12

Peripheral Nervous System

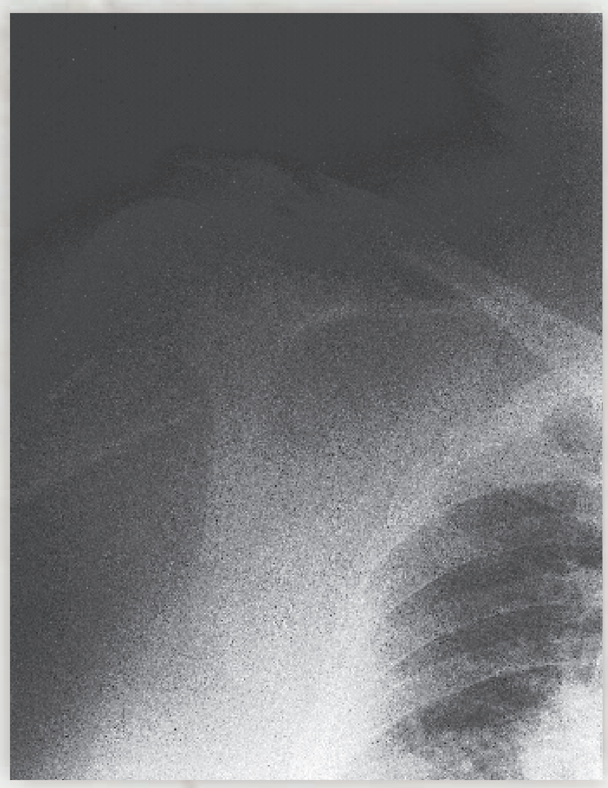


FIGURE: Trauma to a particular body region may cause profound effects elsewhere. This underscores the importance of visualizing regional anatomy (see chapter 10) and knowing vascular routes and innervation pathways.

Clinical Case Study

Following an auto accident, a 23-year-old male was brought to the emergency room for treatment of a fractured right humerus. Although the skin was not broken, there was an obvious deformity caused by an angulated fracture at the midshaft. While conducting an examination on the patient's injured arm, the attending orthopedist noticed that the patient was unable to extend the joints of his wrist and hand.

What structure could be injured in the brachial region of this patient that would account for his inability to extend his hand? List the muscles that would be affected and describe the movements that would be diminished. Do you think there might be other neurological defects? Explain.

Hints: Because the nervous system functions to coordinate body movement, nerve trauma may be expressed in structures far removed from the site of injury. Carefully read the section dealing with the brachial plexus.

INTRODUCTION TO THE PERIPHERAL NERVOUS SYSTEM

The peripheral nervous system consists of all of the nervous tissue outside the central nervous system, including sensory receptors, nerves and their associated ganglia, and nerve plexuses. It provides a communication pathway for impulses traveling between the CNS and the rest of the body.

Objective 1 Define *peripheral nervous system* and distinguish between sensory and mixed nerves.

The **peripheral nervous system (PNS)** is that portion of the nervous system outside the central nervous system. The PNS conveys impulses to and from the brain and spinal cord. Sensory receptors within the sensory organs, nerves, ganglia, and plexuses are all part of the PNS, which serves virtually every part of the body (fig. 12.1). The sensory receptors are discussed in chapter 15.

The nerves of the PNS are classified as cranial nerves or spinal nerves depending on whether they arise from the brain or the spinal cord. A cross section of a spinal nerve is shown in figure 12.2. The terms *sensory nerve*, *motor nerve*, and *mixed nerve* relate to the direction in which the nerve impulses are being

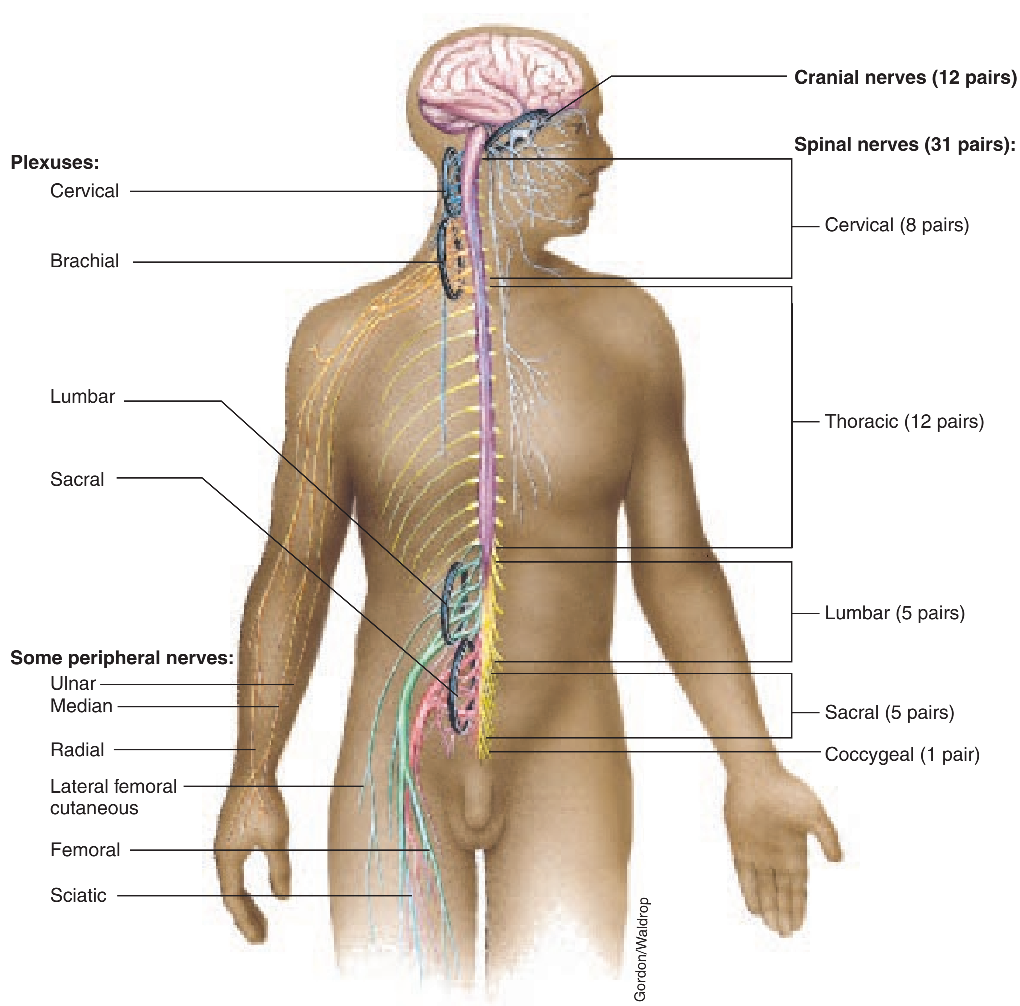


FIGURE 12.1 The peripheral nervous system includes cranial nerves and spinal nerves, and the nerves that arise from them. Plexuses and ganglia (not shown) are also part of the peripheral nervous system.

CHAPTER 12

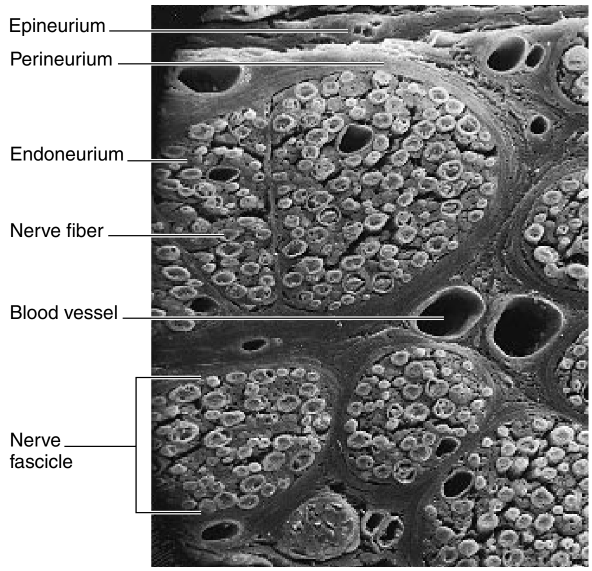


FIGURE 12.2 A scanning electron micrograph of a spinal nerve seen in cross section (about 1,000×).
(*From: R. G. Kessel and R. H. Kardon,* Tissues and Organs: A Text-Atlas of Scanning Electron Microscopy, *© 1979 W. H. Freeman and Company.*)

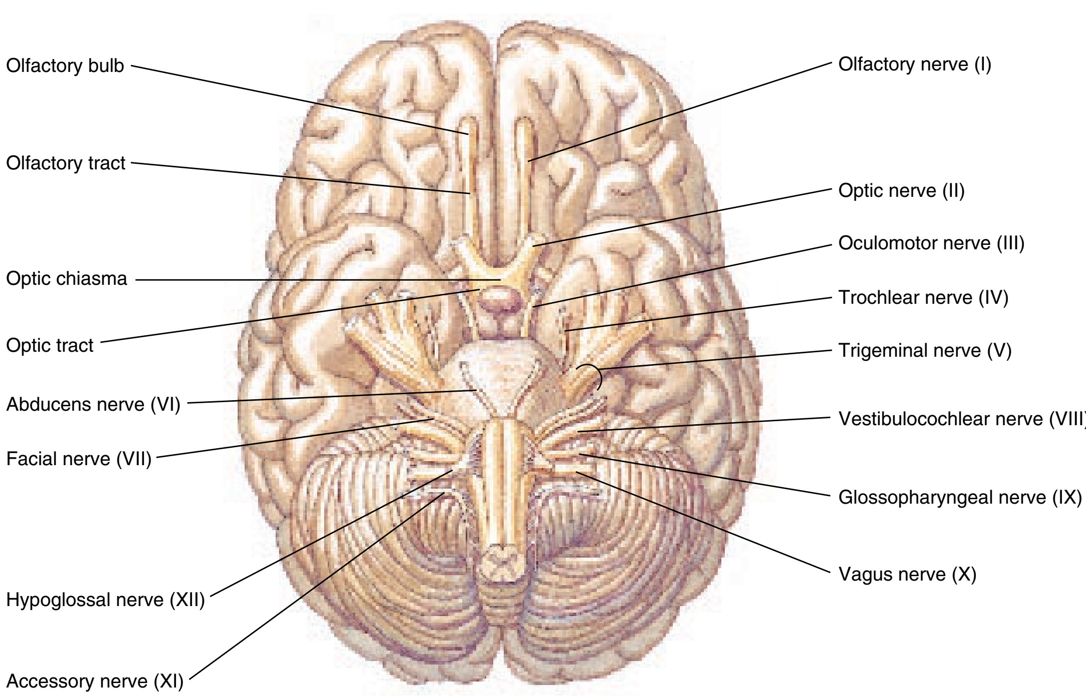


FIGURE 12.3 The cranial nerves. With the exception of the olfactory nerves, each cranial nerve is composed of a bundle of nerve fibers. The olfactory nerves are minute and diffuse strands of nerve fibers that attach to the olfactory bulb (see fig. 12.4).

conducted. **Sensory nerves** consists of sensory (afferent) neurons that convey impulses toward the CNS. **Motor nerves** consist primarily of motor (efferent) neurons that convey impulses away from the CNS. (Technically speaking, there are no nerves that are motor only; all motor nerves contain some proprioceptor fibers (see fig. 15.3) that convey sensory information to the CNS.) **Mixed nerves** are composed of both sensory and motor neurons in about equal numbers, and they convey impulses both to and from the CNS.

Knowledge Check

1. The tongue responds to tastes and pain and moves to manipulate food. Make a quick sketch of the brain and the tongue to depict the relationship between the CNS and the PNS. Use lines and arrows to indicate the sensory and motor innervation of the tongue. Define *mixed nerve*. What kinds of sensory stimulation arise from the tongue? What type of response is caused by motor stimulation to the tongue?
2. List the structures of the nervous system that are considered part of the PNS.

CRANIAL NERVES

Twelve pairs of cranial nerves emerge from the inferior surface of the brain and pass through the foramina of the skull to innervate structures in the head, neck, and visceral organs of the trunk.

Objective 2 List the 12 pairs of cranial nerves and describe the location and function of each.

Objective 3 Describe the clinical methods for determining cranial nerve dysfunction.

Structure and Function of the Cranial Nerves

Of the 12 pairs of cranial nerves, 2 pairs arise from the forebrain and 10 pairs arise from the midbrain and brain stem (fig. 12.3). The cranial nerves are designated by Roman numerals and names. The Roman numerals refer to the order in which the nerves are positioned from the front of the brain to the back. The names indicate the structures innervated or the principal functions of the nerves. A summary of the cranial nerves is presented in table 12.1.

Although most cranial nerves are mixed, some are associated with special senses and consist of sensory neurons only. The cell bodies of sensory neurons are located in ganglia outside the brain.

Generations of anatomy students have used a mnemonic device to help them remember the order in which the cranial nerves emerge from the brain: "On old Olympus's towering top, a Finn and German viewed a hop." The initial letter of each word in this jingle corresponds to the initial letter of each pair of cranial nerves. A problem with this classic verse is that the eighth cranial nerve represented by *and* in the jingle, which used to be referred to as auditory, is currently recognized as the vestibulocochlear nerve. Hence, the following topical mnemonic: "On old Olympus's towering top, a fat vicious goat vandalized a hat."

I Olfactory Nerve

Actually, numerous olfactory nerves relay sensory impulses of smell from the mucous membranes of the nasal cavity (fig. 12.4). Olfactory nerves are composed of bipolar neurons that function as *chemoreceptors,* responding to volatile chemical particles breathed into the nasal cavity. The dendrites and cell bodies of olfactory neurons are positioned within the mucosa, primarily that which covers the superior nasal conchae and adjacent nasal septum. The axons of these neurons pass through the cribriform plate of the ethmoid bone to the **olfactory bulb** where synapses are made, and the sensory impulses travel through the **olfactory tract** to the primary olfactory area in the cerebral cortex.

II Optic Nerve

The optic nerve, another sensory nerve, conducts impulses from the *photoreceptors* (rods and cones) in the retina of the eye. Each optic nerve is composed of an estimated 125 million nerve fibers that converge at the back of the eyeball and enter the cranial cavity through the optic canal. The two optic nerves unite on the floor of the diencephalon to form the **optic chiasma** (*ki-as′mă*) (fig. 12.5). Nerve fibers that arise from the medial half of each retina cross at the optic chiasma to the opposite side of the brain, whereas fibers arising from the lateral half remain on the same side of the brain. The optic nerve fibers pass posteriorly from the optic chiasma to the thalamus via the **optic tracts.** In the thalamus, a majority of the fibers terminate within certain thalamic nuclei. A few of the ganglion-cell axons that reach the thalamic nuclei have collaterals that convey impulses to the superior colliculi. Synapses within the thalamic nuclei, however, permit impulses to pass through neurons to the **visual cortex** within the occipital lobes. Other synapses permit impulses to reach the nuclei for the oculomotor, trochlear, and abducens nerves, which regulate intrinsic (internal) and extrinsic (from orbit to eyeball) eye muscles. The visual pathway into the eyeball functions reflexively to produce motor responses to light stimuli. If an optic nerve is damaged, the eyeball served by that nerve is blinded.

III Oculomotor

Nerve impulses through the oculomotor nerve produce certain extrinsic and intrinsic movements of the eyeball. The oculomotor is primarily a motor nerve that arises from nuclei within the

olfactory: L. *olfacere,* smell out

optic: L. *optica,* see

chiasma: Gk. *chiasma,* an X-shaped arrangement

TABLE 12.1 Summary of Cranial Nerves

Number and Name	Foramen Transmitting	Composition	Location of Cell Bodies	Function
I Olfactory	Foramina in cribriform plate of ethmoid bone	Sensory	Bipolar cells in nasal mucosa	Olfaction
II Optic	Optic canal	Sensory	Ganglion cells of retina	Vision
III Oculomotor	Superior orbital fissure	Somatic motor	Oculomotor nucleus	Motor impulses to levator palpebrae superioris and extrinsic eye muscles, except superior oblique and lateral rectus
		Motor: parasympathetic		Innervation to muscles that regulate amount of light entering eye and that focus the lens
		Sensory: proprioception		Proprioception from muscles innervated with motor fibers
IV Trochlear	Superior orbital fissure	Somatic motor	Trochlear nucleus	Motor impulses to superior oblique muscle of eyeball
		Sensory: proprioception		Proprioception from superior oblique muscle of eyeball
V Trigeminal				
Ophthalmic nerve	Superior orbital fissure	Sensory	Trigeminal ganglion	Sensory impulses from cornea, skin of nose, forehead, and scalp
Maxillary nerve	Foramen rotundum	Sensory	Trigeminal ganglion	Sensory impulses from nasal mucosa, upper teeth and gums, palate, upper lip, and skin of cheek
Mandibular nerve	Foramen ovale	Sensory	Trigeminal ganglion	Sensory impulses from temporal region, tongue, lower teeth and gums, and skin of chin and lower jaw
		Sensory: proprioception		Proprioception from muscles of mastication
		Somatic motor	Motor trigeminal nucleus	Motor impulses to muscles of mastication and muscle that tenses the tympanum
VI Abducens	Superior orbital fissure	Somatic motor	Abducens nucleus	Motor impulses to lateral rectus muscle of eyeball
		Sensory: proprioception		Proprioception from lateral rectus muscle of eyeball
VII Facial	Stylomastoid foramen	Somatic motor	Motor facial nucleus	Motor impulses to muscles of facial expression and muscle that tenses the stapes
		Motor: parasympathetic	Superior salivatory nucleus	Secretion of tears from lacrimal gland and salivation from sublingual and submandibular glands

midbrain. It divides into superior and inferior branches as it passes through the superior orbital fissure in the orbit (fig. 12.6). The superior branch innervates the **superior rectus** muscle, which moves the eyeball superiorly, and the **levator palpebrae** (*le-va'tor pal'pĕ-bre*) **superioris** muscle, which raises the upper eyelid. The inferior branch innervates the **medial rectus, inferior rectus,** and **inferior oblique** eye muscles for medial, inferior, and superior and lateral movement of the eyeball, respectively. In addition, fibers from the inferior branch of the oculomotor nerve enter the eyeball to supply parasympathetic autonomic motor innervation to the intrinsic smooth muscles of the iris for pupil constriction and to the muscles within the ciliary body for lens accommodation.

