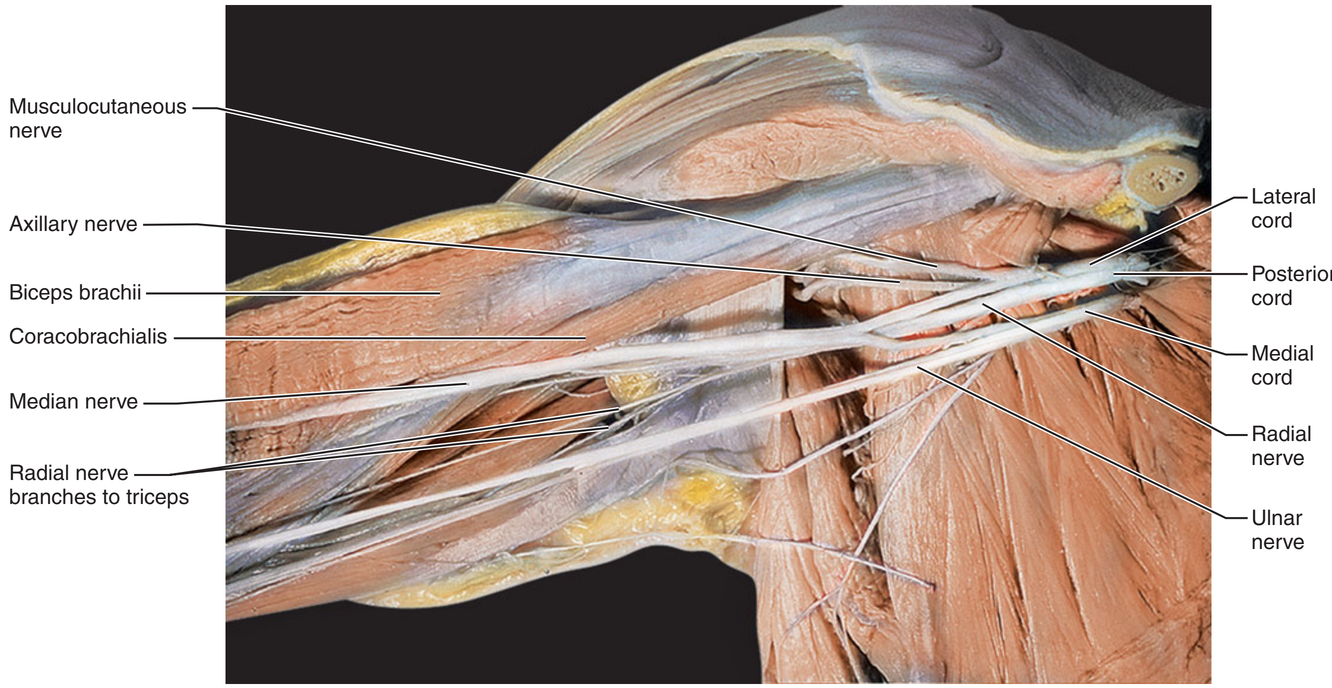
(c) Flowchart summarizing relationships within the brachial plexus

FIGURE 14.9 **The brachial plexus, anterior view.**

The brachial plexus ends in the axilla, where its three cords give rise to the main nerves of the upper limb (see Figure 14.9). *Focus on Innervation of the Upper Limb* **(Figure 14.10)** shows the distribution and targets of five of the most important of these peripheral nerves—the *musculocutaneous, median,* and *ulnar nerves* from the anterior divisions of the plexus, and the *axillary* and *radial nerves* from the posterior divisions.

The **musculocutaneous nerve** (Figures 14.9d and 14.10), the main terminal branch of the lateral cord, courses within the anterior arm. It passes through the coracobrachialis muscle and descends between the muscles biceps brachii and brachialis, innervating these three arm flexors. Distal to the elbow, it becomes cutaneous and enables skin sensation on the lateral forearm.

The **median nerve** (Figures 14.9a and 14.10) innervates most muscles of the anterior forearm and the lateral palm. After originating from the lateral and medial cords, it descends through the arm without branching, lying medial and posterior to the biceps brachii muscle. Just distal to the elbow region, the median nerve gives off branches to most muscles in the flexor compartment of the forearm (but not the flexor carpi ulnaris and the medial part of the flexor digitorum profundus). Passing through the carpal tunnel deep to the tendon of the palmaris longus and reaching the hand, it innervates five intrinsic muscles in the lateral part of the palm, including the thenar muscles used to oppose the thumb.



(d) Cadaver dissection of right brachial plexus

FIGURE 14.9 The brachial plexus, anterior view, *continued.*

MEDIAN NERVE INJURY Because the median nerve descends through the exact middle of the forearm and wrist, it is often severed during wrist-slashing suicide attempts. Destruction of the median nerve makes it difficult to oppose the thumb toward the little finger; thus, the ability to pick up small objects is diminished. This deficit is referred to as "ape hand."

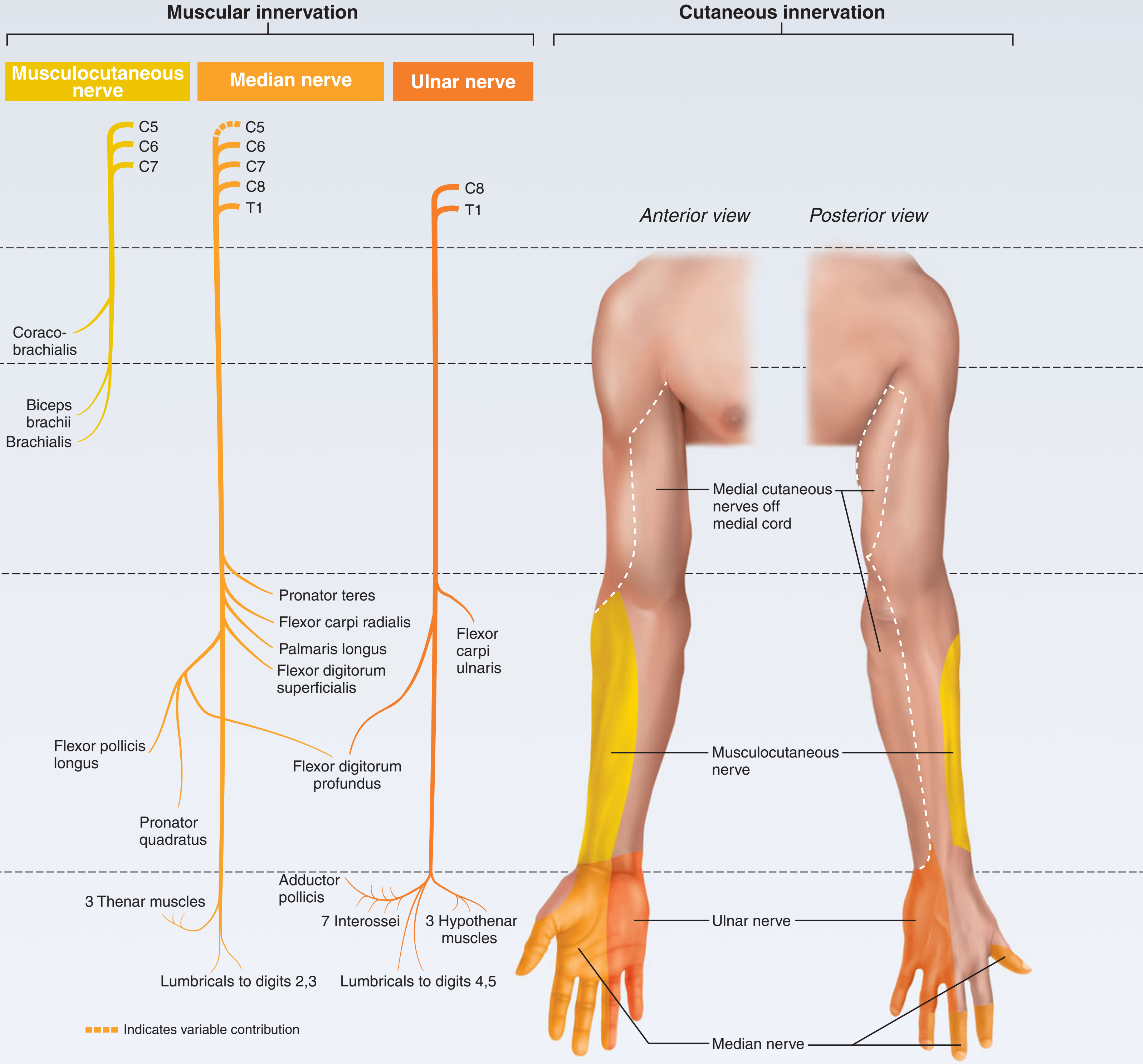
An injury to the median nerve in the elbow region results in loss of flexion at the interphalangeal joints of digits 2 and 3 (due to deficit of innervation to the digital flexors) and inability of these digits to flex at the metacarpophalangeal joint (due to loss of innervation to the lateral lumbricals). Clinically, this type of injury presents as the "hand of benediction" **(Figure 14.11a)**.

ULNAR NERVE INJURIES Because of its exposed position at the elbow, the ulnar nerve is vulnerable to injury. Striking the "funny bone"—the spot where this nerve rests against the medial epicondyle—causes tingling of the little finger. Repeated throwing can also damage the nerve here because it stresses the medial part of the elbow region. Even more commonly, the ulnar nerve is injured in the carpal region of the palm, another place where it is superficially located. People with damage to this nerve can neither adduct and abduct their fingers (because the interossei and medial lumbrical muscles are paralyzed) nor form a tight grip (because the hypothenar muscles are useless). Without the interossei muscles to extend the fingers at the interphalangeal joints, the fingers flex at these joints, and the hand contorts into a *clawhand* (Figure 14.11b).

The **ulnar nerve** (Figures 14.9a and 14.10) branches off the medial cord of the brachial plexus, then descends along the medial side of the arm. At the elbow it passes posterior to the medial epicondyle of the humerus; then it follows the ulna along the forearm, where it supplies the flexor carpi ulnaris and the medial (ulnar) part of the flexor digitorum profundus. The ulnar nerve then continues into the hand, where it innervates most of the intrinsic hand muscles and the skin on the medial side of the hand. A dorsal branch supplies the skin of the dorsal medial hand.

FIGURE 14.10

The nerves from the **anterior division of the brachial plexus** innervate the muscles in the anterior compartments: the flexor muscles of the arm, forearm, and hand. These nerves continue distally to supply cutaneous innervation to the forearm and hand.



The nerves from the **posterior division of the brachial plexus** innervate the muscles in the posterior compartments: the extensor muscles of the upper limb. These nerves continue distally to supply cutaneous innervation to much of the posterior arm, forearm, and hand.

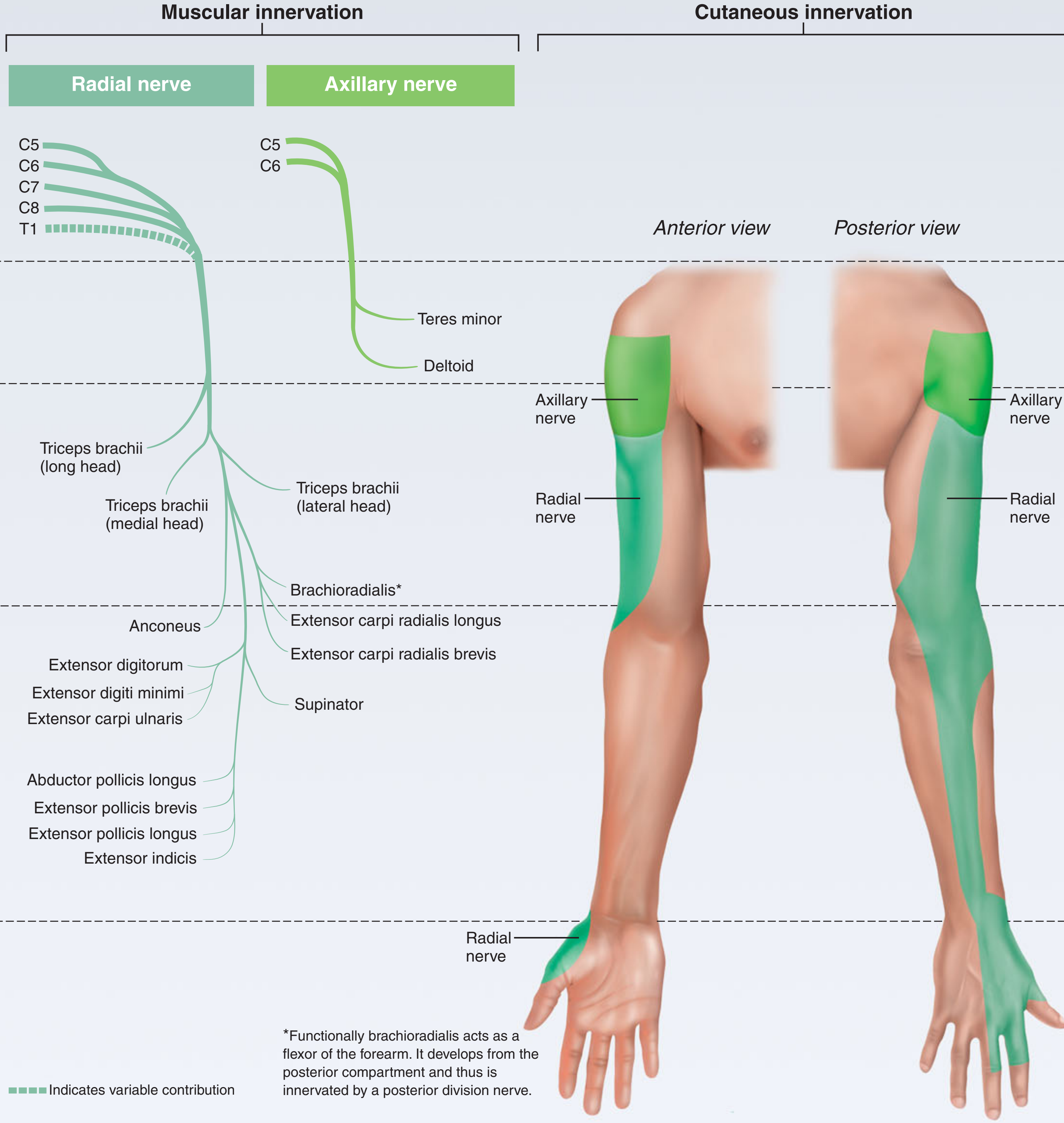


FIGURE 14.11 Appearance of hand resulting from nerve injury.

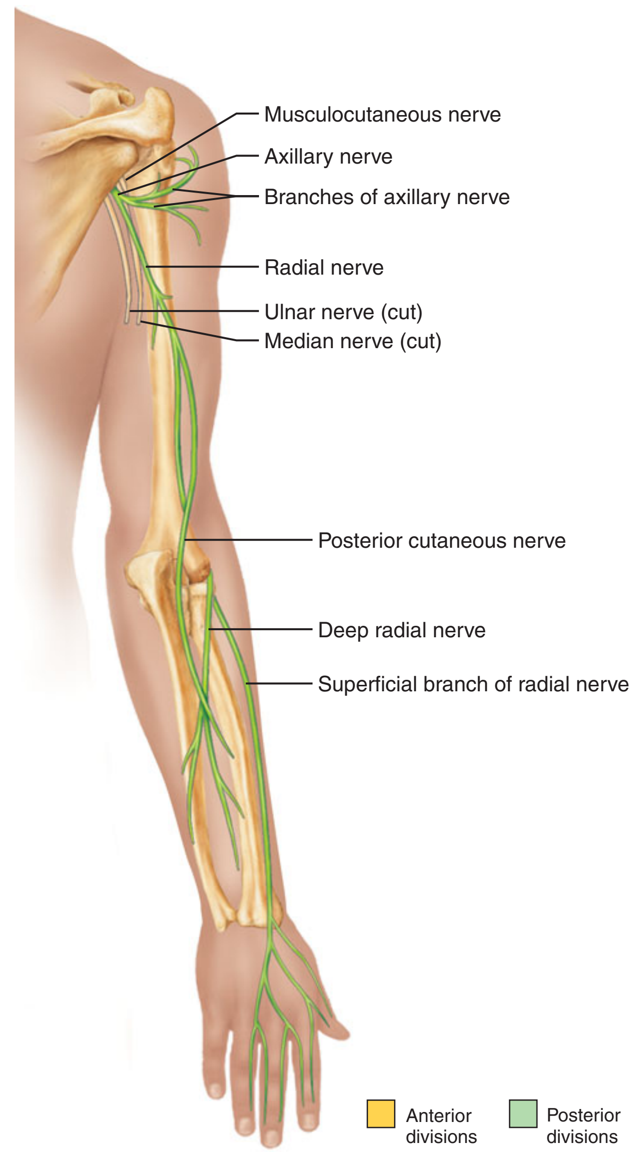


FIGURE 14.12 Course of the axillary and radial nerves. Posterior view.

The **axillary nerve,** a branch of the posterior cord (Figure 14.10 and Figure 14.12), runs posterior to the surgical neck of the humerus and innervates the deltoid and teres minor muscles. Its sensory fibers supply the capsule of the shoulder joint and the skin covering the inferior half of the deltoid muscle.

The **radial nerve** (Figures 14.10 and 14.12), a continuation of the posterior cord, is the largest branch of the brachial plexus, innervating almost the entire posterior side of the upper limb, including all the limb extensor muscles. As it descends through the arm, it wraps around the humerus in the radial groove, sending branches to the triceps brachii. It then curves anteriorly around the lateral epicondyle at the elbow, where it divides into a superficial and a deep branch. The superficial branch descends along the lateral edge of the radius under cover of the brachioradialis muscle; distally, it supplies the skin on the dorsolateral surface of the hand. The deep branch of the radial nerve runs posteriorly to supply the extensor muscles on the forearm.

TABLE 14.4 Branches of the Brachial Plexus to Trunk and Shoulder Muscles

Nerves	Cord and Spinal Roots (Ventral Rami)	Structures Innervated
Dorsal scapular	Branches of C_5 rami	Rhomboid muscles and levator scapulae
Long thoracic	Branches of C_5–C_7 rami	Serratus anterior muscle
Subscapular	Posterior cord; branches of C_5 and C_6 rami	Teres major and subscapularis muscles
Thoracodorsal	Posterior cord; branches of C_6–C_8 rami	Latissimus dorsi
Suprascapular	Upper trunk (C_5, C_6)	Shoulder joint; supraspinatus and infraspinatus muscles
Pectoral (lateral and medial)	Branches of lateral and medial cords (C_5–T_1)	Pectoralis major and minor muscles

RADIAL NERVE INJURIES Trauma to the radial nerve results in **wrist-drop,** an inability to extend the hand at the wrist (Figure 14.11c). If the lesion occurs far enough superiorly, the triceps muscle is paralyzed, so that the forearm cannot be actively extended at the elbow. Many fractures of the humerus follow the radial groove and harm the radial nerve there. This nerve can also be crushed in the axilla by improper use of a crutch or if a person falls asleep with an arm draped over the back of a chair.