A few sensory fibers of the oculomotor nerve originate from proprioceptors within the intrinsic muscles of the eyeball. These fibers convey impulses that affect the position and activity of the muscles they serve. A person whose oculomotor nerve is damaged may have a drooping upper eyelid or dilated pupil, or be unable to move the eyeball in the directions permitted by the four extrinsic muscles innervated by this nerve.

IV Trochlear

The trochlear (*trok'le-ar*) nerve is a very small mixed nerve that emerges from a nucleus within the midbrain and passes from the cranium through the superior orbital fissure of the orbit. The trochlear nerve innervates the **superior oblique** muscle of the eyeball with both motor and sensory fibers (fig. 12.6). Motor impulses to the superior oblique cause the eyeball to rotate downward and away from the midline. Sensory impulses originate in

trochlear: Gk. *trochos*, a wheel

Number and Name	Foramen Transmitting	Composition	Location of Cell Bodies	Function
VII Facial, *continued*		Sensory	Geniculate ganglion	Sensory impulses from taste buds on anterior two-thirds of tongue; nasal and palatal sensation
		Sensory: proprioception		Proprioception from muscles of facial expression
VIII Vestibulocochlear	Internal acoustic meatus	Sensory	Vestibular ganglion	Sensory impulses associated with equilibrium
			Spiral ganglion	Sensory impulses associated with hearing
IX Glossopharyngeal	Jugular foramen	Somatic motor	Nucleus ambiguus	Motor impulses to muscles of pharynx used in swallowing
		Sensory: proprioception	Petrosal ganglion	Proprioception from muscles of pharynx
		Sensory	Petrosal ganglion	Sensory impulses from taste buds on posterior one-third of tongue, pharynx, middle-ear cavity, and carotid sinus
		Parasympathetic	Inferior salivatory nucleus	Salivation from parotid gland
X Vagus	Jugular foramen	Somatic motor	Nucleus ambiguus	Contraction of muscles of pharynx (swallowing) and larynx (phonation)
		Sensory: proprioception		Proprioception from visceral muscles
		Sensory	Nodose ganglion	Sensory impulses from taste buds on rear of tongue; sensations from auricle of ear; general visceral sensations
		Motor: parasympathetic	Dorsal motor nucleus	Motor impulses to visceral muscles
XI Accessory	Jugular foramen	Somatic motor	Nucleus ambiguus	Laryngeal movement; soft palate
			Accessory nucleus	Motor impulses to trapezius and sternocleidomastoid muscles for movement of head, neck,and shoulders
		Sensory: proprioception		Proprioception from muscles that move head, neck, and shoulders
XII Hypoglossal	Hypoglossal canal	Somatic motor	Hypoglossal nucleus	Motor impulses to intrinsic and extrinsic muscles of tongue and infrahyoid muscles
		Sensory: proprioception		Proprioception from muscles of tongue

proprioceptors of the superior oblique muscle and provide information about its position and activity. Damage to the trochlear nerve impairs movement in the direction permitted by the superior oblique eye muscle.

V Trigeminal

The large trigeminal (*tri-jem'in-al*) nerve is a mixed nerve with motor functions originating from the nuclei within the pons and sensory functions terminating in nuclei within the midbrain, pons, and medulla oblongata. Two roots of the trigeminal nerve are apparent as they emerge from the anterolateral side of the pons (see fig. 12.3). The larger **sensory root** immediately enlarges into a swelling called the **trigeminal** (semilunar) **ganglion,** located in a bony depression on the inner surface of the petrous part of the temporal bone. Three large nerves arise from the trigeminal ganglion (fig. 12.7): the **ophthalmic nerve** enters the orbit through the superior orbital fissure, the **maxillary nerve** extends through the foramen rotundum, and the **mandibular nerve** passes through the foramen ovale. The smaller **motor root** consists of motor fibers of the trigeminal nerve that accompany the mandibular nerve through the foramen ovale and innervate the muscles of mastication and certain muscles in the floor of the mouth. Impulses through the motor portion of the mandibular nerve of the trigeminal ganglion stimulate contraction of the muscles of mastication, including the **medial** and **lateral pterygoids, masseter, temporalis, mylohyoid,** and the anterior belly of the **digastric** muscle.

trigeminal: L. *trigeminus*, three born together

ophthalmic: L. *opthalmia*, region of the eye

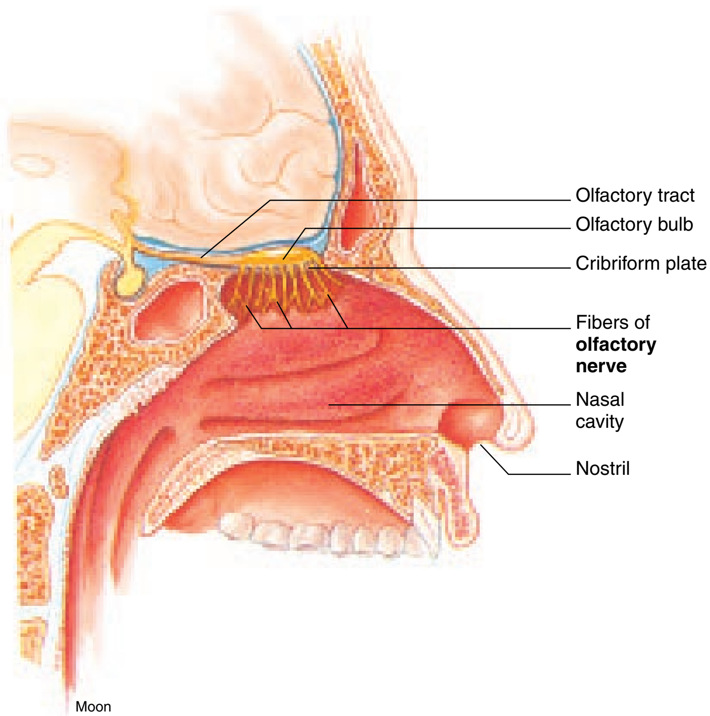


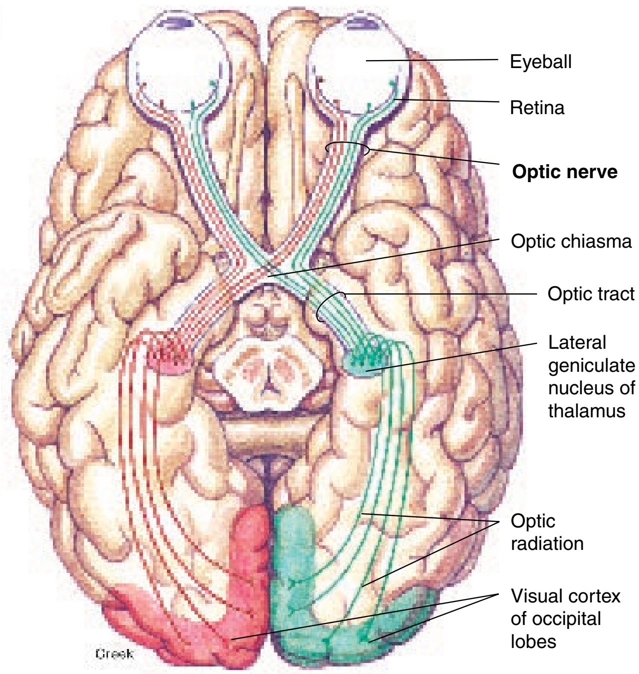
FIGURE 12.4 The olfactory nerve and olfactory pathway.

Although the trigeminal is a mixed nerve, its sensory functions are much more extensive than its motor functions. The three sensory nerves of the trigeminal ganglion respond to touch, temperature, and pain sensations from the face. More specifically, the ophthalmic nerve consists of sensory fibers from the anterior half of the scalp, skin of the forehead, upper eyelid, surface of the eyeball, lacrimal (tear) gland, side of the nose, and upper mucosa of the nasal cavity. The maxillary nerve is composed of sensory fibers from the lower eyelid, lateral and inferior mucosa of the nasal cavity, palate and portions of the pharynx, teeth and gums of the upper jaw, upper lip, and skin of the cheek. Sensory fibers of the mandibular nerve transmit impulses from the teeth and gums of the lower jaw, anterior two-thirds of the tongue (not taste), mucosa of the mouth, auricle of the ear, and lower part of the face. Trauma to the trigeminal nerve results in a lack of sensation from specific facial structures. Damage to the mandibular nerve impairs chewing.

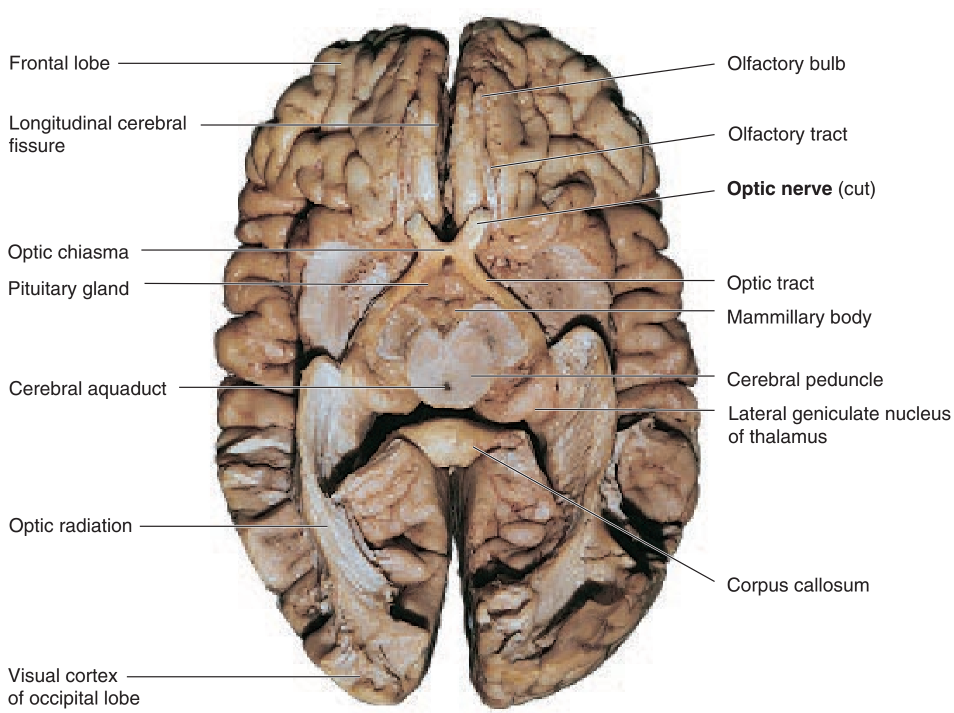
The trigeminal nerve is the principal nerve relating to the practice of dentistry. Before teeth are filled or extracted, anesthetic is injected near the appropriate nerve to block sensation. A *maxillary,* or *second-division, nerve block,* performed by injecting near the sphenopalatine (pterygopalatine) ganglion (see fig. 12.7), desensitizes the teeth in the upper jaw. A *mandibular,* or *third-division, nerve block* desensitizes the lower teeth. This is performed by injecting anesthetic near the inferior alveolar nerve, which branches off the mandibular nerve as it enters the mandible through the mandibular foramen.

VI Abducens

The small abducens (*ab-doo'senz*) nerve originates from a nucleus within the pons and emerges from the lower portion of the pons and the anterior border of the medulla oblongata. It is a mixed nerve that traverses the superior orbital fissure of the orbit to innervate the **lateral rectus** eye muscle (see fig. 12.6). Impulses through the motor fibers of the abducens nerve cause the lateral rectus eye muscle to contract and the eyeball to move away from the midline laterally. Sensory impulses through the abducens nerve originate in proprioceptors in the lateral rectus muscle and are conveyed to the pons, where muscle contraction is mediated. If the abducens nerve is damaged, not only will the patient be unable to move the eyeball laterally, but because of the lack of muscle tonus to the lateral rectus muscle, the eyeball will be pulled medially.



(a)



(b)

FIGURE 12.5 The optic nerve and visual pathways. (*a*) An illustration and (*b*) a dissected brain.

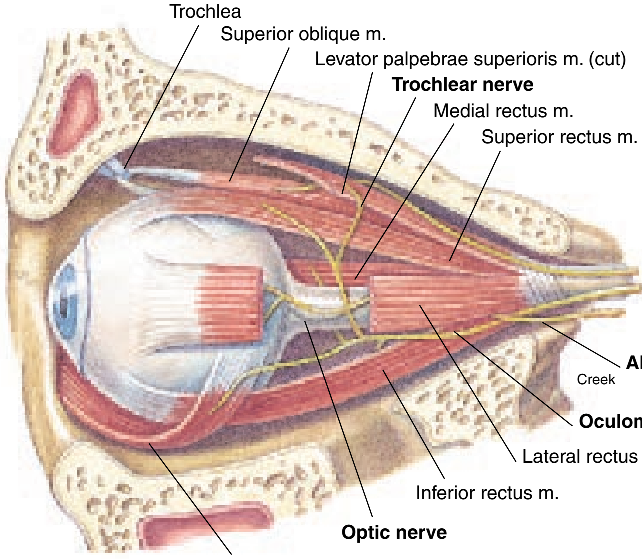


FIGURE 12.6 The optic nerve, which provides sensory innervation to the eye, and the oculomotor, trochlear, and abducens nerves, which provide motor innervation to the extrinsic eye muscles.

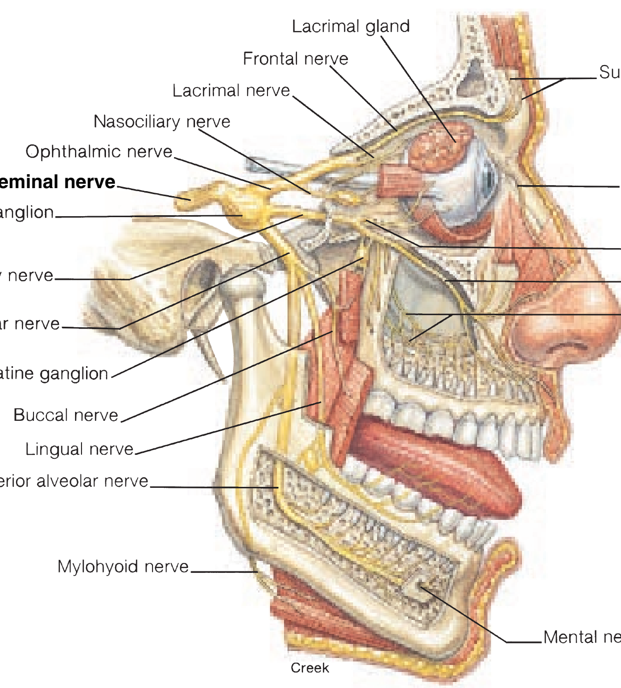


FIGURE 12.7 The trigeminal nerve and its distribution.