Smaller branches off the brachial plexus innervating muscles of the trunk and scapula that move the shoulder are summarized in **Table 14.4**.

check your understanding

11. Would a patient with a spinal injury at C_5 be able to breathe independently?
12. What nerve innervates all of the extensor muscles of the arm and forearm?
13. A crushing blow to the elbow injured the ulnar nerve where it crosses the medial epicondyle. What sensory and motor deficits will be apparent on examination?
14. Would the patient with the injury at C_5 (described above) have any function in the muscles of the upper limb?

For answers, see Appendix B.

The Lumbar Plexus and Innervation of the Lower Limb

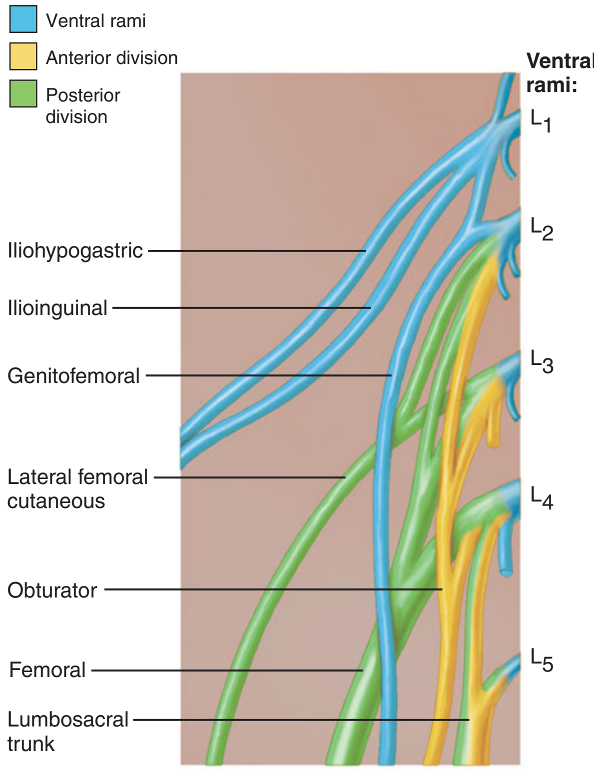
The **lumbar plexus** **(Figure 14.13)** arises from the first four lumbar spinal nerves (L_1–L_4) and lies within the psoas major muscle in the posterior abdominal wall. Its smaller branches innervate parts of the abdominal wall and the psoas muscle itself, but the main branches descend to innervate the anterior thigh. The **femoral nerve,** the largest terminal branch, runs deep to the inguinal ligament to enter the thigh. It descends vertically through the center of the femoral triangle (shown in Figure 11.38b, p. 339). From there it divides into several large branches. Motor branches of the femoral nerve innervate the muscles of the anterior compartment of the thigh, including the important quadriceps femoris. Cutaneous branches of the femoral nerve serve the skin of the anterior thigh and the medial surface of the leg from the knee to the foot. The **obturator nerve** passes through the large obturator foramen of the pelvis, enters the medial compartment of the thigh, and innervates the adductor muscle group plus some skin on the superomedial thigh. These major branches of the lumbar plexus are summarized in *Focus on Innervation of the Lower Limb* (see Figure 14.15). Smaller cutaneous branches are summarized in **Table 14.5**, p. 454.

Compression of the spinal roots of the lumbar plexus by a herniated disc causes a major disturbance in gait. This is because the femoral nerve innervates muscles that flex the thigh at the hip (rectus femoris and iliacus), and muscles that extend the leg at the knee (the entire quadriceps femoris group). Other symptoms are pain or anesthesia of the anterior thigh and of the medial thigh if the obturator nerve is impaired.

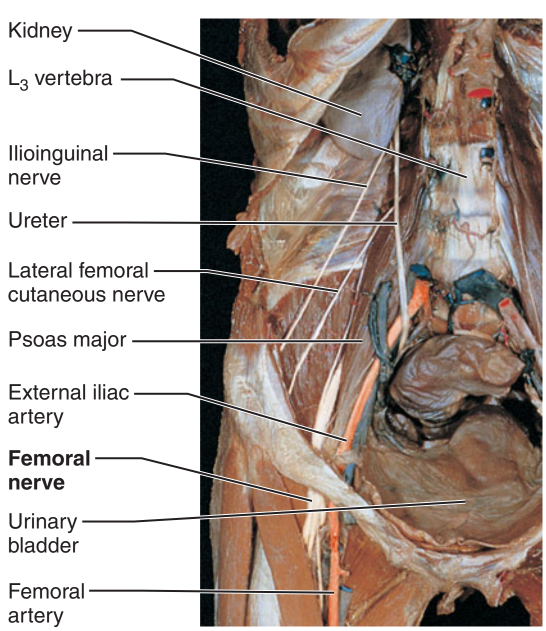
The Sacral Plexus and Innervation of the Lower Limb

The **sacral plexus** **(Figure 14.14)** arises from spinal nerves L_4–S_4 and lies immediately caudal to the lumbar plexus. Because some fibers from the lumbar plexus contribute to the sacral plexus via the **lumbosacral trunk,** the two plexuses are often considered together as the *lumbosacral plexus.* Of the dozen named branches of the sacral plexus, about half serve the buttock and lower limb, whereas the rest innervate parts of the pelvis and perineum. The most important branches are described next and summarized in *Focus on Innervation of the Lower Limb* **(Figure 14.15)**.

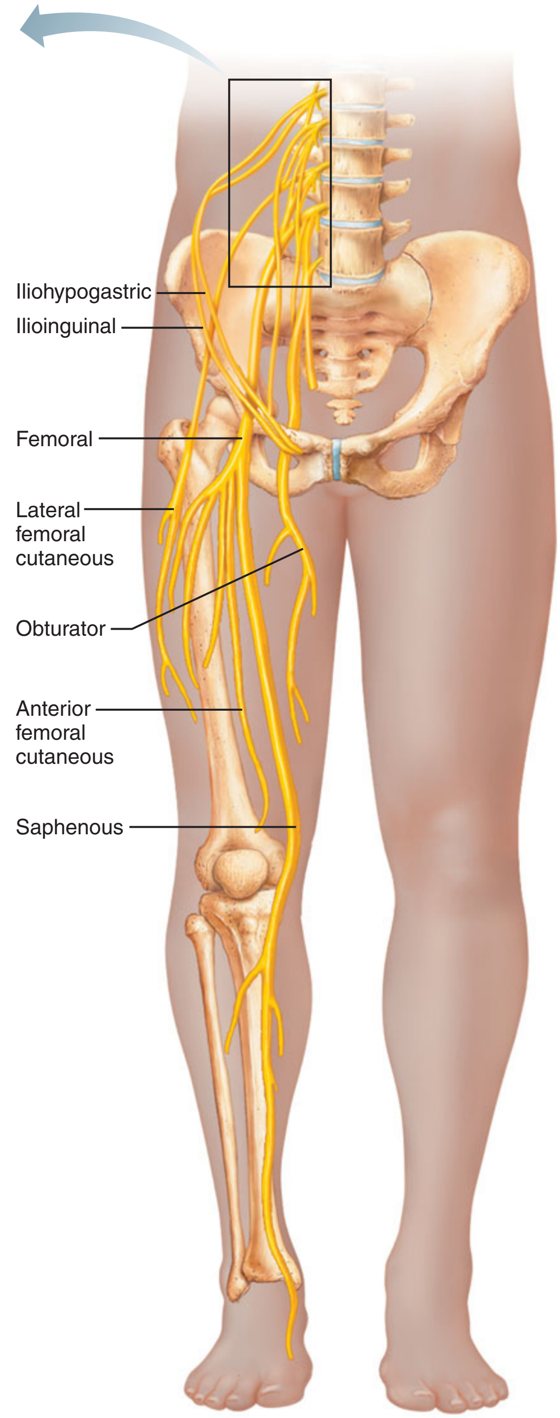
The largest branch is the **sciatic** (si-at′ik) **nerve,** the thickest and longest nerve in the body (Figures 14.14c and 14.15). It supplies all of the lower limb except the anterior and medial regions of the thigh. Actually, the sciatic is two nerves—the *tibial* and *common fibular nerves*—wrapped in a common sheath. It leaves the pelvis by passing through the



(a) Ventral rami and major branches of the lumbar plexus



(b) Nerves of the lumbar plexus, anterior view

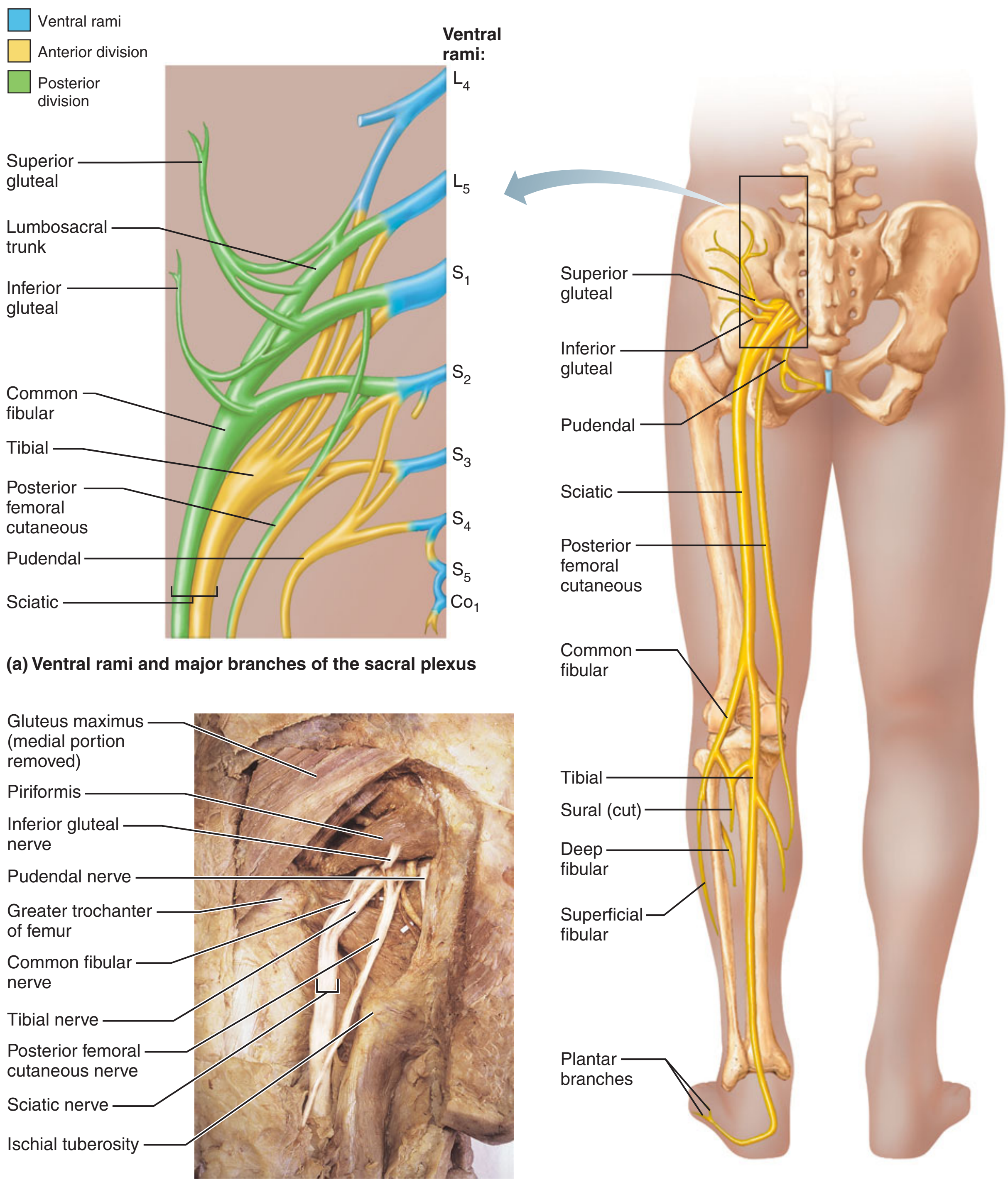


(c) Distribution of the major nerves from the lumbar plexus to the lower limb

FIGURE 14.13 The lumbar plexus.

greater sciatic notch, then courses deep to the broad gluteus maximus muscle and enters the thigh just medial to the hip joint (*sciatic* literally means "of the hip"). From there it descends through the posterior thigh deep to the hamstrings, which it innervates. Superior to the knee region, it branches into the tibial nerve and the common fibular nerve.

The **tibial nerve** (Figures 14.14c and 14.15) courses through the popliteal fossa (the region just posterior to the knee joint, shown in Figure 11.40, p. 341), and then descends through the calf deep to the soleus muscle. At the ankle, it passes posterior to the medial malleolus and divides into the two main nerves of the sole of the foot, the medial and lateral



(a) Ventral rami and major branches of the sacral plexus

(b) Dissection of the gluteal region, posterior view

(c) Distribution of the major nerves from the sacral plexus to the lower limb

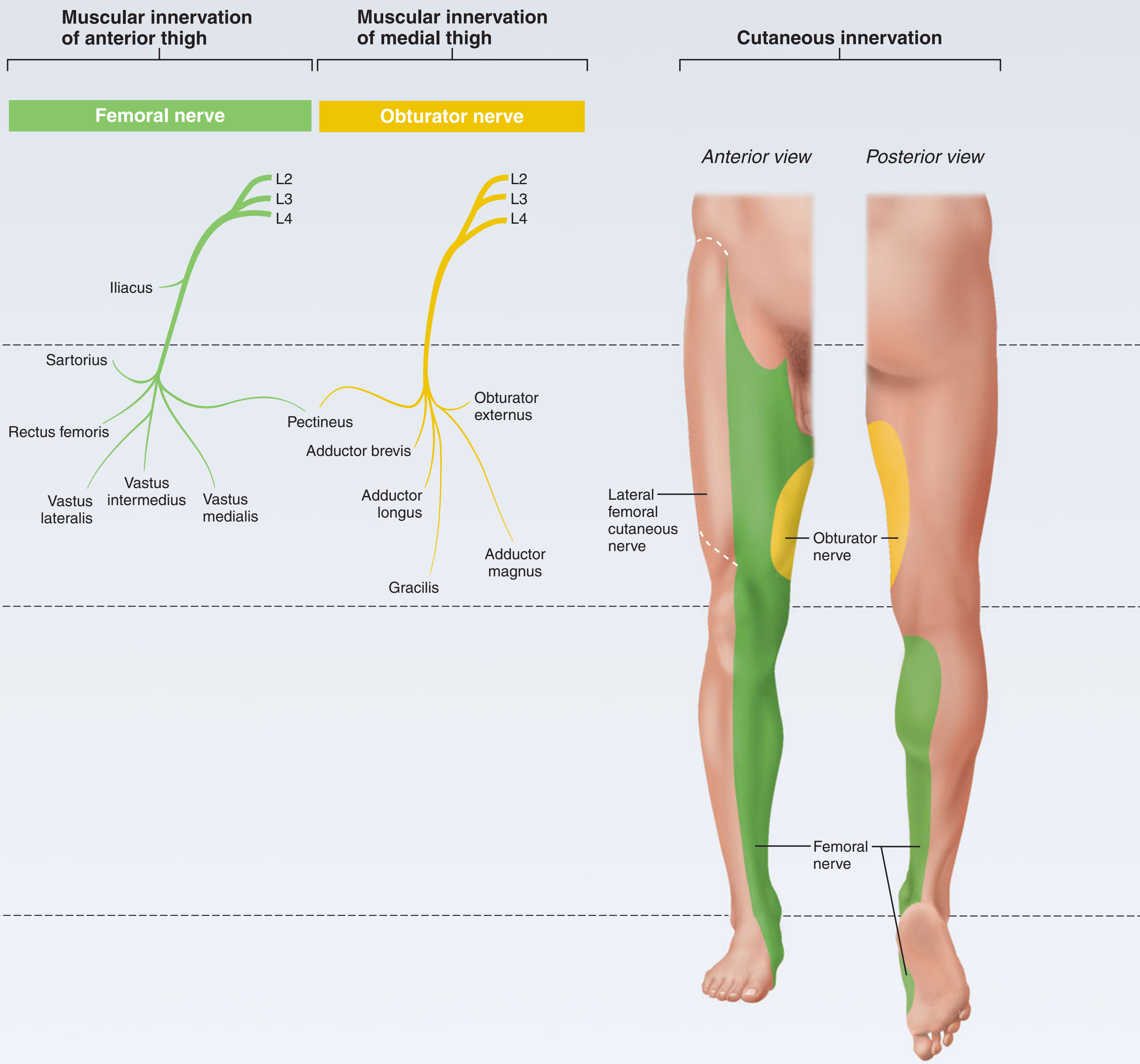
FIGURE 14.14 The sacral plexus.

plantar nerves. The tibial nerve and its branches supply almost all muscles in the posterior region of the lower limb and supply cutaneous innervation to (1) the skin of the sole of the foot, through the plantar nerves, and (2) a vertical strip of skin along the posterior leg through a **sural nerve,** to which the common fibular nerve also contributes.