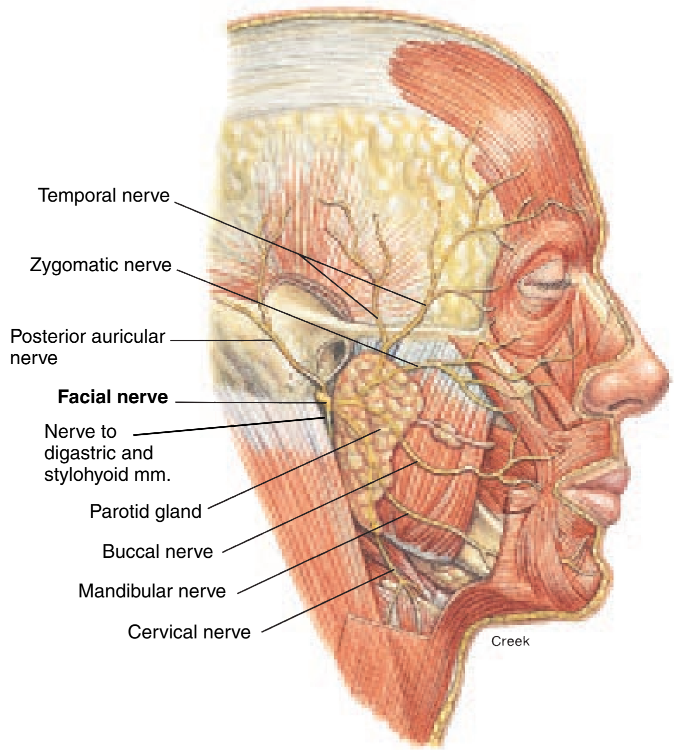


FIGURE 12.8 The facial nerve and its distribution to superficial structures.

VII Facial

The facial nerve arises from nuclei within the lower portion of the pons, traverses the petrous part of the temporal bone (see fig. 12.9), and emerges on the side of the face near the parotid (salivary) gland. The facial nerve is mixed. Impulses through the motor fibers cause contraction of the posterior belly of the digastric muscle and the muscles of facial expression, including the scalp and platysma muscles (fig. 12.8). The submandibular and sublingual (salivary) glands also receive some parasympathetic autonomic motor innervation from the facial nerve, as does the lacrimal gland (see fig. 13.6).

Sensory fibers of the facial nerve arise from taste buds on the anterior two-thirds of the tongue. Taste buds function as *chemoreceptors* because they respond to specific chemical stimuli.

The **geniculate** (*jĕ-nik′you-lāt*) **ganglion** is the enlargement of the facial nerve just before the entrance of the sensory portion into the pons. Sensations of taste are conveyed to nuclei within the medulla oblongata, travel through the thalamus, and ultimately to the gustatory (taste) area in the parietal lobe of the cerebral cortex.

Trauma to the facial nerve results in inability to contract facial muscles on the affected side of the face and distorts taste perception, particularly of sweets. The affected side of the face tends to sag because muscle tonus is lost. *Bell's palsy* is a functional disorder (probably of viral origin) of the facial nerve.

VIII Vestibulocochlear

The vestibulocochlear (*ves-tib′′yŭ-lo-kok′le-ar*) nerve, also referred to as the **auditory, acoustic,** or **statoacoustic nerve,** serves structures contained within the skull. It is the only cranial nerve that does not exit the cranium through a foramen. A purely sensory nerve, the vestibulocochlear is composed of two nerves that arise within the inner ear (fig. 12.9). The **vestibular nerve** arises from the **vestibular organs** associated with equilibrium and balance. Bipolar neurons from the vestibular organs (saccule, utricle, and semicircular ducts) extend to the **vestibular ganglion,**

Bell's palsy: from Sir Charles Bell, Scottish physician, 1774–1842
vestibulocochlear: L. *vestibulum*, chamber, *cochlea*, snail shell

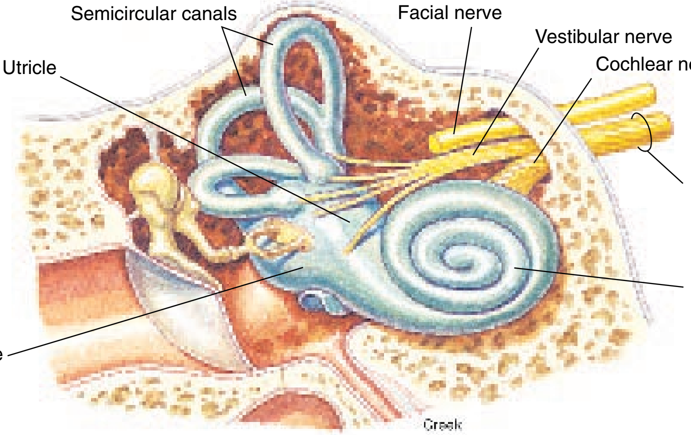


FIGURE 12.9 The vestibulocochlear nerve. The structures of the inner ear are served by this nerve. The semicircular ducts, concerned with balance and equilibrium, form the membranous labyrinth within the semicircular canals. The cochlea contains the structures concerned with hearing.

where cell bodies are contained. From there, fibers convey impulses to the **vestibular nuclei** within the pons and medulla oblongata. Fibers from there extend to the thalamus and the cerebellum.

The **cochlear nerve** arises from the **spiral organ** (organ of Corti) within the cochlea and is associated with hearing. The cochlear nerve is composed of bipolar neurons that convey impulses through the **spiral ganglion** to the **cochlear nuclei** within the medulla oblongata. From there, fibers extend to the thalamus and synapse with neurons that convey the impulses to the auditory areas of the cerebral cortex.

Injury to the cochlear nerve results in perception deafness, whereas damage to the vestibular nerve causes dizziness and loss of balance.

IX Glossopharyngeal

The glossopharyngeal (*glos''o-fă-rin'je-al*) nerve is a mixed nerve that innervates part of the tongue and pharynx (fig. 12.10). The motor fibers of this nerve originate in a nucleus within the medulla oblongata and pass through the jugular foramen. The motor fibers innervate the muscles of the pharynx and the parotid gland to stimulate the swallowing reflex and the secretion of saliva.

The sensory fibers of the glossopharyngeal nerve arise from the pharyngeal region, the parotid gland, the middle-ear cavity, and the taste buds on the posterior one-third of the tongue. These taste buds, like those innervated by the facial nerve, are *chemoreceptors*. Some sensory fibers also arise from sensory receptors within the carotid sinus of the neck and help to regulate blood pressure. Impulses from the glossopharyngeal nerve travel through the medulla oblongata and into the thalamus, where they synapse with fibers that convey the impulses to the gustatory area of the cerebral cortex.

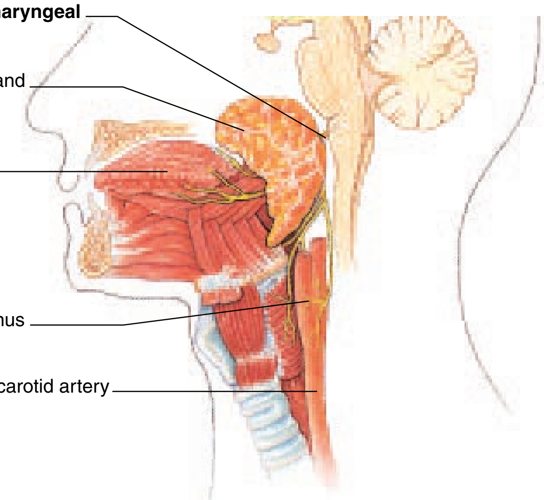


FIGURE 12.10 The glossopharyngeal nerve.

organ of Corti: from Alfonso Corti, Italian anatomist, 1822–88

glossopharyngeal: L. *glossa*, tongue; Gk. *pharynx*, throat

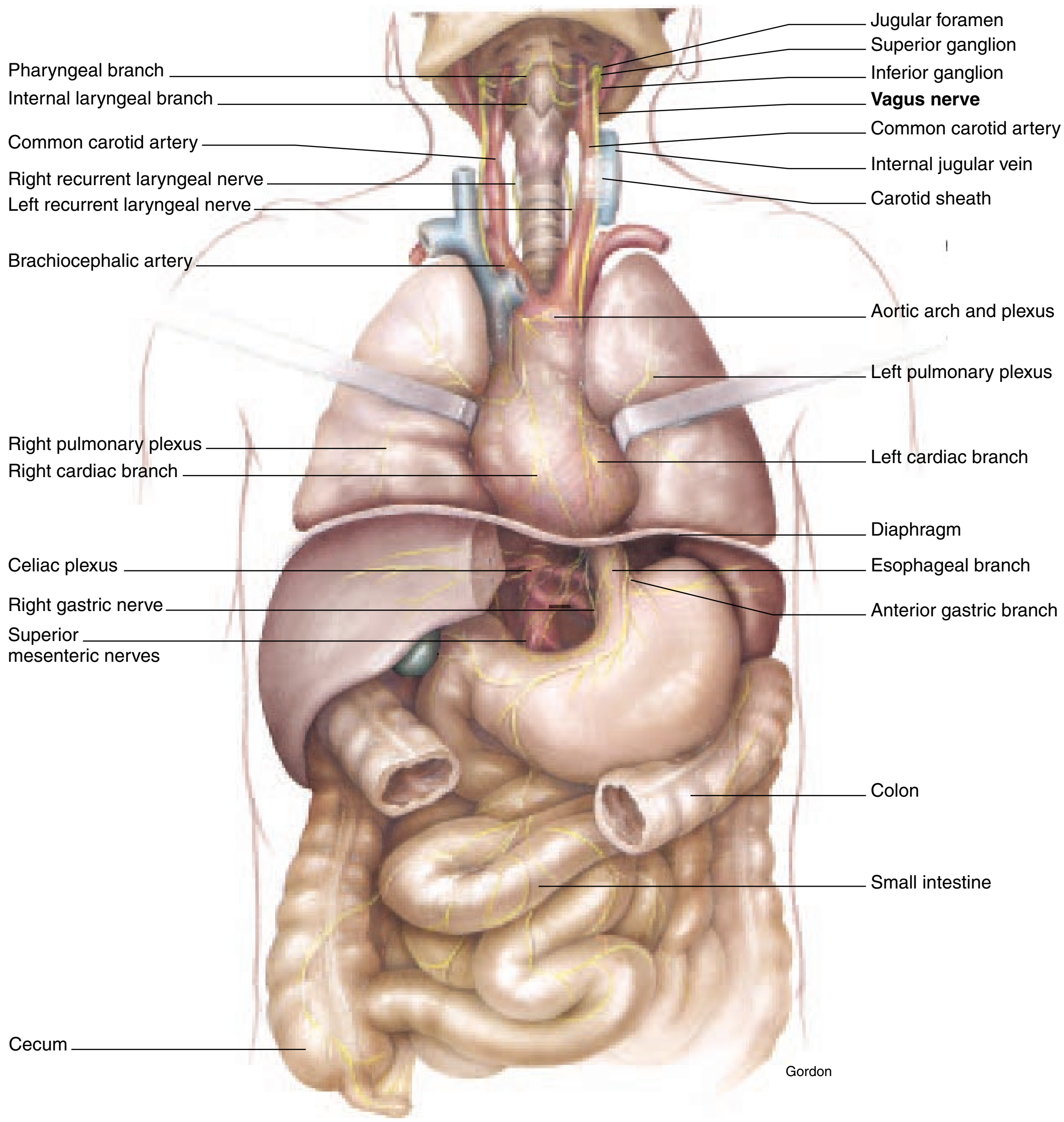


FIGURE 12.11 Distribution of the vagus nerves.

Damage to the glossopharyngeal nerve results in the loss of perception of bitter and sour taste from taste buds on the posterior portion of the tongue. If the motor portion of this nerve is damaged, swallowing becomes difficult.

X Vagus

The vagus (*va′gus*) nerve has motor and sensory fibers that innervate visceral organs of the thoracic and abdominal cavities (fig. 12.11). The motor portion arises from the **nucleus ambiguus** and **dorsal motor nucleus** of the vagus within the medulla oblongata and passes through the jugular foramen. The vagus is the longest of the cranial nerves, and through various branches it innervates the muscles of the pharynx, larynx, respiratory tract, lungs, heart, and esophagus, and those of the abdominal viscera, with the exception of the lower portion of the large intestine. One motor branch of the vagus nerve, the **recurrent laryngeal nerve,** innervates the larynx, enabling speech.

Sensory fibers of the vagus nerve convey impulses from essentially the same organs served by motor fibers. Impulses through the sensory fibers relay specific sensations, such as

vagus: L. *vagus*, wandering

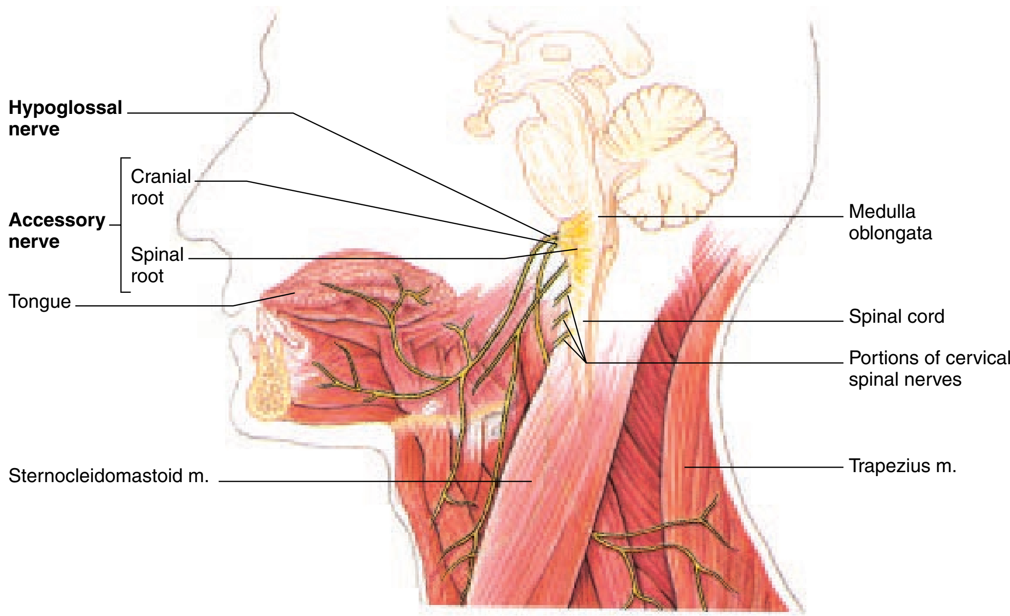


FIGURE 12.12 The accessory and hypoglossal nerves.

hunger pangs, distension, intestinal discomfort, or laryngeal movements. Sensory fibers also arise from proprioceptors in the muscles innervated by the motor fibers of this nerve.

If both vagus nerves are seriously damaged, death ensues rapidly because vital autonomic functions stop. The injury of one nerve causes vocal impairment, difficulty in swallowing, or other visceral disturbances.

XI Accessory

The accessory nerve is principally a motor nerve, but it does contain some sensory fibers from proprioceptors within the muscles it innervates. The accessory nerve is unique in that it arises from both the brain and the spinal cord (fig. 12.12). The **cranial root** arises from nuclei within the medulla oblongata (ambiguus and accessory), passes through the jugular foramen with the vagus nerve, and innervates the skeletal muscles of the soft palate, pharynx, and larynx, which contract reflexively during swallowing. The **spinal root** arises from the first five segments of the cervical portion of the spinal cord, passes cranially through the foramen magnum to join with the cranial root, and then passes through the jugular foramen. The spinal root of the accessory nerve innervates the sternocleidomastoid and the trapezius muscles that move the head, neck, and shoulders. Damage to an accessory nerve makes it difficult to move the head or shrug the shoulders.

XII Hypoglossal

The hypoglossal nerve is a mixed nerve. The motor fibers arise from the hypoglossal nucleus within the medulla oblongata and pass through the hypoglossal canal of the skull to innervate both the extrinsic and intrinsic muscles of the tongue (fig. 12.12). Motor impulses along these fibers account for the coordinated contraction of the tongue muscles that is needed for such activities as food manipulation, swallowing, and speech.

The sensory portion of the hypoglossal nerve arises from proprioceptors within the same tongue muscles and conveys impulses to the medulla oblongata regarding the position and function of the muscles.

If a hypoglossal nerve is damaged, a person will have difficulty in speaking, swallowing, and protruding the tongue.

Neurological Assessment of the Cranial Nerves

Head injuries and brain concussions are common occurrences in automobile accidents. The cranial nerves would seem to be well protected on the inferior side of the brain. But the brain, immersed in and filled with cerebrospinal fluid, is like a water-sodden log; a blow to the top of the head can cause a serious rebound of the brain from the floor of the cranium. Routine neurological examinations involve testing for cranial nerve dysfunction.

Commonly used clinical methods for determining cranial nerve dysfunction are presented in table 12.2.