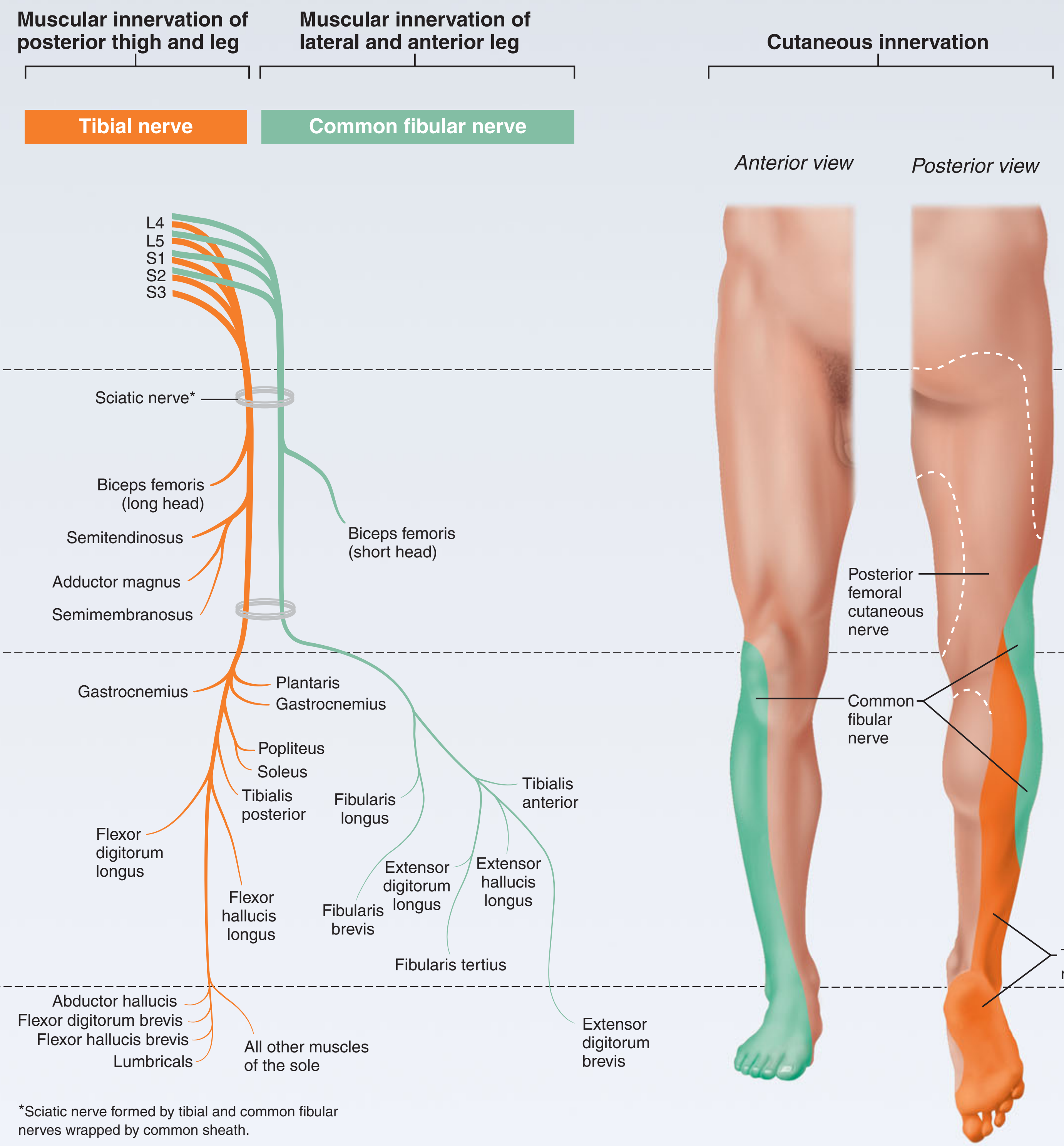
The **common fibular nerve** (Figures 14.14c and 14.15), or *common peroneal nerve* (*perone* = fibula), supplies most structures on the anterolateral aspect of the leg. It descends laterally from its point of origin in the popliteal fossa and enters the superior part of the leg, where it can be palpated as it wraps around the neck of the fibula. It then divides into deep and superficial branches. The **superficial fibular (peroneal) nerve** supplies the fibular muscles in the lateral compartment

FIGURE 14.15

The nerves from the **lumbar plexus** innervate the muscles in the anterior and medial compartments of the thigh, and supply cutaneous innervation to anterior and medial portions of the thigh and leg.



The nerves from the **sacral plexus** innervate the muscles in the posterior compartment of the thigh and all of the muscles in the leg, and supply cutaneous innervation to the lateral and posterior portions of the leg and to the foot.



*Sciatic nerve formed by tibial and common fibular nerves wrapped by common sheath.

TABLE 14.5 Cutaneous Branches of the Lumbar Plexus (Figure 14.13)

Nerves	Ventral Rami	Structures Innervated
Lateral femoral cutaneous	L_2–L_3	Skin of lateral thigh; some sensory branches to peritoneum
Iliohypogastric	L_1	Skin on side of buttock and skin on pubis; proprioceptor (and motor?) to the most inferior parts of the oblique and transversus abdominis muscles
Ilioinguinal	L_1	Skin of external genitalia and proximal medial aspect of the thigh
Genitofemoral	L_1, L_2	Skin of scrotum in males, of labia majora in females, and of anterior thigh inferior to middle portion of inguinal region; cremaster muscle in males

of the leg and most of the skin on the superior surface of the foot. The **deep fibular (peroneal) nerve** serves the muscles of the anterior compartment of the leg—the extensors that dorsiflex the foot.

Except for the sciatic nerve, the largest branches of the sacral plexus are the **superior** and **inferior gluteal nerves,** which innervate the gluteal muscles (Figure 14.14a). Other branches of the sacral plexus supply the lateral rotators of the thigh and the muscles of the pelvic floor and perineum. The **pudendal nerve** (pu-den′dal; "shameful") innervates the muscles and skin of the perineum, helps stimulate erection, and is responsible for voluntary inhibition of defecation and urination (Table 11.9, pp. 294–295). As it passes anteriorly to enter the perineum, the pudendal nerve lies just medial to the ischial tuberosity. The pudendal nerve may be blocked with anesthetic, either to help block pain in the perineum during childbirth, or as preparation for surgery on the anal or genital regions. In a **pudendal nerve block,** the injection needle is inserted just medial to the ischial tuberosity. These nerves are summarized in Table 14.6.

SCIATIC NERVE INJURIES The sciatic nerve can be injured in many ways. **Sciatica** (si-at′ĭ-kah), characterized by a stabbing pain over the course of this nerve, often occurs when a herniated lumbar disc presses on the sacral dorsal roots within the vertebral canal. Furthermore, wounds to the buttocks or posterior thigh can sever the sciatic nerve, in which case the leg cannot be flexed at the knee (because the hamstrings are paralyzed) and the foot cannot be moved at the ankle. When only the tibial nerve is injured, the paralyzed muscles in the calf cannot plantar flex the foot, and a shuffling gait results. When the common fibular nerve is damaged, dorsiflexion is lost and the foot drops into plantar flexion, a condition called **footdrop.** The common fibular nerve is susceptible to injury in the superolateral leg, where it is superficially located and easily crushed against the neck of the fibula.

Innervation of the Skin: Dermatomes

The area of skin innervated by the cutaneous branches from a single spinal nerve is called a **dermatome,** literally a "skin segment." All spinal nerves except C_1 participate in dermatomes. The map of dermatomes illustrated in Figure 14.16 was constructed by recording areas of numbness in patients who had experienced injuries to specific spinal roots. In the *trunk* region, the dermatomes are almost horizontal, relatively uniform in width, and in direct line with their spinal nerves. In the *limbs,* however, the pattern of dermatomes is less straightforward. In the upper limb, the skin is supplied by the nerves participating in the brachial plexus: the ventral rami of C_5 to T_1 or T_2. In the lower limb, lumbar nerves supply most of the anterior surface, whereas sacral nerves supply much of the posterior surface. This distribution basically reflects the areas supplied by the lumbar and sacral plexuses, respectively.

Adjacent dermatomes are not as clearly demarcated from one another as a dermatome map indicates. On the trunk, neighboring dermatomes overlap each other by a full 50%; as a result, destruction of a single spinal nerve does not produce complete numbness anywhere. On the limbs, by contrast, the overlap is not complete: Some skin patches are innervated by one spinal nerve only.

CLINICAL IMPORTANCE OF DERMATOMES Clinicians use dermatomes in at least two ways. First, dermatomes can help pinpoint the level of spinal injuries. Numbness in all dermatomes below T_1, for example, indicates a spinal cord injury at T_1. Additionally, because the varicella-zoster virus that produces shingles (see next section) resides in a single dorsal root ganglion, a flare-up of this infection may produce skin blisters along the entire course of the associated dermatome. Finally, dermatomes may also have surgical applications, because anesthetic agents may be injected into specific spinal nerves or roots to desensitize specific skin regions during surgery.

TABLE 14.6 Additional Branches of the Sacral Plexus (Figure 14.14)

Nerves	Ventral Rami	Structures Innervated
Superior gluteal	L_4, L_5, S_1	Motor branches to gluteus medius and minimus and tensor fasciae latae
Inferior gluteal	L_5–S_2	Motor branches to gluteus maximus
Posterior femoral cutaneous	S_1–S_3	Skin of most inferior part of buttock, posterior thigh, and popliteal region; length variable; may also innervate part of skin of calf and heel
Pudendal	S_2–S_4	Supplies most of skin and muscles of perineum (region encompassing external genitalia and anus and including clitoris, labia, and vaginal mucosa in female, and scrotum and penis in males); external anal sphincter