Knowledge Check

3. Which cranial nerves consist of sensory fibers only?
4. Which cranial nerves pass through the superior orbital fissure? Through the jugular foramen?

hypoglossal: Gk. *hypo,* under; L. *glossa,* tongue

TABLE 12.2 Methods of Determining Cranial Nerve Dysfunction

Nerve	Techniques of Examination	Comments
Olfactory	Patient asked to differentiate odors (tobacco, coffee, soap, etc.) with eyes closed.	Nasal passages must be patent and tested separately by occluding the opposite side.
Optic	Retina examined with ophthalmoscope; visual acuity tested with eye charts.	Visual acuity must be determined with lenses on, if patient wears them.
Oculomotor	Patient follows examiner's finger movement with eyes—especially movement that causes eyes to cross; pupillary change observed by shining light into each eye separately.	Examiner should note rate of pupillary change and coordinated constriction of pupils. Light in one eye should cause a similar pupillary change in other eye, but to a lesser degree.
Trochlear	Patient follows examiner's finger movement with eyes—especially lateral and downward movement.	
Trigeminal	Motor portion: Temporalis and masseter muscles palpated as patient clenches teeth; patient asked to open mouth against resistance applied by examiner.	Muscles of both sides of the jaw should show equal contractile strength.
	Sensory portion: Tactile and pain receptors tested by lightly touching patient's entire face with cotton and then with pin stimulus.	Patient's eyes should be closed and innervation areas for all three nerves branching from the trigeminal nerve should be tested.
Abducens	Patient follows examiner's finger movement—especially lateral movement.	Motor functioning of cranial nerves III, IV, and VI may be tested simultaneously through selective movements of eyeball.
Facial	Motor portion: Patient asked to raise eyebrows, frown, tightly constrict eyelids, smile, puff out cheeks, and whistle.	Examiner should note lack of tonus expressed by sagging regions of face.
	Sensory portion: Sugar placed on each side of tip of patient's tongue.	Not reliable test for specific facial-nerve dysfunction because of tendency to stimulate taste buds on both sides of tip of tongue.
Vestibulocochlear	Vestibular portion: Patient asked to walk a straight line. Cochlear portion: Tested with tuning fork.	Not usually tested unless patient complains of dizziness or balance problems.
		Examiner should note ability to discriminate sounds.
Glossopharyngeal and vagus	Motor: Examiner notes disturbances in swallowing, talking, and movement of soft palate; gag reflex tested.	Visceral innervation of vagus cannot be examined, except for innervation to larynx, which is also served by glossopharyngeal.
Accessory	Patient asked to shrug shoulders against resistance of examiner's hand and to rotate head against resistance.	Sides should show uniformity of strength.
Hypoglossal	Patient asked to protrude tongue; tongue thrust may be resisted with tongue blade.	Tongue should protrude straight out; deviation to side indicates ipsilateral-nerve dysfunction; asymmetry, atrophy, or lack of strength should be noted.

5. Which cranial nerves are involved in tasting, chewing and manipulating food, and swallowing?
6. Which cranial nerves have to do with the structure, function, or movement of the eyeball?
7. List the cranial nerves and indicate how each would be tested (both motor and sensory fibers) for possible dysfunction.

SPINAL NERVES

Each of the 31 pairs of spinal nerves is formed by the union of a posterior and an anterior spinal root that emerges from the spinal cord through an intervertebral foramen to innervate a body dermatome.

Objective 4 Discuss how the spinal nerves are grouped.

Objective 5 Describe the general distribution of a spinal nerve.

The 31 pairs of **spinal nerves** (see fig. 12.1) are grouped as follows: 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal. With the exception of the first cervical nerve, the spinal nerves leave the spinal cord and vertebral canal through intervertebral foramina. The first pair of cervical nerves emerges between the occipital bone of the skull and the atlas. The second through the seventh pairs of cervical nerves emerge above the vertebrae for which they are named, whereas the eighth pair of cervical nerves passes between the seventh cervical and first thoracic vertebrae.

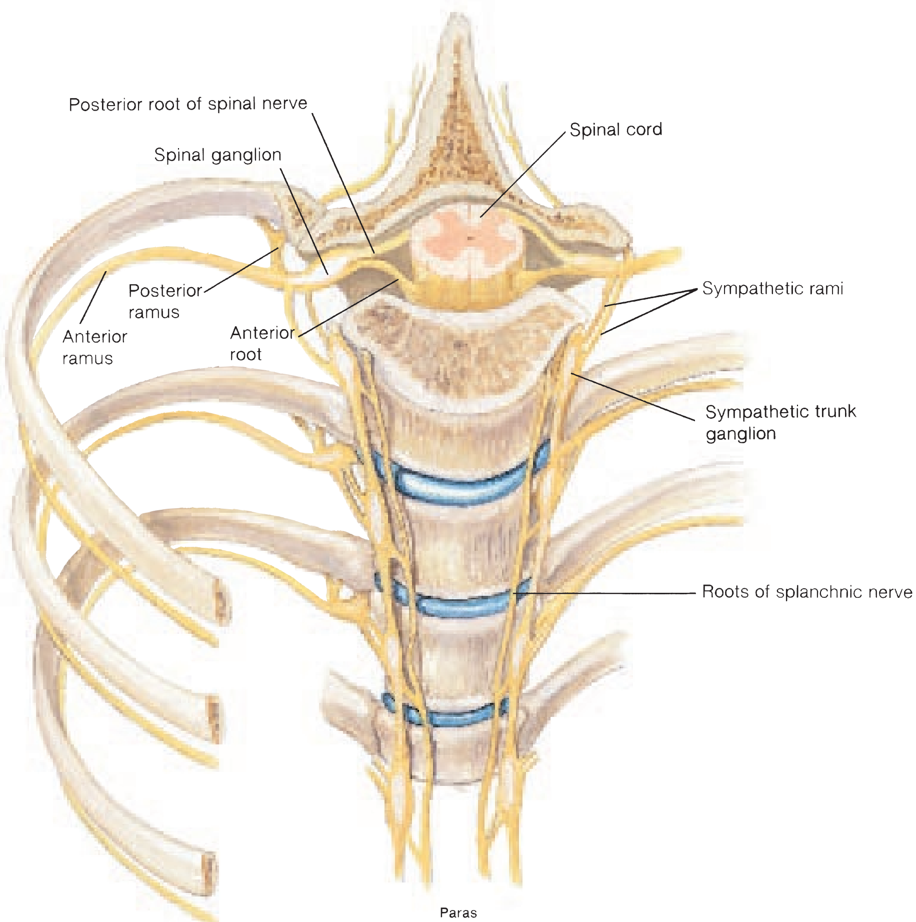


FIGURE 12.13 A section of the spinal cord and thoracic spinal nerves.

The remaining pairs of spinal nerves emerge below the vertebrae for which they are named.

A spinal nerve is a mixed nerve attached to the spinal cord by a **posterior** (dorsal) **root,** composed of sensory fibers, and an **anterior** (ventral) **root,** composed of motor fibers (fig. 12.13). The posterior root contains an enlargement called the **spinal** (sensory) **ganglion,** where the cell bodies of sensory neurons are located. The axons of sensory neurons convey sensory impulses through the posterior root into the spinal cord, where synapses occur with dendrites of other neurons. The anterior root consists of axons of motor neurons, which convey motor impulses away from the CNS. A spinal nerve is formed as the fibers from the posterior and anterior roots converge and emerge through an intervertebral foramen.

The disease *herpes zoster,* also known as *shingles,* is a viral infection of the spinal ganglia. Herpes zoster causes painful, often unilateral, clusters of fluid-filled vesicles in the skin along the paths of the affected peripheral sensory neurons. The disease develops in adults who were first exposed to the virus as children, and is usually self-limited. Treatment may involve large doses of the antiviral drug acyclovir (Zorivax).

A spinal nerve divides into several branches immediately after it emerges through the intervertebral foramen. The small **meningeal branch** reenters the vertebral canal to innervate the meninges, vertebrae, and vertebral ligaments. A larger branch, called the **posterior ramus,** innervates the muscles, joints, and skin of the back along the vertebral column (fig. 12.13). An **anterior ramus** of a spinal nerve innervates the muscles and skin on the lateral and anterior side of the trunk. Combinations of anterior rami innervate the limbs.

The **rami communicantes** are two branches from each spinal nerve that connect to a **sympathetic trunk ganglion,** which is part of the autonomic nervous system. The rami communicantes are composed of a **gray ramus,** containing unmyelinated fibers, and a **white ramus,** containing myelinated fibers. This arrangement is described in more detail in chapter 13.

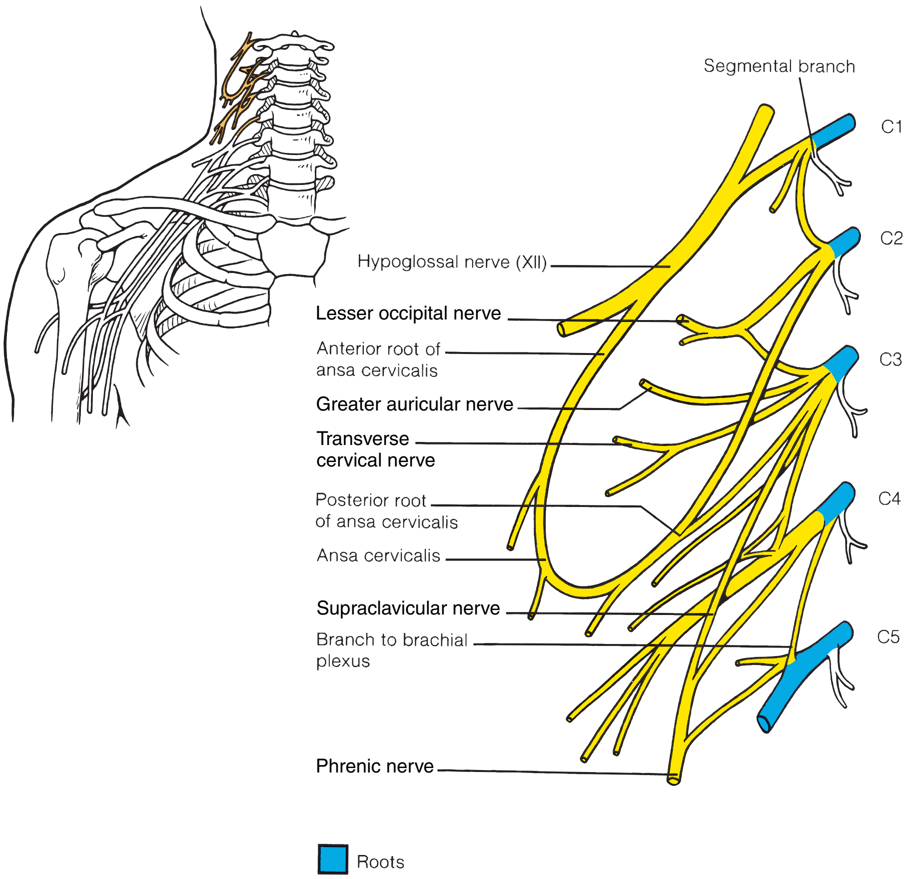


FIGURE 12.14 The cervical plexus.

Knowledge Check

8. List the number of nerves in each of the five regions of the vertebral column.
9. What are the four principal branches, or rami, from a spinal nerve, and what structures does each innervate?

NERVE PLEXUSES

Except in thoracic nerves T2 through T12, the anterior rami of the spinal nerves combine and then split again as networks of nerve fibers referred to as nerve plexuses. There are four plexuses of spinal nerves: the cervical, the brachial, the lumbar, and the sacral. Nerves emerging from the plexuses are named according to the structures they innervate or the general course they take.

Objective 6 List the spinal nerve composition of each of the plexuses arising from the spinal cord.

Objective 7 List the principal nerves that emerge from the plexuses and describe their general innervation.

Cervical Plexus

The **cervical plexus** (*plek'sus*) is positioned deep on the side of the neck, lateral to the first four cervical vertebrae (see fig. 12.1). It is formed by the anterior rami of the first four cervical nerves (C1–C4) and a portion of C5 (fig. 12.14). Branches of the cervical plexus innervate the skin and muscles of the neck and portions of the head and shoulders. Some fibers of the cervical plexus also combine with the accessory and hypoglossal cranial nerves to supply dual innervation to some specific neck and pharyngeal muscles (see fig. 12.16). Fibers from the third, fourth,

TABLE 12.3 Branches of the Cervical Plexus

Nerve	Spinal Component	Innervation
Superficial Cutaneous Branches		
Lesser occipital	C2, C3	Skin of scalp above and behind ear
Greater auricular	C2, C3	Skin in front of, above, and below ear
Transverse cervical	C2, C3	Skin of anterior aspect of neck
Supraclavicular	C3, C4	Skin of upper portion of chest and shoulder
Deep Motor Branches		
Ansa cervicalis		
Anterior root	C1, C2	Geniohyoid, thyrohyoid, and infrahyoid muscles of neck
Posterior root	C3, C4	Omohyoid, sternohyoid, and sternothyroid muscles of neck
Phrenic	C3–C5	Diaphragm
Segmental branches	C1–C5	Deep muscles of neck (levator scapulae ventralis, trapezius, scalenus, and sternocleidomastoid)

and fifth cervical nerves unite to become the **phrenic** (*fren'ik*) **nerve,** which innervates the diaphragm. Motor impulses through the paired phrenic nerves cause the diaphragm to contract, moving air into the lungs.

The nerves of the cervical plexus are summarized in table 12.3.

Brachial Plexus

The **brachial plexus** is positioned to the side of the last four cervical vertebrae and the first thoracic vertebra. It is formed by the anterior rami of C5 through T1, with occasional contributions from C4 and T2. From its emergence, the brachial plexus extends downward and laterally, passes over the first rib behind the clavicle, and enters the axilla. Each brachial plexus innervates the entire upper extremity of one side, as well as a number of shoulder and neck muscles.

Structurally, the brachial plexus is divided into *roots*, *trunks*, *divisions*, and *cords* (figs. 12.15 and 12.16). The roots of the brachial plexus are simply continuations of the anterior rami of the cervical nerves. The anterior rami of C5 and C6 converge to become the **superior trunk,** the C7 ramus becomes the **middle trunk,** and the ventral rami of C8 and T1 converge to become the **inferior trunk.** Each of the three trunks immediately divides into an **anterior division** and a **posterior division.** The divisions then converge to form three cords. The **posterior cord** is formed by the convergence of the posterior divisions of the upper, middle, and lower trunks; hence, it contains fibers from C5 through C8. The **medial cord** is a continuation of the anterior division of the lower trunk and primarily contains fibers from C8 and T1. The **lateral cord** is formed by the convergence of the anterior division of the upper and middle trunk and consists of fibers from C5 through C7.

In summary, the brachial plexus is composed of nerve fibers from the anterior branches of spinal nerves C5 through T1 and a few fibers from C4 and T2. Roots are continuations of the anterior rami. The roots converge to form trunks, and the trunks branch into divisions. The divisions in turn form cords, and the nerves of the upper extremity arise from the cords.

The brachial plexus may suffer trauma, especially if the clavicle, upper ribs, or lower cervical vertebrae are seriously fractured. Occasionally, the brachial plexus of a newborn is severely strained during a difficult delivery when the baby is pulled through the birth canal. In such cases, the arm of the injured side is paralyzed and eventually withers as the muscles atrophy in relation to the extent of the injury.

The entire upper extremity can be anesthetized in a procedure called a *brachial block* or *brachial anesthesia*. The site for injection of the anesthetic is located midway between the base of the neck and the shoulder, posterior to the clavicle. At this point, the anesthetic can be injected close to the brachial plexus.

Five major nerves—the axillary, radial, musculocutaneous, ulnar, and median—arise from the three cords of the brachial plexus to supply cutaneous and muscular innervation to the upper extremity (table 12.4). The **axillary nerve** arises from the posterior cord. It provides sensory innervation to the skin of the shoulder and shoulder joint, and motor innervation to the deltoid and teres minor muscles (fig. 12.17). The **radial nerve** arises from the posterior cord and extends along the posterior aspect of the brachial region to the radial side of the forearm. It provides sensory innervation to the skin of the posterior lateral surface of the upper extremity, including the posterior surface of the hand (fig. 12.18), and motor innervation to all of the extensor muscles of the elbow joint, the brachioradialis muscle that flexes the elbow joint, and the supinator muscle that supinates the forearm and hand.

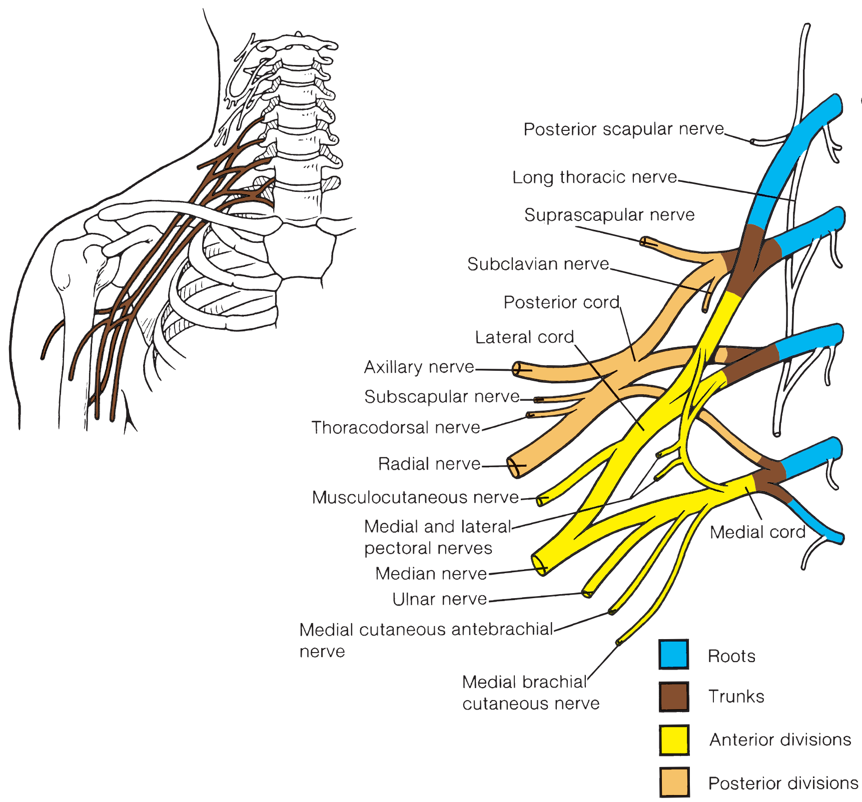


FIGURE 12.15 The brachial plexus.

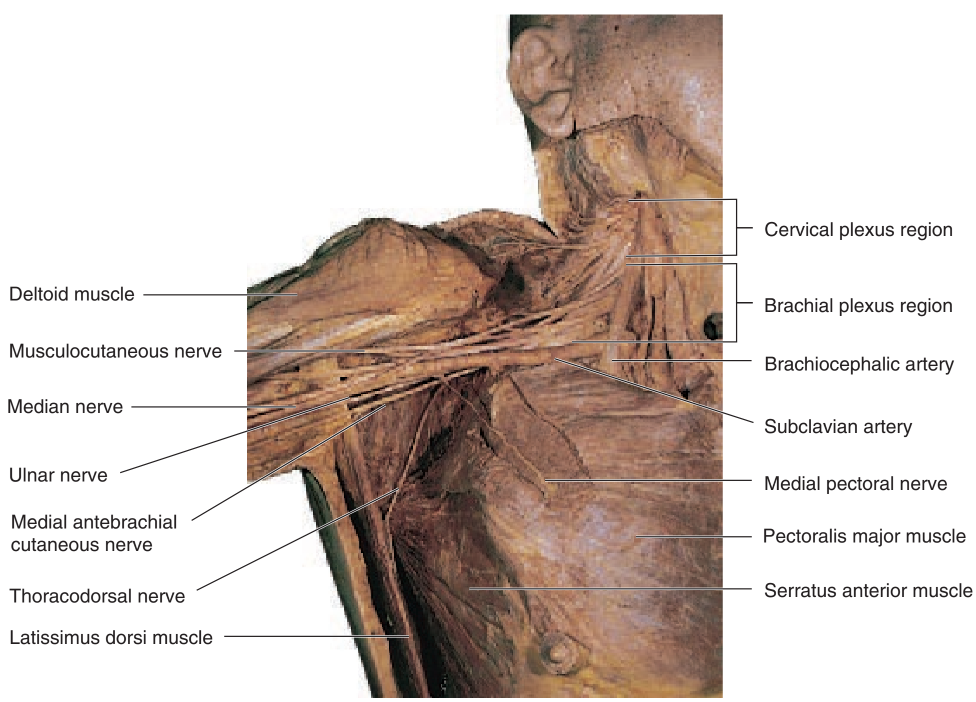


FIGURE 12.16 An anterior view of the cervical and brachial plexuses from a dissected human cadaver.

TABLE 12.4 Selected Branches of the Brachial Plexus

Nerve	Cord and Spinal Components	Innervation
Axillary	Posterior cord (C5, C6)	Skin of shoulder; shoulder joint, deltoid and teres minor muscles
Radial	Posterior cord (C5–C8, T1)	Skin of posterior lateral surface of arm, forearm, and hand; posterior muscles of brachium and antebrachium (triceps brachii, supinator, anconeus, brachioradialis, extensor carpi radialis brevis, extensor carpi radialis longus, extensor carpi ulnaris)
Musculocutaneous	Lateral cord (C5–C7)	Skin of lateral surface of forearm; anterior muscles of brachium (coracobrachialis, biceps brachii, brachialis)
Ulnar	Medial cord (C8, T1)	Skin of medial third of hand; flexor muscles of anterior forearm (flexor carpi ulnaris, flexor digitorum), medial palm, and intrinsic flexor muscles of hand (profundus, third and fourth lumbricales)
Median	Medial cord (C6–C8, T1)	Skin of lateral two-thirds of hand; flexor muscles of anterior forearm, lateral palm, and first and second lumbricales

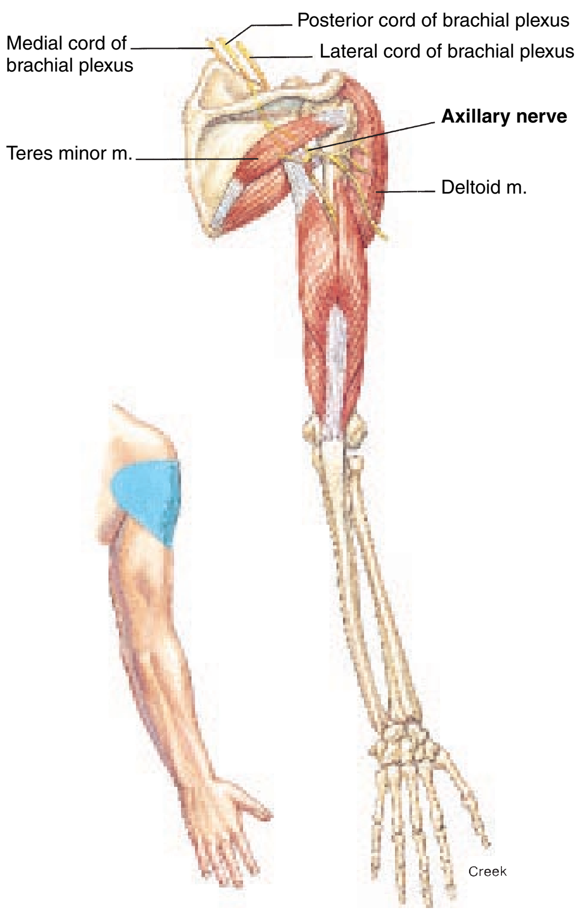


FIGURE 12.17 Muscular and cutaneous distribution of the axillary nerve.

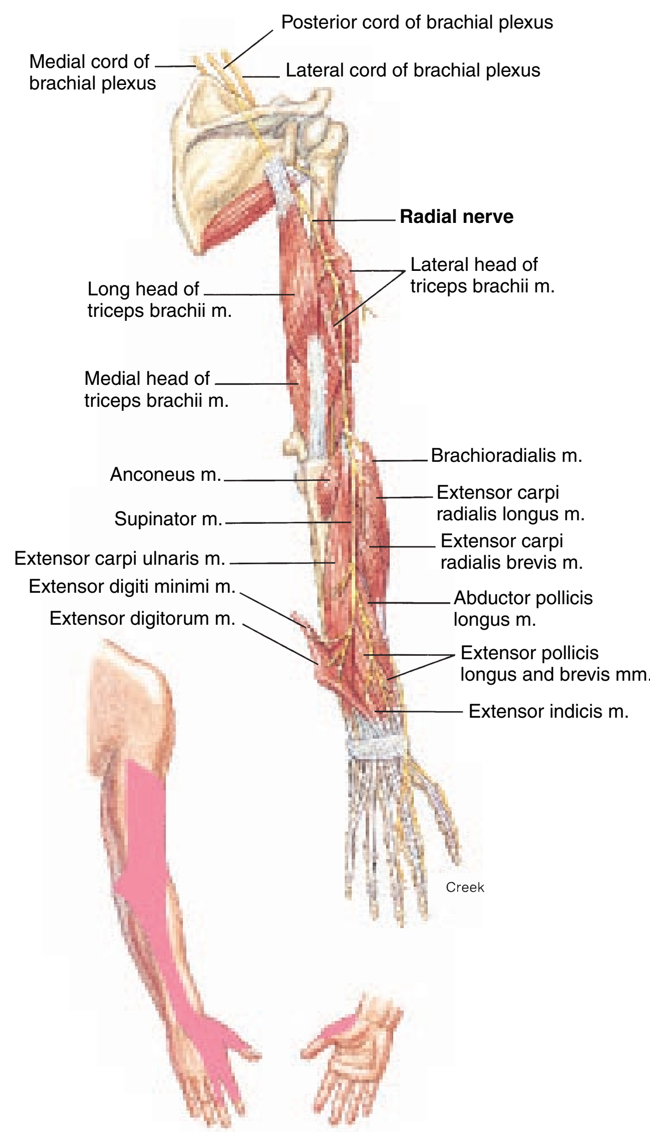


FIGURE 12.18 Muscular and cutaneous distribution of the radial nerve.

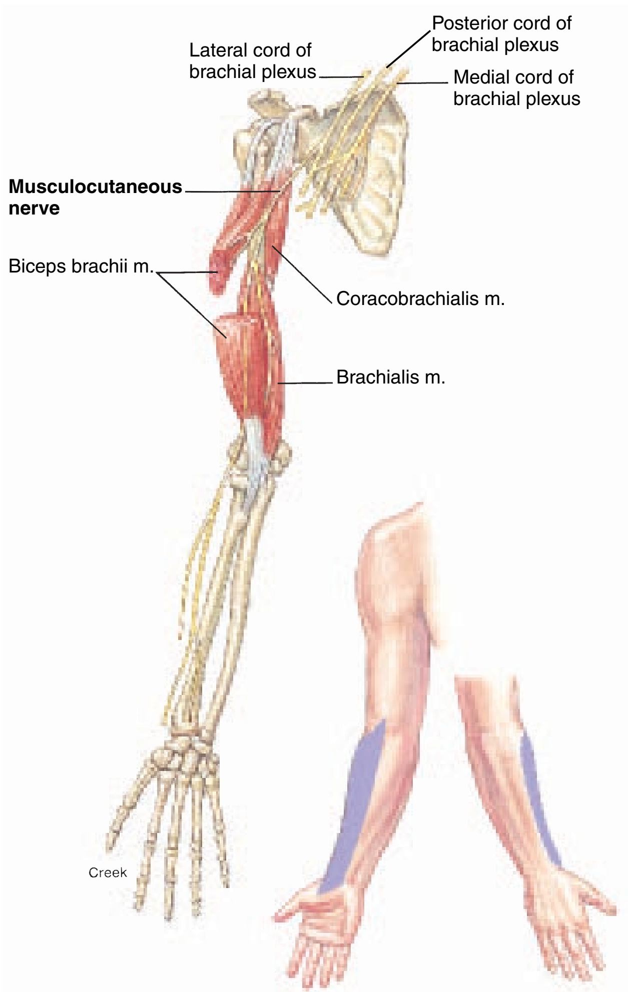


FIGURE 12.19 Muscular and cutaneous distribution of the musculocutaneous nerve.

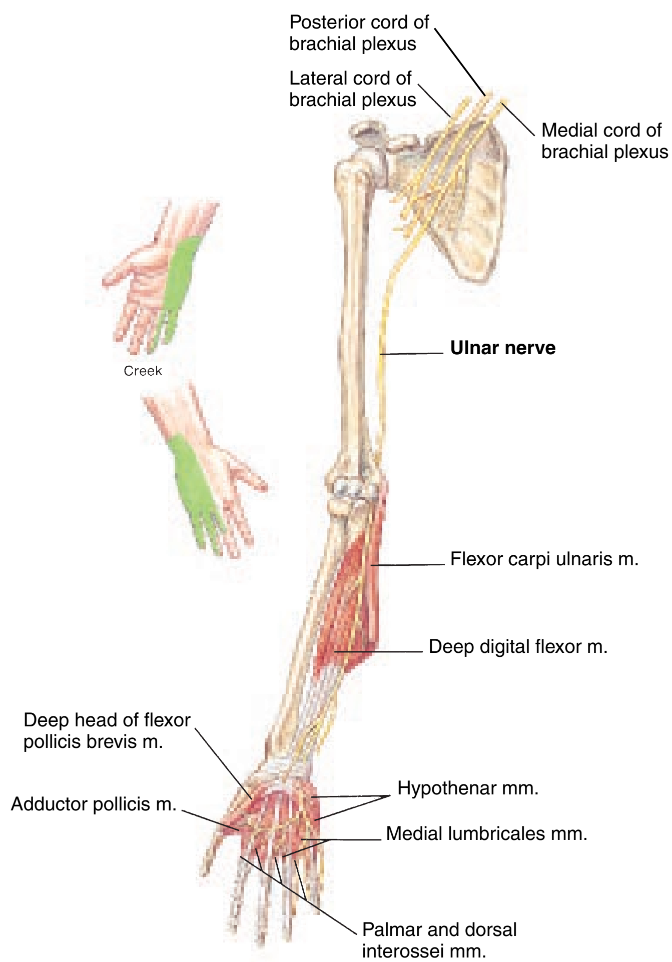


FIGURE 12.20 Muscular and cutaneous distribution of the ulnar nerve.

The radial nerve is vulnerable to several types of trauma. *Crutch paralysis* may result when a person improperly supports the weight of the body for an extended period of time with a crutch pushed tightly into the axilla. Compression of the radial nerve between the top of the crutch and the humerus may result in radial nerve damage. Likewise, dislocation of the shoulder frequently traumatizes the radial nerve. Children are particularly at risk as adults yank on their arms. A fracture to the body of the humerus may damage the radial nerve, which parallels the bone at this point. The principal symptom of radial nerve damage is *wristdrop,* in which the extensor muscles of the fingers and wrist fail to function. As a result, the joints of the fingers, wrist, and elbow are in a constant state of flexion.

The **musculocutaneous nerve** arises from the lateral cord. It provides sensory innervation to the skin of the posterior lateral surface of the arm and motor innervation to the anterior muscles of the brachium (fig. 12.19). The **ulnar nerve** arises from the medial cord and provides sensory innervation to the skin on the medial (ulnar side) third of the hand (fig. 12.20). The motor innervation of the ulnar nerve is to two muscles of the forearm and the intrinsic muscles of the hand (except some that serve the thumb).

The ulnar nerve can be palpated in the ulnar sulcus between the medial epicondyle of the humerus and the olecranon of the ulna (see fig. 7.5). This area is commonly known as the "funny bone" or "crazy bone." Ulnar nerve damage may occur as the medial side of the elbow is banged against a hard object. The immediate perception of this trauma is a painful tingling that extends down the ulnar side of the forearm and into the hand and medial two digits. Although common, ulnar nerve damage is generally not serious.

The **median nerve** arises from the medial cord. It provides sensory innervation to the skin on the radial portion of the palm of the hand (fig. 12.21) and motor innervation to all but one of the flexor muscles of the forearm and to most of the hand muscles of the thumb (thenar muscles).

CHAPTER 12

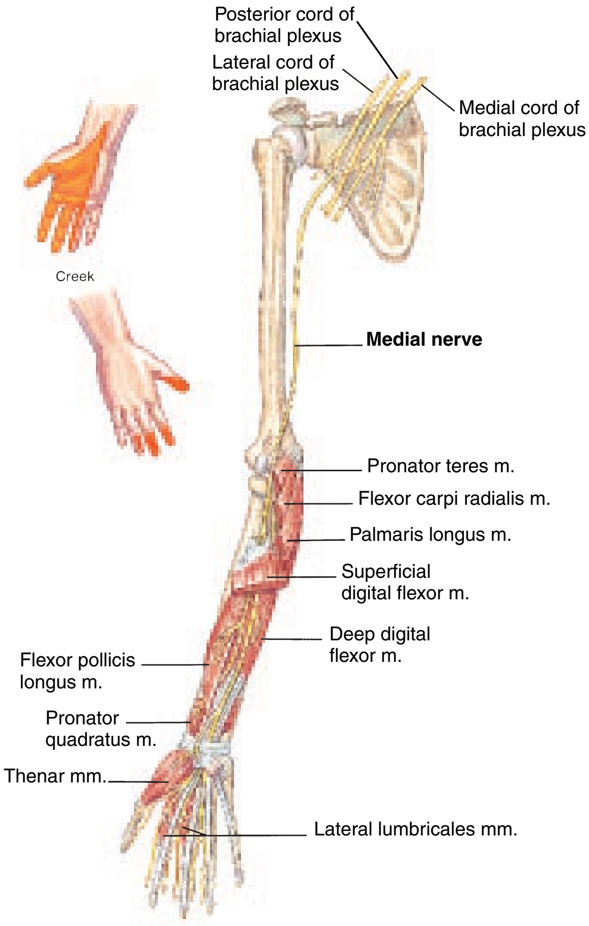


FIGURE 12.21 Muscular and cutaneous distribution of the median nerve.