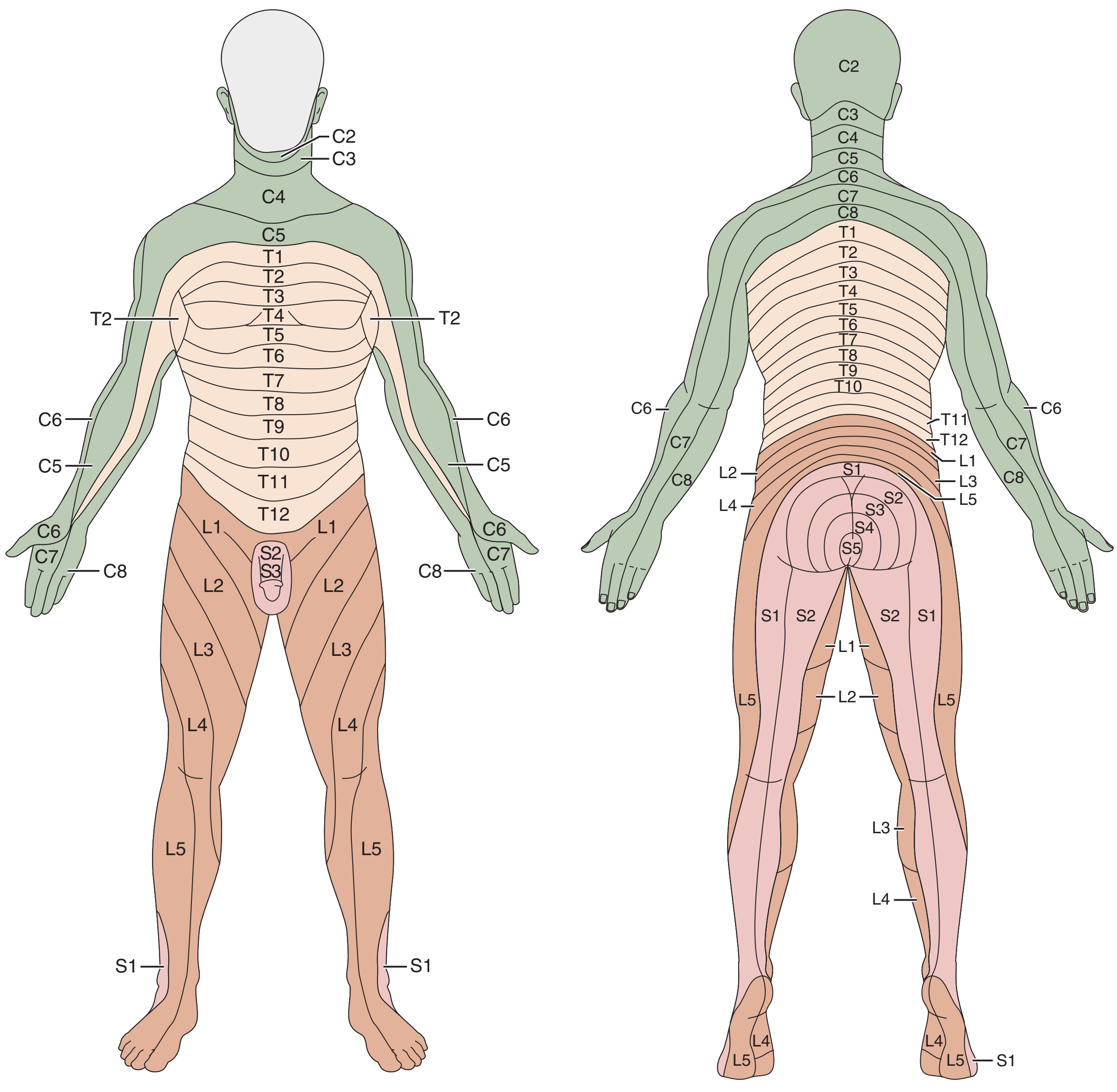


FIGURE 14.16 Map of dermatomes. **(a)** Anterior view. **(b)** Posterior view. A dermatome is an area of skin innervated by the sensory fibers of a single spinal nerve (both ventral and dorsal rami). In the limbs there is considerable overlap between adjacent dermatomes.

Innervation of Joints of the Body

Because injuries to joints are common, health professionals should know which nerves serve which synovial joints. Memorizing so much information is almost impossible, however, because every joint capsule receives sensory branches from several different nerves.

The most helpful guideline for deducing which nerves supply a given joint is provided by **Hilton's law:** *Any nerve that innervates a muscle producing movement at a joint also innervates the joint itself (and the skin over it).* Applied to the knee joint, for example, the process of deduction would be as follows: Because the knee is crossed by the quadriceps, hamstring, and gracilis muscles (see Table 11.15, p. 312), and because the nerves to these muscles are the femoral, obturator, and branches of the sciatic nerves (see Figure 14.15), then all these nerves innervate the knee joint as well.

check your understanding

15. Name the three nerves that innervate the muscles of the thigh, and identify the muscle compartment innervated by each.
16. Using Hilton's law, identify the nerves that innervate the elbow joint.
17. Explain why a disc herniation at the level of lumbar vertebra L_5 can cause loss of sensation on the anterolateral surface of the leg.
18. Shingles blisters that encircle the abdomen at the level of the navel indicate viral infection in which spinal nerve?

For answers, see Appendix B.

DISORDERS OF THE PERIPHERAL NERVOUS SYSTEM

➤ Explain the causes and symptoms of shingles, migraine headaches, and peripheral neuropathy.

This section considers two disorders that involve sensory neurons (shingles and migraine headaches) and one disorder that can affect both sensory and motor innervation (peripheral neuropathy). For information on other selected motor disorders—polio and postpolio syndrome—see **A Closer Look**.

Shingles (herpes zoster) is a varicella-zoster viral infection of sensory neurons innervating the skin. It is characterized by a rash of scaly, painful blisters usually confined to a narrow strip of skin on one side of the trunk (that is, to one or several adjacent dermatomes). The disease stems from a childhood infection of chicken pox, during which the viruses are transported from the skin lesions, through the peripheral processes of the sensory neurons, to the cell bodies in a sensory ganglion. There, in the nuclei of the nerve cells, the viruses remain dormant for many years, held in check by the immune system. When the immune system is weakened as a result of age, stress, or another medical condition (HIV infection, cancer treatment, organ transplant), the viruses can multiply and travel back through the sensory axons to the skin, producing the inflammatory rash of shingles. The attacks last for several weeks. In a minority of cases, the attacks recur, separated by periods of healing and remission. Shingles affects 1–2 of every 1000 people, mostly those over 50 years of age. Treatment is to administer pain-relieving drugs and, under certain conditions, antiviral medicines.

Following a shingles outbreak, some patients experience **postherpetic neuralgia,** a condition that occurs if the zoster virus damages the sensory nerve fibers and disrupts the sensory pathways. Sensory signals from the skin are exaggerated, and even light touch (as from clothing) or a slight temperature change (such as stepping outdoors) causes excruciating pain. This condition can last for months and can be debilitating, as the pain is severe and unpredictable.

A zoster virus vaccine, similar to the chicken pox vaccine used for children, was recently approved by the U.S. Food and Drug Administration. This vaccine has been shown to be effective in reducing the incidence of shingles in people over age 60 by 50% compared to a control group.

Migraine headaches are extremely painful, episodic headaches that affect 25 million Americans. The cause of migraines was long debated, but they are now known to relate to the sensory innervation of the brain's cerebral arteries by the trigeminal nerve: A signal from the brain stem causes the sensory nerve endings of the ophthalmic division to release chemicals onto the cerebral arteries that they innervate, signaling these arteries to dilate (widen). This dilation then compresses and irritates these sensory nerve endings, causing the headache. New drugs can relieve migraines by blocking pain receptors on the trigeminal endings.

Peripheral neuropathy refers to any pathologic condition of the peripheral nerves that disrupts nerve function. If an individual nerve is affected, the condition is called a *mononeuropathy;* if multiple nerves are involved, it is termed a *polyneuropathy.* Symptoms of a neuropathy vary according to the nerve fibers affected. Symptoms of sensory nerve involvement include paresthesia, severe pain, burning, or loss of feeling. If motor fibers are affected, muscle weakness and paralysis result. Peripheral neuropathies may be caused by trauma to individual nerves or by repetitive-use injuries that compress nerves. Many systemic disorders (diabetes, autoimmune disorders, HIV, vitamin B deficiency, and alcoholism) can also cause peripheral neuropathy. In fact, 70% of all diabetics have some nerve dysfunction. Treatment of peripheral neuropathy is directed toward treating the cause of the nerve dysfunction and relief of symptoms, most notably pain relief.

a closer look

Postpolio Syndrome: The Plight of Some "Recovered" Polio Victims

Poliomyelitis, or infantile paralysis, was the most feared infectious disease in America in the first half of the twentieth century.

Polio is caused by a virus spread via fecal contamination (in swimming pools or on dirty hands, for example) and by coughs. It enters the mouth, multiplies in the gut, and then travels to various preferred cell types in the body—mainly motor neurons. The initial symptoms resemble those of flu, including fever, headache, and stiffness of the neck and back, but about 10% of cases progress further, destroying some motor neurons of the spinal cord or brain. The result is the loss of the motor functions of certain nerves and paralysis of muscles (including the respiratory muscles; see the photo of its victims in iron lungs).

Fortunately, only about 3% of people who contracted polio were paralyzed permanently; the rest recovered either full or partial use of their muscles. The epidemic was halted in the mid-1950s by the development of the Salk and Sabin polio vaccines. Through aggressive vaccination, polio was eliminated from the entire Western Hemisphere in 1991, and since then from Europe and China as well. It continues to persist in parts of Asia and Africa, where ongoing vaccination efforts are working toward eradication.

Even though the devastating epidemics appear to be a thing of the past, many of the "recovered" survivors are now experiencing a surprising "postpolio" deterioration. People now in their 50s, 60s, and 70s, who struggled to regain health

Iron lungs provided breathing assistance to polio patients whose respiratory muscles were paralyzed. After several weeks in an iron lung, many patients recovered the ability to breathe on their own.

and to live active lives, have developed new symptoms: lethargy; sensitivity to cold; sharp, burning pains in muscles and joints; and weakness and loss of mass in muscles that had earlier recovered. When these symptoms first appeared in the 1980s, they were dismissed as the flu or a psychosomatic illness, or misdiagnosed as multiple sclerosis, arthritis, lupus, or amyotrophic lateral sclerosis (see p. 415). But as the number of complaints increased, more attention was given to this group of symptoms, now named *postpolio syndrome (PPS)*. About one-third of polio survivors, approximately 500,000 Americans, have developed PPS. Certain survivors seem to be particularly vulnerable: those who contracted polio after age 10, those who needed ventilatory support, and those in whom all four limbs were affected.