TABLE 12.5 Branches of the Lumbar Plexus

Nerve	Spinal Components	Innervation
Iliohypogastric	T12, L1	Skin of lower abdomen and buttock; muscles of anterolateral abdominal wall (external abdominal oblique, internal abdominal oblique, transversus abdominis)
Ilioinguinal	L1	Skin of upper median thigh, scrotum and root of penis in male, and labia majora in female; muscles of anterolateral abdominal wall with iliohypogastric nerve
Genitofemoral	L1, L2	Skin of middle anterior surface of thigh, scrotum in male, and labia majora in female; cremaster muscle in male
Lateral cutaneous femoral	L2, L3	Skin of anterior, lateral, and posterior aspects of thigh
Femoral	L2–L4	Skin of anterior and medial aspect of thigh and medial aspect of leg and foot; anterior muscles of thigh (iliacus, psoas major, pectineus, rectus femoris, sartorius) and extensor muscles of leg (rectus femoris, vastus lateralis, vastus medialis, vastus intermedius)
Obturator	L2–L4	Skin of medial aspect of thigh; adductor muscles of lower extremity (external obturator, pectineus, adductor longus, adductor brevis, adductor magnus, gracilis)
Saphenous	L2–L4	Skin of medial aspect of lower extremity

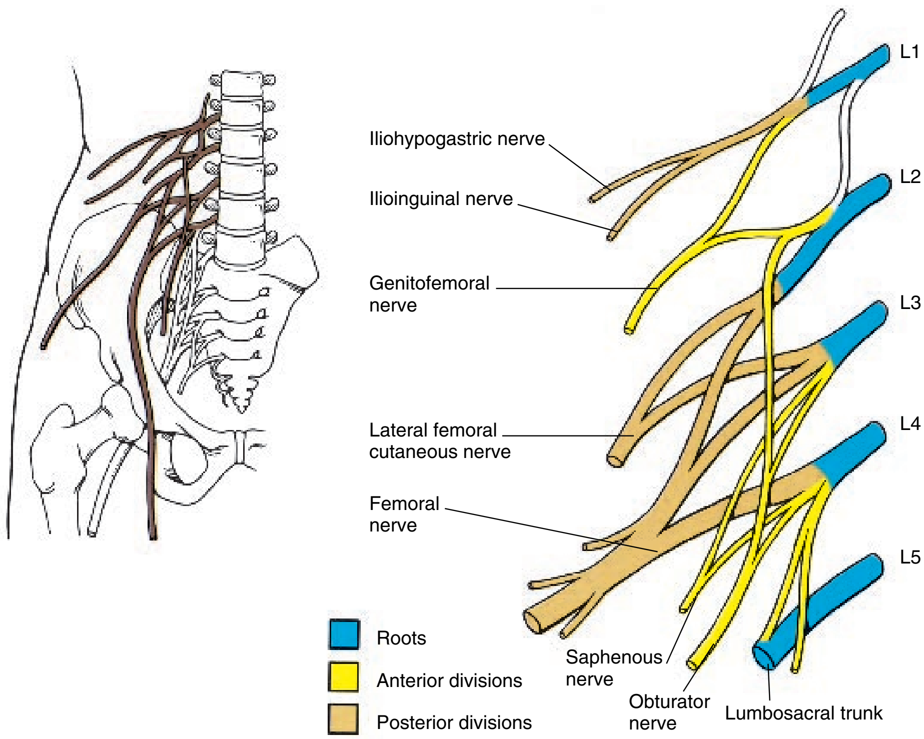


FIGURE 12.22 The lumbar plexus.

Lumbar Plexus

The **lumbar plexus** is positioned to the side of the first four lumbar vertebrae. It is formed by the anterior rami of spinal nerves L1 through L4 and some fibers from T12 (fig. 12.22). The nerves that arise from the lumbar plexus innervate structures of the lower abdomen and anterior and medial portions of the lower extremity. The lumbar plexus is not as complex as the brachial plexus, having only roots and divisions rather than the roots, trunks, divisions, and cords of the brachial plexus.

Structurally, the **posterior division** of the lumbar plexus passes obliquely outward, deep to the psoas major muscle, whereas the **anterior division** is superficial to the quadratus lumborum muscle. The nerves that arise from the lumbar plexus are summarized in table 12.5. Because of their extensive innervation, the femoral nerve and the obturator nerve are illustrated in figures 12.23 and 12.24, respectively.

The **femoral** (*fem'or-al*) **nerve** arises from the posterior division of the lumbar plexus and provides cutaneous innervation to the anterior and lateral thigh and the medial leg and foot (fig. 12.23). The motor innervation of the femoral nerve is to the anterior muscles of the thigh, including the iliopsoas and sartorius muscles and the quadriceps femoris group.

The **obturator** (*ob'too-ra''tor*) **nerve** arises from the anterior division of the lumbar plexus. It provides cutaneous innervation to the medial thigh and motor innervation to the adductor muscles of the thigh (fig. 12.24).

Sacral Plexus

The **sacral plexus** lies immediately inferior to the lumbar plexus. It is formed by the anterior rami of spinal nerves L4, L5, and S1 through S4 (figs. 12.25 and 12.26). The nerves arising from the sacral plexus innervate the lower back, pelvis, perineum, posterior surface of the thigh and leg, and dorsal and plantar surfaces of the foot (table 12.6). Like the lumbar plexus, the sacral plexus consists of **roots** and **anterior** and **posterior divisions,** from which nerves arise. Because some of the nerves of the sacral plexus also contain fibers from the nerves of the lumbar plexus through the **lumbosacral trunk,** these two plexuses are frequently described collectively as the **lumbosacral plexus.**

The **sciatic** (*si-at'ik*) **nerve** is the largest nerve arising from the sacral plexus and is the largest nerve in the body. The sciatic nerve passes from the pelvis through the greater sciatic notch of the os coxae and extends down the posterior aspect of the thigh. It is actually composed of two nerves—the tibial and common fibular nerves—wrapped in a connective tissue sheath.

sacral: L. *sacris*, sacred

sciatic: L. *sciaticus*, hip joint

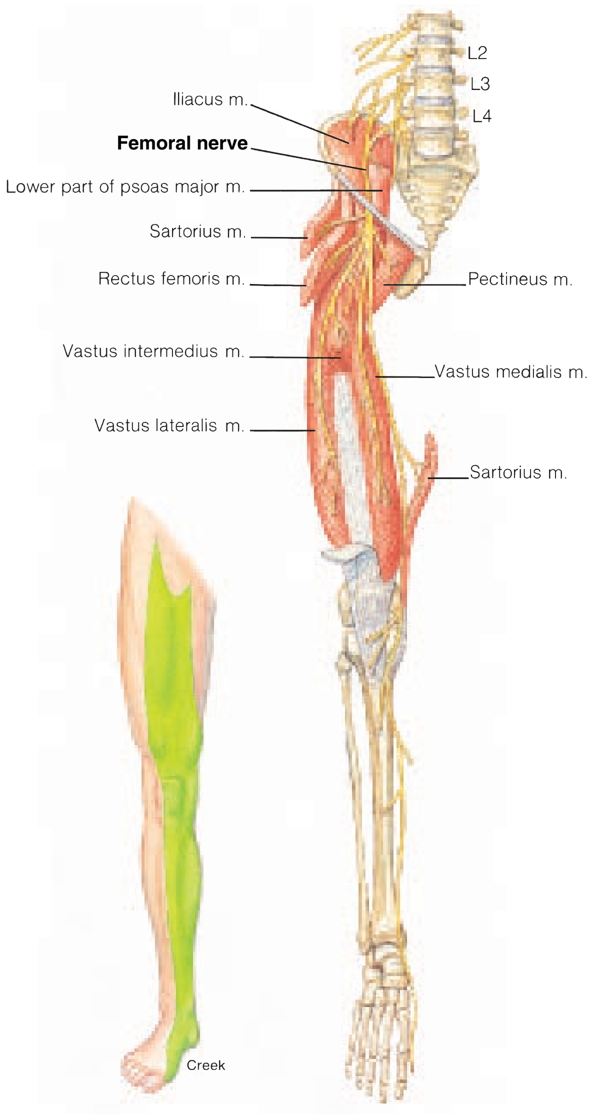


FIGURE 12.23 Muscular and cutaneous distribution of the femoral nerve.

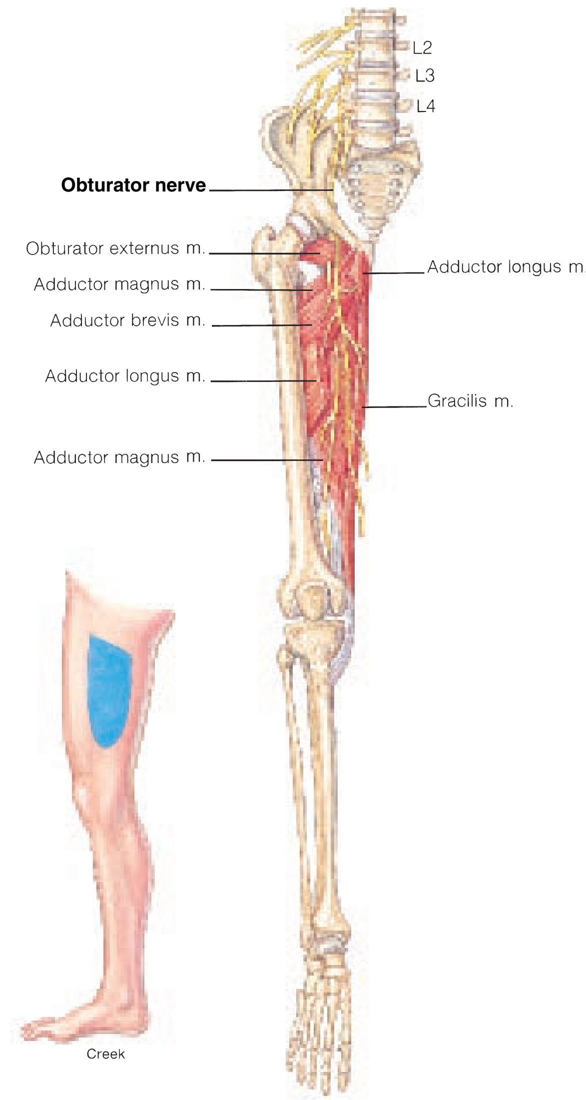


FIGURE 12.24 Muscular and cutaneous distribution of the obturator nerve.

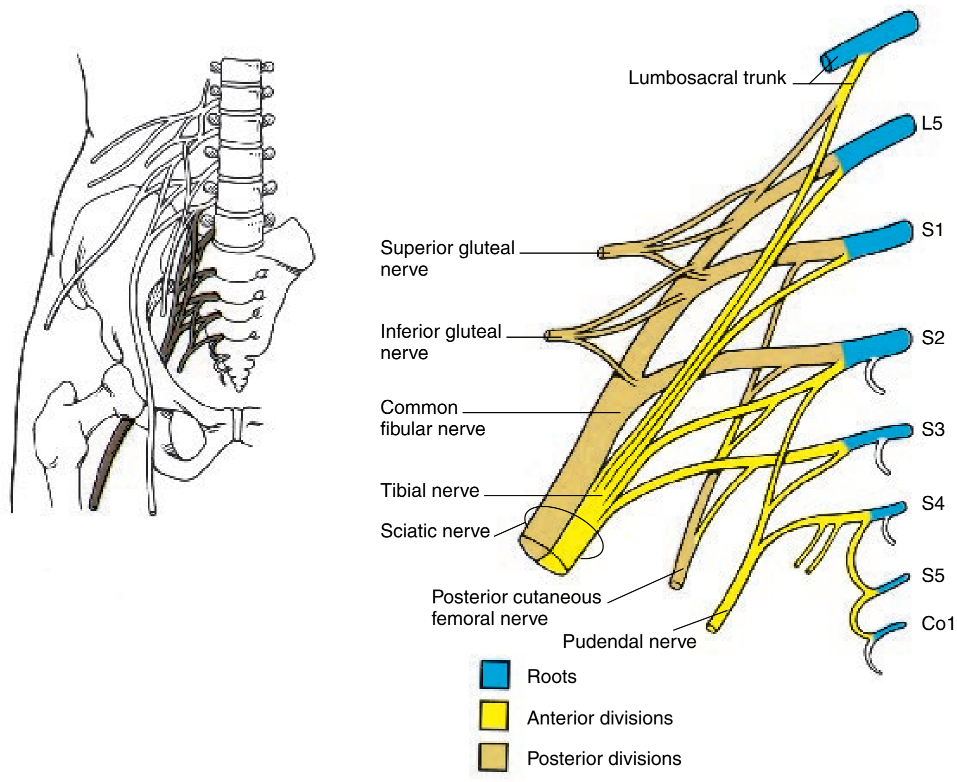


FIGURE 12.25 The sacral plexus.

The **tibial nerve** arises from the anterior division of the sacral plexus, extends through the posterior regions of the thigh and leg, and branches in the foot to form the **medial** and **lateral plantar nerves** (fig. 12.27). The cutaneous innervation of the tibial nerve is to the calf of the leg and the plantar surface of the foot. The motor innervation of the tibial nerve is to most of the posterior thigh and leg muscles and to many of the intrinsic muscles of the foot.

The **common fibular nerve** (peroneal nerve) arises from the posterior division of the sacral plexus, extends through the posterior region of the thigh, and branches in the upper portion of the leg into the **deep** and **superficial fibular nerves** (fig. 12.28). The cutaneous innervation of the common fibular nerve and its branches is to the anterior and lateral leg and to the dorsum of the foot. The motor innervation is to the anterior and lateral muscles of the leg and foot.

The sciatic nerve in the buttock lies deep to the gluteus maximus muscle, midway between the greater trochanter and the ischial tuberosity. Because of its position, the sciatic nerve is of tremendous clinical importance. A posterior dislocation of the hip joint will generally injure the sciatic nerve. A *herniated disc* (fig. 12.29) or pressure from the uterus during pregnancy may damage the nerve roots, resulting in a condition called *sciatica* (*si-at'ĭ-kă*). Sciatica is characterized by sharp pain in the gluteal region that extends down the posterior side of the thigh. An improperly administered injection into the buttock may injure the sciatic nerve itself. Even a temporary compression of the sciatic nerve as a person sits on a hard surface for a period of time may result in the perception of tingling throughout the limb as the person stands up. The limb is said to have "gone to sleep."

Knowledge Check

10. Define *nerve plexus*. What are the four spinal nerve plexuses and which spinal nerves contribute to each?
11. Which spinal nerves are not involved in a plexus?
12. Distinguish between a posterior ramus and an anterior ramus. Which is involved in the formation of plexuses?
13. Construct a table that lists the plexus of origin and the general region of innervation for the following nerves: (a) pudendal, (b) phrenic, (c) femoral, (d) ulnar, (e) median, (f) sciatic, (g) saphenous, (h) axillary, (i) radial, (j) ansa cervicalis, (k) tibial, and (l) common fibular.

FIGURE 12.26 A posterior view of the lumbosacral plexus from a dissected human cadaver.

TABLE 12.6 Branches of the Sacral Plexus

Nerve	Spinal Components	Innervation
Superior gluteal	L4, L5, S1	Abductor muscles of thigh (gluteus minimus, gluteus medius, tensor fasciae latae)
Inferior gluteal	L5–S2	Extensor muscle of hip joint (gluteus maximus)
Nerve to piriformis	S1, S2	Abductor and rotator of thigh (piriformis)
Nerve to quadratus femoris	L4, L5, S1	Rotators of thigh (gemellus inferior, quadratus femoris)
Nerve to internal obturator	L5–S2	Rotators of thigh (gemellus superior, internal obturator)
Perforating cutaneous	S2, S3	Skin over lower medial surface of buttock
Posterior cutaneous femoral	S1–S3	Skin over lower lateral surface of buttock, anal region, upper posterior surface of thigh, upper aspect of calf, scrotum in male and labia majora in female
Sciatic	L4–S3	Composed of two nerves (tibial and common fibular); splits into two portions at popliteal fossa; branches from sciatic in thigh region to "hamstring muscles" (biceps femoris, semitendinosus, semimembranosus) and adductor magnus muscle
Tibial (sural, medial and lateral plantar)	L4–S3	Skin of posterior surface of leg and sole of foot; muscle innervation includes gastrocnemius, soleus, flexor digitorum longus, flexor hallucis longus, tibialis posterior, popliteus, and intrinsic foot muscles
Common fibular (superficial and deep fibular)	L4–S2	Skin of anterior surface of the leg and dorsum of foot; muscle innervation includes peroneus tertius, peroneus brevis, peroneus longus, tibialis anterior, extensor hallucis longus, extensor digitorum longus, extensor digitorum brevis
Pudendal	S2–S4	Skin of penis and scrotum in male and skin of clitoris, labia majora, labia minora, and lower vagina in female; muscles of perineum

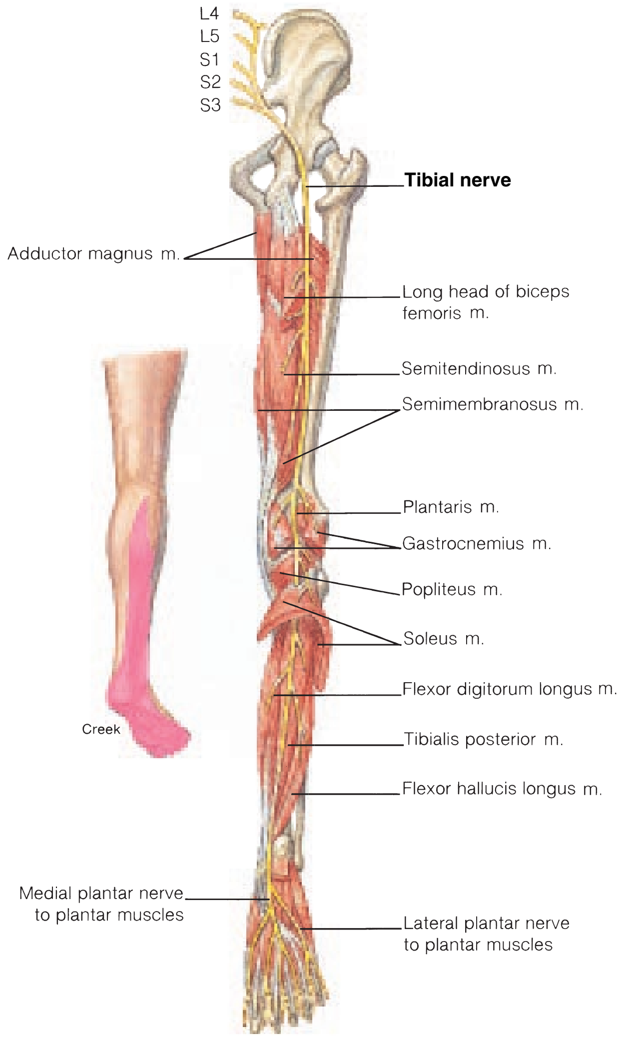


FIGURE 12.27 Muscular and cutaneous distribution of the tibial nerve.