The cause of PPS is not known. Most evidence indicates that polio survivors, like all of us, lose neurons throughout life. Unimpaired nervous systems can enlist nearby neurons to compensate for the losses; however, polio survivors have already lost many motor neurons. As polio victims recovered, remaining healthy motor neurons sprouted branches that grew to reinnervate the muscle fibers that had lost their motor innervation. This resulted in enlarged motor units. Degeneration of these enlarged motor units results in the return of muscle weakness and fatigue.

Fortunately, PPS progresses slowly and is not life-threatening. Its victims are advised to conserve energy by resting more and by using canes, walkers, and braces to support their wasting muscles. Still, many PPS sufferers are emotionally devastated—cruelly surprised by the return of an old enemy and angry because no remedy exists. The medical community has recognized their plight and has established research funding and postpolio assessment clinics across the nation, but this is little comfort to those experiencing the limbo of PPS.

THE PERIPHERAL NERVOUS SYSTEM THROUGHOUT LIFE

➤ Relate the development of the PNS to the basic segmental pattern of the outer tube of the human body.

The spinal nerves start to form late in the fourth week of development. Motor axons grow outward from the early spinal cord, whereas sensory peripheral axons grow out from the neural crest of the dorsal root ganglia (see Figure 12.16, p. 368). The bundles of these motor and sensory axons exit between successive developing vertebrae, where they converge to form the early spinal nerves. Each of the 31 spinal nerves sends motor fibers into a single myotome, and sensory fibers to the overlying band of skin, which accounts for the segmented pattern of dermatomes. Cranial nerves grow to innervate the head in a roughly comparable manner. Some of their sensory neurons—those for some of the special senses—develop from plate-shaped thickenings of the head ectoderm called **ectodermal placodes** (plak′odz; "platelike"); others develop from the neural crest.

During week 5 of development, nerves reach the organs they innervate. Shortly thereafter, some of the embryonic muscles migrate to new locations, and some skin dermatomes become displaced as they are pulled along the elongating limbs. Even though they may migrate for considerable distances, these muscles and skin areas always retain their original nerve supply.

Aging of the nervous system is discussed in Chapters 12 and 13. In the PNS, sensory receptors atrophy to some degree with age, and tone in the muscles of the face and neck decreases. Reflexes slow a bit with age, but this change seems to reflect a slowing of central processing more than changes in peripheral nerve fibers.

check your understanding

19. Use the word roots at the back of the text to define these terms: (a) neuralgia, (b) paresthesia, (c) neuropathy.
20. Does postpolio syndrome result from a dormant poliovirus becoming active again?

For answers, see Appendix B.

RELATED CLINICAL TERMS

NERVE INJURIES The following terms describe various injuries, listed here in order of increasing severity. (1) *Neurapraxia* is a temporary and incomplete loss of nerve function, resulting from pressure and the ensuing ischemia; only the myelin is seriously harmed, and it regenerates so that function returns in a few weeks. (2) *Axonotmesis* is an injury that causes breaks in the axons, but the surrounding epineurium remains intact; axonal regrowth proceeds at the rate of about a centimeter a week. (3) In *neurotmesis*, the whole nerve is severed. Surgical reconnection is necessary for regeneration to occur.

NEURALGIA (nu-ral′je-ah) (*algia* = pain) Sharp, spasmlike pain along the course of one or more nerves, usually caused by inflammation or injury to the nerves.

NEURITIS Inflammation of a nerve. There are many different forms of neuritis with different effects, including increased or decreased nerve sensitivity, paralysis of the structure served, and pain.

SCAPULAR WINGING Condition in which the medial border of the scapula projects posteriorly, due to the paralysis of the serratus anterior muscle. The ultimate cause is damage to the long thoracic nerve supplying the serratus anterior.

CHAPTER SUMMARY

You can use the following media study tool for additional help when you review specific key topics in Chapter 14.

PAL = ***Practice Anatomy Lab™***

Organization of the Peripheral Nervous System (p. 427)

1. The PNS consists of sensory receptors, motor endings that innervate effector organs, nerves, and ganglia. Most nerves contain both sensory and motor fibers (mixed nerves), but some are purely sensory or purely motor.

Peripheral Sensory Receptors (pp. 427–431)

2. Sensory receptors monitor stimuli (environmental changes) from both inside and outside the body. The widespread receptors for the general senses tend to be free nerve endings of sensory neurons, whereas the localized receptors for the special senses tend to be distinct receptor cells.

Classification by Location (p. 428)

3. Receptors are classified by location as exteroceptors for external stimuli, interoceptors for internal stimuli in the viscera, and proprioceptors for measuring stretch in muscles and the skeleton.

Classification by Stimulus Detected (p. 428)

4. Receptors are classified by stimuli detected as mechanoreceptors, thermoreceptors, chemoreceptors, photoreceptors, and nociceptors.

Classification by Structure (pp. 428–431)

5. Nerve endings of sensory neurons monitor general sensory information. Structurally, they are either (1) free nerve endings or (2) encapsulated nerve endings. The free endings are mainly receptors for pain and temperature, although two are for light touch: epithelial tactile complexes (Merkel discs) and hair follicle receptors. The encapsulated endings are mechanoreceptors: They include

tactile (Meissner's) corpuscles (discriminative touch), lamellar (Pacinian) corpuscles and bulbous corpuscles (Ruffini endings, deep pressure), and most proprioceptors.

6. The proprioceptors include muscle spindles, tendon organs (Golgi tendon organs), and joint kinesthetic receptors. Muscle spindles are small bags of muscle fibers (intrafusal fibers) innervated by sensory nerve endings within the skeletal muscles of the body. They monitor muscle length by measuring muscle stretch.

7. Tendon organs (Golgi tendon organs) are encapsulated nerve endings embedded in muscle tendons. They monitor the tension generated in tendons during muscle contraction. Joint kinesthetic receptors occur in joint capsules. Some joint receptors measure tension placed on the joint (lamellar corpuscles and bulbous corpuscles). Free nerve endings in joints are receptors for pain.

Cranial Nerves (pp. 431–439)

8. Twelve pairs of cranial nerves originate from the brain and issue through the skull to innervate the head and neck. Only the vagus nerves extend into the thoracic and abdominal cavities.

9. The following are the cranial nerves:

   I. The olfactory nerves: purely sensory; concerned with smell; attach to the olfactory bulb of the cerebrum.

   II. The optic nerves: purely sensory; transmit visual impulses from the retina to the thalamus.

   III. The oculomotor nerves: primarily motor; emerge from the midbrain and serve four extrinsic muscles that move the eye and some smooth muscle within the eye; also carry proprioceptive impulses from the skeletal muscles served.

   IV. The trochlear nerves: primarily motor; emerge from the dorsal midbrain and carry motor and proprioceptive impulses to and from superior oblique muscles of the eyes.

   V. The trigeminal nerves: contain both sensory and motor fibers; emerge from the pons; the main general sensory nerves of the face, nasal cavity, and mouth; three divisions: ophthalmic, maxillary, and mandibular; the mandibular branch contains motor fibers that innervate the chewing muscles.

   VI. The abducens nerves: primarily motor; emerge from the pons and supply motor and proprioceptive innervation to the lateral rectus muscles of the eyes.

   VII. The facial nerves: contain both sensory and motor fibers; emerge from the pons; motor nerves to muscles of facial expression, sublingual and submandibular salivary glands, and the lacrimal glands; also carry sensory impulses from the taste buds of anterior two-thirds of the tongue.

   VIII. The vestibulocochlear nerves: primarily sensory; enter brain at the pons-medulla border; transmit impulses from the hearing and equilibrium receptors of the inner ears.

   IX. The glossopharyngeal nerves: contain both sensory and motor fibers; issue from the medulla; transmit sensory impulses from the posterior tongue (including taste) and the pharynx; innervate the stylopharyngeus muscle and parotid gland.

   X. The vagus nerves: contain both sensory and motor fibers; arise from the medulla; most of its motor fibers are autonomic; carry motor fibers to, and sensory fibers from, the pharynx, larynx, and visceral organs of the thorax and abdomen.

   XI. The accessory nerves: primarily motor; arise from the cervical spinal cord; supply the trapezius and sternocleidomastoid.

   XII. The hypoglossal nerves: primarily motor; issue from the medulla; supply motor innervation to the tongue muscles.

10. The cranial nerves can be grouped according to function. Some are *sensory,* containing special somatic sensory fibers (I, II, VIII); some are primarily *motor,* containing somatic motor fibers (III, IV, VI, XI, and XII); and some are *mixed,* containing both sensory and motor fibers (V, VII, IX, X).

Spinal Nerves (pp. 439–456)

11. The 31 pairs of spinal nerves are numbered according to the region of the vertebral column from which they issue: cervical, thoracic, lumbar, sacral, and coccygeal. There are 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal spinal nerves.

12. Each spinal nerve forms from the union of a dorsal sensory root and a ventral motor root in an intervertebral foramen. On each dorsal root is a dorsal root ganglion containing the cell bodies of sensory neurons. The branches of each spinal nerve are the dorsal and ventral rami (somatic branches) and rami communicantes (visceral branches).

13. Dorsal rami serve the muscles and skin of the posterior trunk, whereas ventral rami serve the muscles and skin of the lateral and anterior trunk. Ventral rami also serve the limbs.

14. The back, from neck to sacrum, is innervated by the dorsal rami in a neatly segmented pattern.

15. The anterior and lateral wall of the thorax (and abdomen) are innervated by thoracic ventral rami—the segmented intercostal and subcostal nerves. Thoracic ventral rami do not form nerve plexuses.

16. The major nerve plexuses are networks of successive ventral rami that exchange fibers. They primarily innervate the limbs.

17. The cervical plexus (C_1–C_4) innervates the muscles and skin of the neck and shoulder. Its phrenic nerve (C_3–C_5) serves the diaphragm.

18. The brachial plexus serves the upper limb, including the muscles of the shoulder girdle. It arises primarily from C_5–T_1. From proximal to distal, the brachial plexus consists of "roots" (ventral rami), trunks, divisions, and cords.

19. The main nerves arising from the brachial plexus are the musculocutaneous (to flexors on the arm), median (to anterior forearm muscles and the lateral palm), ulnar (to anteromedial muscles of the forearm and the medial hand), axillary (to the deltoid and teres minor muscles), and radial (to the posterior part of the upper limb).

20. The lumbar plexus (L_1–L_4) innervates the anterior and medial muscles of the thigh, through the femoral and obturator nerves, respectively. The femoral nerve also innervates the skin on the anterior thigh and medial leg.

21. The sacral plexus (L_4–S_4) supplies the muscles and skin of the posterior thigh and almost all of the leg. Its main branch is the large sciatic nerve, which consists of the tibial nerve (to most of the hamstrings and all muscles of the calf and sole) and the common fibular nerve (to muscles of the anterior and lateral leg and the overlying skin). Other branches of the sacral plexus supply the posterior and lateral muscles of the pelvic girdle (such as the gluteal muscles) and the perineum (pudendal nerve).

22. A dermatome is a segment of skin innervated by the sensory fibers of a single spinal nerve. Adjacent dermatomes overlap to some degree, more so on the trunk than on the limbs. Loss of sensation in

specific dermatomes reveals sites of damage to spinal nerves or the spinal cord.

23. The sensory nerves to a joint are branches of the nerves innervating the muscles that cross that joint (Hilton's law).

PAL **Human Cadaver/Nervous System/Peripheral Nervous System**

Disorders of The Peripheral Nervous System (pp. 456–458)

24. Shingles and migraine headaches are painful sensory disorders of dermatomes and the brain arteries, respectively. Peripheral neuropathy refers to any pathology of the peripheral nerves that disrupts nerve function.

The Peripheral Nervous System Throughout Life (p. 458)

25. During embryonic development, each spinal nerve grows out between newly formed vertebrae to provide the motor innervation of an adjacent myotome (future trunk muscle) and the sensory innervation of the adjacent skin region (dermatome).

REVIEW QUESTIONS

Multiple Choice/Matching Questions

For answers, see Appendix B.

1. Proprioceptors include all of the following except (a) muscle spindles, (b) tendon organs, (c) epithelial tactile complexes, (d) lamellar corpuscles in joint capsules.

2. The large, onion-shaped pressure receptors in deep connective tissues are (a) epithelial tactile complexes, (b) lamellar corpuscles, (c) free nerve endings, (d) bulbous corpuscles.

3. Choose the correct receptor type from column B for each description given in column A.

Column A	Column B
____ **(1)** pain, itch, and temperature receptors	**(a)** bulbous corpuscles
____ **(2)** contain intrafusal fibers and secondary sensory endings	**(b)** tendon organs
____ **(3)** discriminative touch receptors in hairless skin (fingertips)	**(c)** muscle spindles
____ **(4)** contain nerve endings wrapped around thick collagen bundles in a tendon	**(d)** free nerve endings
____ **(5)** rapidly adapting deep-pressure receptors	**(e)** lamellar corpuscles
____ **(6)** slowly adapting deep-pressure receptors	**(f)** tactile corpuscles

4. Choose the correct cranial nerves from the key for each description below.

Key:

(a) abducens	(g) olfactory
(b) accessory	(h) optic
(c) facial	(i) trigeminal
(d) glossopharyngeal	(j) vestibulocochlear
(e) hypoglossal	(k) vagus
(f) oculomotor	(l) trochlear

____ **(1)** innervates four extrinsic eye muscles

____ **(2)** is the major sensory nerve of the face

____ **(3)** innervates the sternocleidomastoid and trapezius

____ **(4)** are primarily or exclusively sensory (three nerves)

____ **(5)** innervates the tongue muscles

____ **(6)** allows chewing of food

____ **(7)** is anesthetized during dental work

____ **(8)** helps to regulate heart activity

____ **(9)** sensory innervation for hearing and equilibrium

____ **(10)** contain parasympathetic motor fibers (four nerves)

____ **(11)** innervates muscles of facial expression

5. For each of the following muscles or body regions, identify the plexus and the peripheral nerve (or branch of one) involved. Use one choice from Key A followed by one choice from Key B.

Key A: Plexuses	**Key B: Nerves**	
(a) brachial	**(1)** common fibular	**(6)** phrenic
(b) cervical	**(2)** femoral	**(7)** radial
(c) lumbar	**(3)** median	**(8)** tibial
(d) sacral	**(4)** musculocutaneous	**(9)** ulnar
	(5) obturator	

Structure Innervated

____, ____ **(1)** the diaphragm

____, ____ **(2)** muscles of the posterior compartments of thigh and leg

____, ____ **(3)** anterior compartment thigh muscles

____, ____ **(4)** medial compartment thigh muscles

____, ____ **(5)** anterior arm muscles that flex the forearm

____, ____ **(6)** muscles that flex the wrist and fingers (two nerves)

____, ____ **(7)** muscles that extend the wrist and fingers

____, ____ **(8)** skin and extensor muscles of the posterior arm

____, ____ **(9)** fibular muscles, tibialis anterior, and toe extensors

6. Which one of the following contains only motor fibers? (a) dorsal root, (b) dorsal ramus, (c) ventral root, (d) ventral ramus.

7. The trigeminal nerve contains which class(es) of nerve fibers? (a) somatic sensory only, (b) somatic motor and proprioceptor, (c) general sensory and somatic motor.

8. Whereas *bronchial* refers to the airways in the lungs, *brachial* refers to the (a) back, (b) pharynx, (c) arm, (d) thigh.

9. Which cranial nerves contain somatic motor axons to pharyngcal arch muscles (see p. 265)? (a) I, II, VII; (b) V, VII, IX, X, XI; (c) III, IV, VI, XI, XII.

10. Which of the following components occur in all of the mixed cranial nerves V, VII, IX, and X? Choose as many as apply: (a) general

somatic sensory; (b) special somatic sensory; (c) general visceral sensory; (d) special visceral sensory (taste), (e) somatic motor to pharyngeal arch muscles.

Short Answer Essay Questions

11. In the sensory receptors called "encapsulated nerve endings," what is the "capsule" made of?

12. (a) Describe the roots to and the composition of a spinal nerve. (b) Are dorsal and ventral roots in the CNS or the PNS? (c) Name the branches of a spinal nerve (other than the rami communicantes), and identify what basic region of the body each branch supplies.

13. (a) Define nerve plexus. (b) List the spinal nerves of origin of the four major nerve plexuses, and name the general body regions served by each plexus.

14. In the brachial plexus, what specific rami make up each of the three trunks?

15. Adrian and Abdul, two anatomy students, were arguing about the facial nerve. Adrian said that it innervates all of the skin of the face, and that it is called the facial nerve for this reason. Abdul claimed the facial nerve does not innervate facial skin at all. Who was correct?

16. Choose the correct answer, and explain why it is correct. Through which pair of intervertebral foramina do spinal nerves L_5 leave the vertebral canal? (a) holes in the sacrum, (b) just superior to vertebra L_5, (c) just superior to S_1, (d) just inferior to S_4.

17. There are 40 roots in the cauda equina. To what spinal nerves do they belong? (See p. 374.)

CRITICAL REASONING & CLINICAL APPLICATION QUESTIONS

1. As Harry was falling off a ladder, he reached out and grabbed a tree branch with his hand. His overstretched upper limb became weak and numb. What major nervous structure had he injured?

2. Frita, in her early 70s, had problems chewing. When she was asked to stick out her tongue, it deviated to the right, and its right half was quite wasted. What nerve was injured?

3. Ted is a war veteran who was hit in the back with small pieces of shrapnel. His skin is numb in the center of his buttocks and along the entire posterior side of a lower limb, but there is no motor problem. Indicate which of the following choices is the most likely site of his nerve injury, and explain your choice: (a) a few dorsal roots of the cauda equina, (b) spinal cord transection at C_6, (c) spinal cord transection at L_5, (d) femoral nerve transected in the lumbar region.

4. A quarterback suffered torn menisci in his right knee joint when he was tackled from the side. The same collision crushed his common fibular nerve against the neck of his right fibula. What locomotor problems can he expect to experience from this nerve injury?

5. In a patient who developed carpal tunnel syndrome, the nerve injury began as a neurapraxia and then became an axonotmesis. (1) Recall what nerve is affected in carpal tunnel syndrome (see Chapter 8, p. 190). (2) Explain the terms *neurapraxia* and *axonotmesis.* (3) Describe the sensory and motor losses experienced. (4) Estimate how long full recovery from this nerve injury will take. (See Related Clinical Terms.)

6. Using Hilton's law, (1) deduce which four nerves send branches that innervate the capsule of the elbow joint and (2) identify the nerves that supply the hip joint.

7. After suffering from a broken humerus, a patient was unable to extend her wrist and complained of paresthesia on the back of her hand. What nerve must have been injured in the humeral break?

8. Name all of the nerves that innervate the tongue.