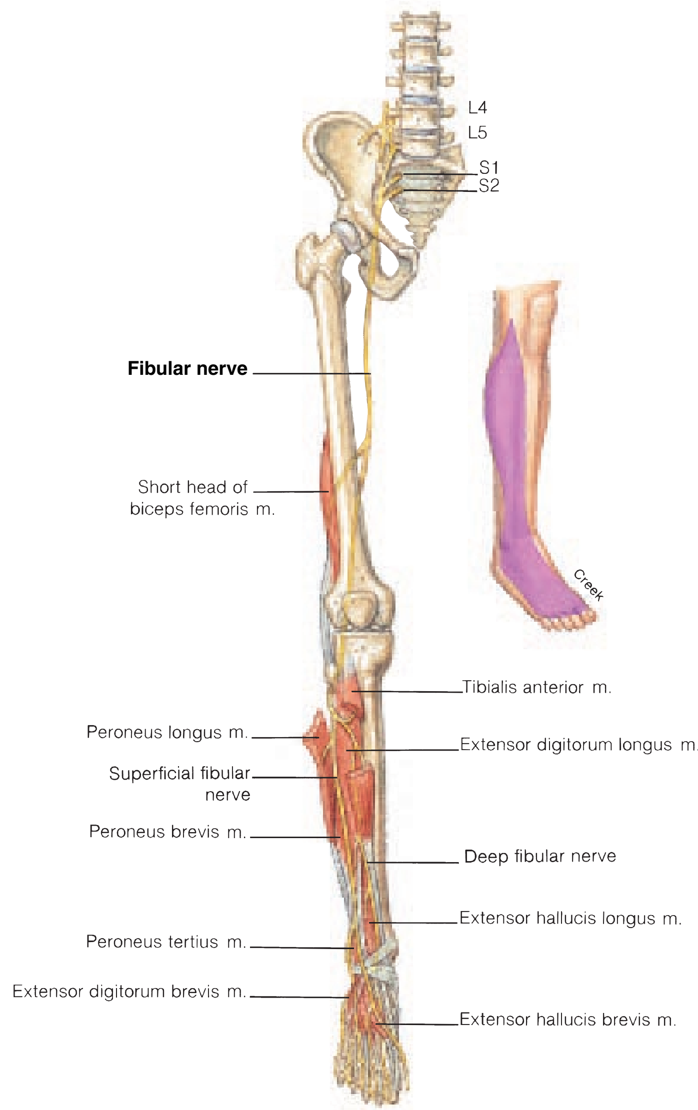


FIGURE 12.28 Muscular and cutaneous distribution of the fibular nerve.

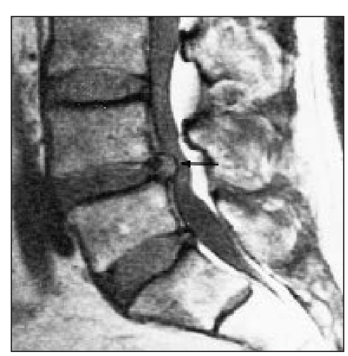


FIGURE 12.29 An MRI of a herniated disc (arrow) in the lumbar region.

Developmental Exposition

The Peripheral Nervous System

EXPLANATION

Development of the peripheral nervous system produces the pattern of dermatomes within the body (exhibit I). A **dermatome** (*der′mă-tōm*) is an area of skin innervated by all the cutaneous neurons of a single spinal nerve or cranial nerve V. Most of the scalp and face is innervated by sensory neurons from the trigeminal (fifth cranial) nerve. With the exception of the first cervical nerve (C1), all of the spinal nerves are associated with specific dermatomes. Dermatomes are consecutive in the neck and trunk regions. In the appendages, however, adjacent dermatome innervations overlap. The apparently uneven dermatome arrangement in the appendages is due to the uneven rate of nerve growth into the limb buds. Actually, the limbs are segmented, and dermatomes overlap only slightly.

dermatone: Gk. *derma*, skin; *tomia*, a cutting

The pattern of dermatome innervation is of clinical importance when a physician wants to anesthetize a particular portion of the body. Because adjacent dermatomes overlap in the appendages, at least three spinal nerves must be blocked to produce complete anesthesia in these regions. Abnormally functioning dermatomes provide clues about injury to the spinal cord or specific spinal nerves. If a dermatome is stimulated but no sensation is perceived, the physician can infer that the injury involves the innervation to that dermatome.

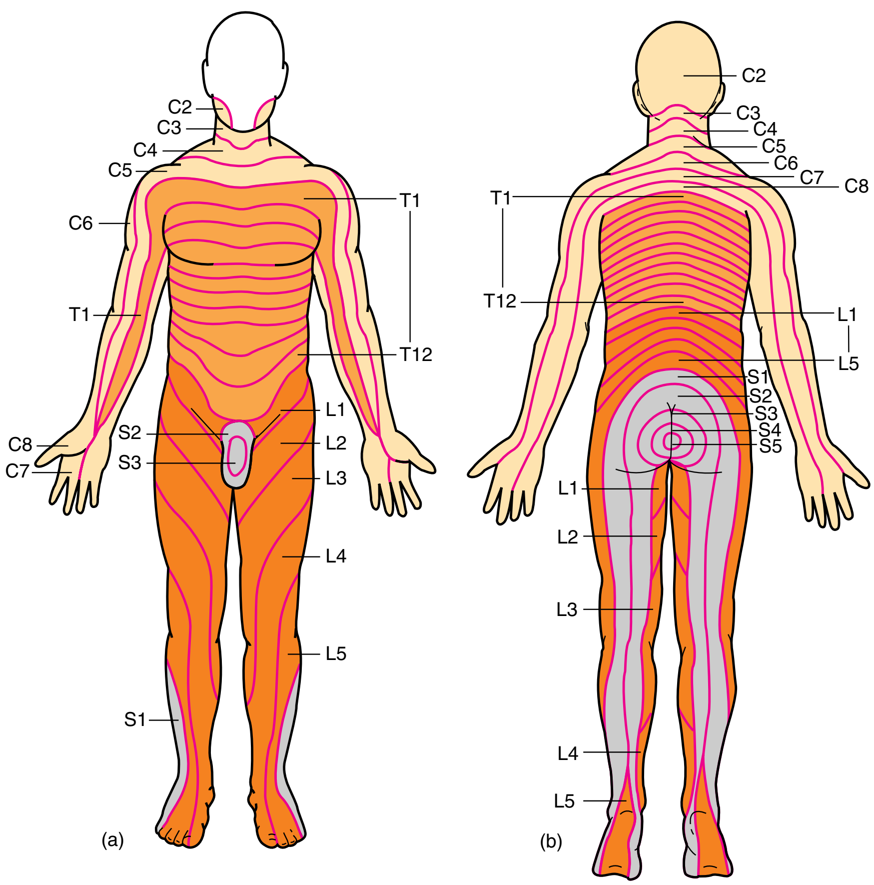


EXHIBIT I The pattern of dermatomes within the body and the peripheral distribution of spinal nerves. (*a*) An anterior view and (*b*) a posterior view.

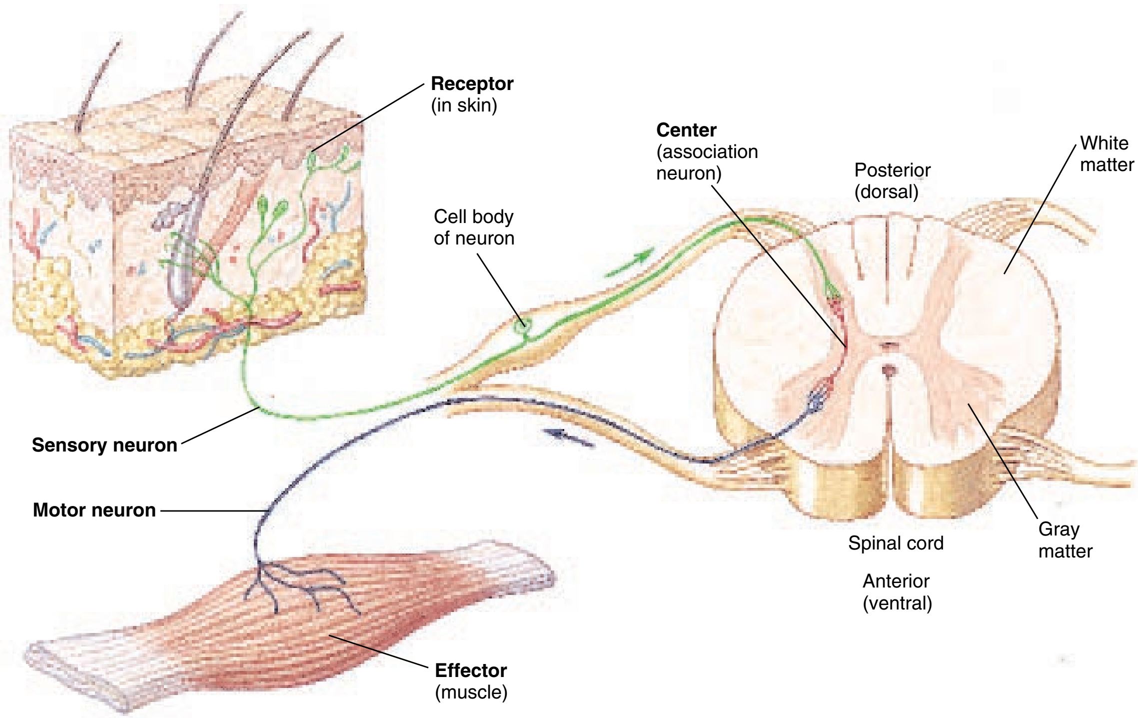


FIGURE 12.30 A reflex arc. (The components of a reflex arc are labeled in boldface type.)

REFLEX ARC AND REFLEXES

The conduction pathway of a reflex arc consists of a receptor, a sensory neuron, a motor neuron and its innervation in the PNS, and one or more association neurons in the CNS. The reflex arc provides the mechanism for a rapid, automatic response to a potentially threatening stimulus.

Objective 8 Define *reflex arc* and list its five components.

Objective 9 Distinguish between the various kinds of reflexes.

Specific **nerve pathways** provide routes by which impulses travel through the nervous system. Frequently, a nerve pathway begins with the conduction of impulses to the CNS through sensory receptors and sensory neurons of the PNS. Once within the CNS, impulses may immediately travel back through motor portions of the PNS to activate specific skeletal muscles, glands, or smooth muscles. Impulses may also be sent simultaneously to other parts of the CNS through ascending tracts within the spinal cord.

Components of the Reflex Arc

The simplest type of nerve pathway is a **reflex arc** (fig. 12.30). A reflex arc implies an automatic, unconscious, protective response to a situation in an attempt to maintain body homeostasis. Impulses are conducted over a short route from sensory to motor neurons, and only two or three neurons are involved. The five components of a reflex arc are the receptor, sensory neuron, center, motor neuron, and effector. The **receptor** includes the dendrite of a sensory neuron and the place where the nerve impulse is initiated. The **sensory neuron** relays the impulse through the posterior root to the CNS. The **center** is located within the CNS and usually involves one or more association neurons (interneurons). It is here that the arc is made and other impulses are sent through synapses to other parts of the body. The **motor neuron** conducts the nerve impulse to an **effector organ** (generally a skeletal muscle). The response of the effector is called a *reflex action* or, simply, a *reflex*.

Kinds of Reflexes

Visceral Reflexes

Reflexes that cause smooth or cardiac muscle to contract or glands to secrete are **visceral** (autonomic) **reflexes.** Visceral reflexes help control the body's many involuntary processes such as heart rate, respiratory rate, blood flow, and digestion. Swallowing, sneezing, coughing, and vomiting may also be reflexive, although they involve the involuntary action of skeletal muscles.

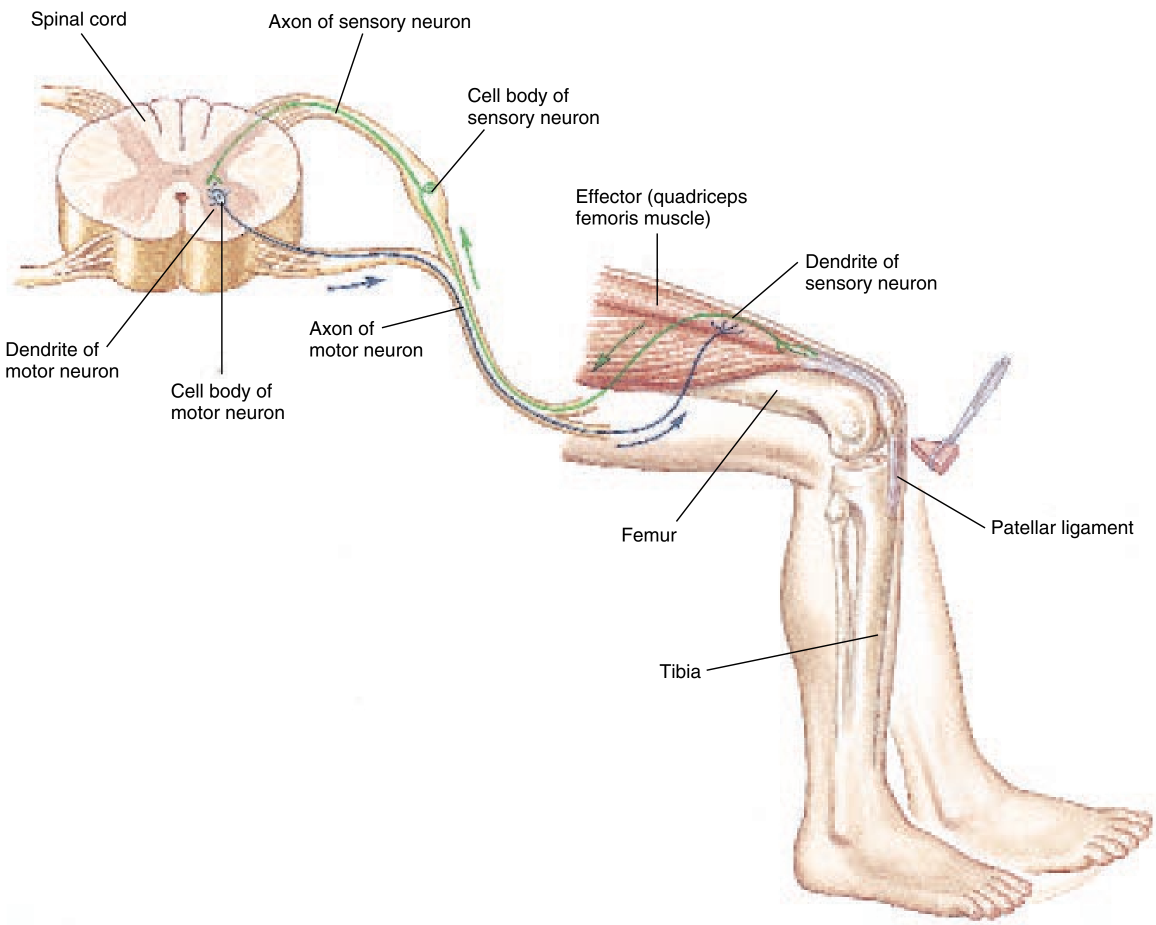


FIGURE 12.31 The knee-jerk reflex is an ipsilateral reflex. The receptor and effector organs are on the same side of the spinal cord. The knee-jerk reflex is also a monosynaptic reflex because it involves only two neurons and one synapse.

Somatic Reflexes

Somatic reflexes are those that result in the contraction of skeletal muscles. The three principal kinds of somatic reflexes are named according to the response they produce.

The **stretch reflex** involves only two neurons and one synapse in the pathway; it is therefore called a *monosynaptic reflex arc*. Slight stretching of the neuromuscular spindle receptors (described in chapter 15) within a muscle initiates an impulse along a sensory neuron to the spinal cord. A synapse with a motor neuron occurs in the anterior gray column, and activation of a motor unit causes specific muscle fibers to contract. Because the receptor and effector organs of the stretch reflex involve structures on the same side of the spinal cord, the reflex arc is an *ipsilateral reflex arc*. The knee-jerk reflex is an ipsilateral reflex (fig. 12.31), as are all monosynaptic reflex arcs.

A **flexor reflex,** or **withdrawal reflex,** involves a *polysynaptic reflex arc* (fig. 12.32). Flexor reflexes involve association neurons in addition to the sensory and motor neurons. A flexor reflex is initiated as a person encounters a painful stimulus, such as a hot or sharp object. As a receptor organ is stimulated, sensory neurons transmit the impulse to the spinal cord, where association neurons are activated. Here, the impulses are directed through motor neurons to flexor muscles, which contract in response. Simultaneously, antagonistic muscles are inhibited (relaxed) so that the traumatized extremity can be quickly withdrawn from the harmful source of stimulation.

Several additional reflexes may be activated while a flexor reflex is in progress. In an *intersegmental reflex arc*, motor units from several segments of the spinal cord are activated by impulses coming in from the receptor organ. In an intersegmental reflex arc, more than one effector organ is stimulated. Frequently, sensory impulses from a receptor organ cross over through the spinal cord to activate effector organs in the opposite (*contralateral*) limb. This type of reflex is called a **crossed extensor reflex** (fig. 12.33) and is important for maintaining body balance while a flexor reflex is in

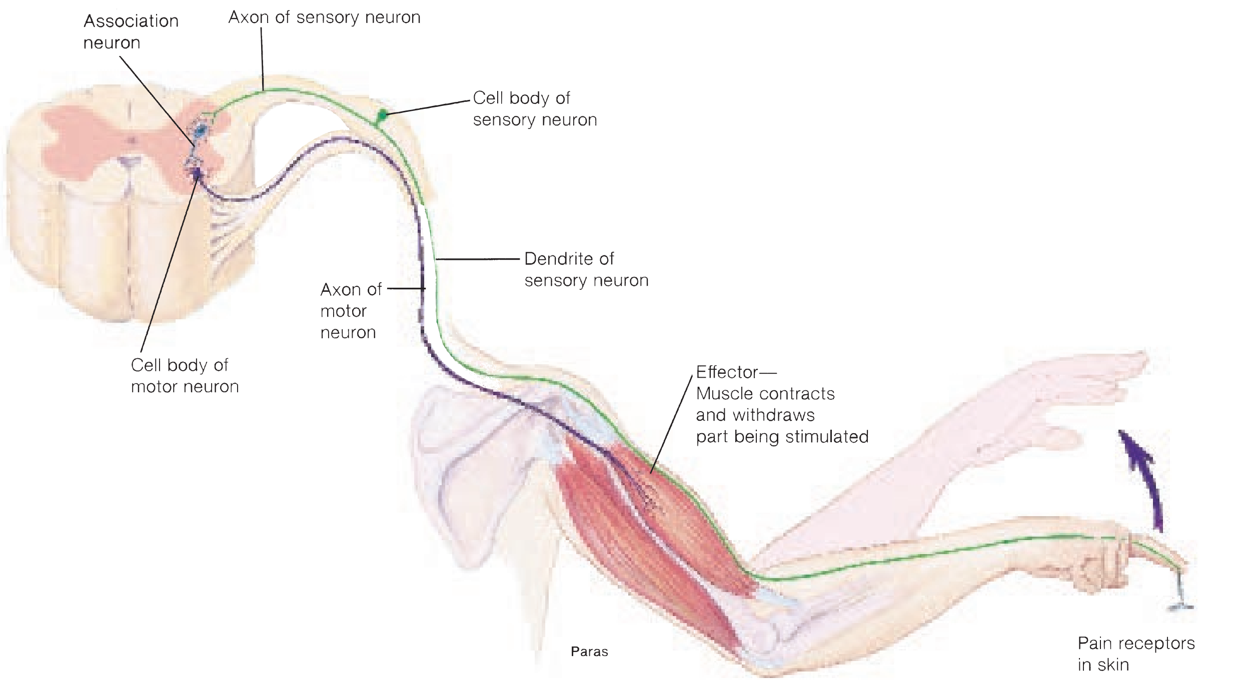


FIGURE 12.32 The flexor, or withdrawal, reflex is a polysynaptic reflex and involves association neurons in addition to sensory and motor neurons.

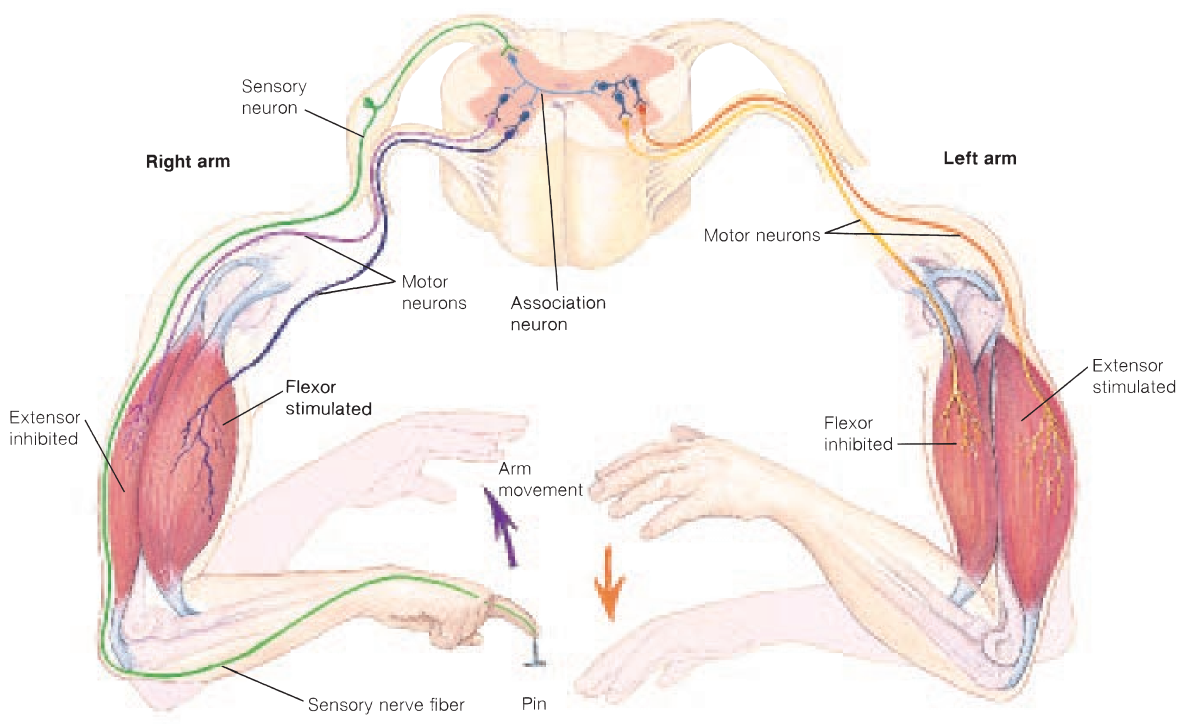


FIGURE 12.33 A crossed extensor reflex causes a reciprocal inhibition of muscles within the opposite appendage. This type of reflex inhibition is important in maintaining balance.

TABLE 12.7 Selected Reflexes of Clinical Importance

Reflex	Spinal Segment	Site of Receptor Stimulation	Effector Action
Biceps reflex	C5, C6	Tendon of biceps brachii muscle, near attachment on radial tuberosity	Contracts biceps brachii muscle to flex elbow
Triceps reflex	C7, C8	Tendon of triceps brachii muscle, near attachment on olecranon	Contracts triceps brachii muscle to extend elbow
Supinator or brachioradialis reflex	C5, C6	Radial attachment of supinator and brachioradialis muscles	Supinates forearm and hand
Knee-jerk	L2–L4	Patellar ligament, just below patella	Contracts quadriceps muscle to extend the knee
Ankle reflex	S1, S2	Tendo calcaneus, near attachment on calcaneus	Plantar flexes ankle
Plantar reflex	L4, L5, S1, S2	Lateral aspect of sole, from heel to ball of foot	Plantar flexes foot and flexes toes
Babinski's reflex*	L4, L5, S1, S2	Lateral aspect of sole, from heel to ball of foot	Extends great toe and fans other toes
Abdominal reflexes	T8–T10 above umbilicus and T10–T12 below umbilicus	Sides of abdomen, above and below level of umbilicus	Contract abdominal muscles and deviate umbilicus toward stimulus
Cremasteric reflex	L1, L2	Upper inside of thigh in males	Contracts cremasteric muscle and elevates testis on same side of stimulation

*If Babinski's reflex rather than the plantar reflex occurs as the sole of the foot is stimulated, damage to the corticospinal tract within the spinal cord may be indicated. However, Babinski's reflex is present in infants up to 12 months of age because of the immaturity of their corticospinal tracts.

Babinski's reflex: from Joseph F. Babinski, French neurologist, 1857–1932

progress. For example, withdrawal of one leg, after stepping on broken glass, requires extension of the other in order to keep from falling. The reflexive inhibition of certain muscles to contract, called *reciprocal inhibition,* also helps maintain balance while either flexor or crossed extensor reflexes are in progress.

Certain reflexes are important for physiological functions, whereas others are important for avoiding injury. Some of the more common reflexes are described in table 12.7 and illustrated in figure 12.34.

Part of a routine physical examination involves testing a person's reflexes. Several reflexes are used to assess certain neurological conditions, including functioning of the synapses. If some portion of the nervous system has been injured, the testing of certain reflexes may indicate the location and extent of the injury. Also, an anesthesiologist may try to initiate a reflex to ascertain the effect of an anesthetic.

Knowledge Check

14. How are reflexes important in maintaining body homeostasis?
15. List the five components of a reflex arc.
16. Define the following terms: *visceral reflex, somatic reflex, stretch reflex, flexor reflex, crossed extensor reflex, ipsilateral reflex,* and *contralateral reflex.*

Clinical Case Study Answer

The radial nerve lies in the radial groove of the humerus as it extends through the brachial region toward the arm and hand. In this position, the radial nerve is susceptible to injury in the case of a fracture to the midshaft of the humerus. The muscles innervated by the radial nerve include those of wrist extension (extensor carpi radialis longus and brevis, extensor carpi ulnaris); wrist adduction (extensor carpi ulnaris); wrist abduction (extensor carpi radialis brevis and longus); supination (supinator); and finger extension (finger extensors). A detectable weakness in flexion of the elbow could also result from impairment of the brachioradialis muscle. The triceps brachii muscle would not be affected, however, because of the more proximal branching point of its motor nerve supply. The radial nerve is a mixed nerve, carrying both motor and sensory fibers; therefore, a sensory deficit would be present. Decreased sensation would be detectable on the posterolateral aspect of the hand (see fig. 12.18).

(a) Glabellar reflex (b) Biceps reflex (c) Triceps reflex

(d) Supinator (brachioradialis) reflex (e) Knee-jerk (patellar) reflex (f) Ankle (Achilles) reflex

(g) Babinski's reflex (h) Plantar reflex (i) Abdominal reflex

FIGURE 12.34 Some reflexes of clinical importance.

CLINICAL PRACTICUM 12.1

A 39-year-old woman is seeing you for left leg and low back pain. She experienced the sudden onset of back pain 2 weeks ago while lifting a heavy object. The back pain is accompanied by a burning pain that spreads from the left buttock down the posterior left thigh and into the calf. Sneezing or coughing sends shooting pains down the leg in the same distribution. She has not experienced any change in urinary bladder or bowel control. In your office she prefers to stand because sitting only makes her leg hurt worse.

On examination you note only minimal tenderness to palpation of the lower back, but her paraspinal muscles are very tight on the left side. You then have her lie flat on her back. In this position you are able to reproduce the shooting pain by lifting the affected leg. She has normal knee and ankle reflexes, but her skin is relatively numb over the anterior tibia ("shin") and superior surface of the foot. Her left great toe extensor is weak. You decide you should order an MRI of the lumbar spine even though you probably know what's causing the problem.

QUESTIONS:

1. What did she do to her back that is causing the leg symptoms?
2. How do the leg problems predict the findings seen on the adjacent MRI?
3. What is the significance of normal urinary bladder and bowel control?

Chapter Summary

Introduction to the Peripheral Nervous System (pp. 401–403)

1. The peripheral nervous system consists of sensory receptors and the nerves that convey impulses to and from the central nervous system. Ganglia and nerve plexuses are also part of the PNS.
2. The cranial nerves arise from the brain and the spinal nerves arise from the spinal cord.
3. Sensory (afferent) nerves convey impulses toward the CNS, whereas motor (efferent) nerves convey impulses away from the CNS. Mixed nerves are composed of both sensory and motor fibers.

Cranial Nerves (pp. 403–413)

1. Twelve pairs of cranial nerves emerge from the inferior surface of the brain and, with the exception of the vestibulocochlear nerve, pass through the foramina of the skull to innervate structures in the head, neck, and visceral organs of the trunk.
2. The names of the cranial nerves indicate their primary function or the general distribution of their fibers.
3. The olfactory, optic, and vestibulocochlear cranial nerves are sensory only; the trigeminal, glossopharyngeal, and vagus are mixed; and the others are primarily motor, with a few proprioceptive sensory fibers.
4. Some of the cranial nerve fibers are somatic; others are visceral.
5. Tests for cranial-nerve dysfunction are clinically important in a neurological examination.

Spinal Nerves (pp. 413–415)

1. Each of the 31 pairs of spinal nerves is formed by the union of an anterior (ventral) and posterior (dorsal) spinal root that emerges from the spinal cord through an intervertebral foramen to innervate a body dermatome.
2. The spinal nerves are grouped according to the levels of the spinal column from which they arise, and they are numbered in sequence.
3. Each spinal nerve is a mixed nerve consisting of a posterior root of sensory fibers and an anterior root of motor fibers.
4. Just beyond its intervertebral foramen, each spinal nerve divides into several branches.

Nerve Plexuses (pp. 415–425)

1. Except in thoracic nerves T2 through T12, the anterior rami of the spinal nerves combine and then split again as networks of nerves called plexuses.
   (a) There are four plexuses of spinal nerves: the cervical, the brachial, the lumbar, and the sacral.
   (b) Nerves that emerge from the plexuses are named according to the structures they innervate or the general course they take.
2. The cervical plexus is formed by the anterior rami of C1 through C4 and a portion of C5.
3. The brachial plexus is formed by the anterior rami of C5 through T1, and occasionally by some fibers from C4 and T2.
   (a) The brachial plexus is divided into roots, trunks, divisions, and cords.
   (b) The axillary, radial, musculocutaneous, ulnar, and median are the five largest nerves arising from the brachial plexus.
4. The lumbar plexus is formed by the anterior rami of L1 through L4 and by some fibers from T12.
   (a) The lumbar plexus is divided into roots and divisions.
   (b) The femoral and obturator are two important nerves arising from the lumbar plexus.
5. The sacral plexus is formed by the anterior rami of L4, L5, and S1 through S4.
   (a) The sacral plexus is divided into roots and divisions.
   (b) The sciatic nerve, composed of the common fibular and tibial nerves, arises from the sacral plexus.
   (c) The lumbar plexus and the sacral plexus are collectively referred to as the lumbosacral plexus.

Reflex Arc and Reflexes (pp. 427–431)

1. The conduction pathway of a reflex arc consists of a receptor, a sensory neuron, a motor neuron and its innervation in the PNS, and a center containing one or more association neurons in the CNS. The reflex arc enables a rapid, automatic response to a potentially threatening stimulus.
2. A reflex arc is the simplest type of nerve pathway.
3. Visceral reflexes cause smooth or cardiac muscle to contract or glands to secrete.
4. Somatic reflexes cause skeletal muscles to contract.
   (a) The stretch reflex is a monosynaptic reflex arc.
   (b) The flexor reflex is a polysynaptic reflex arc.

Review Activities

Objective Questions

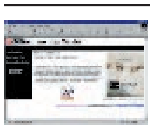
1. Which of the following is a *false* statement concerning the peripheral nervous system?
   (a) It consists of cranial and spinal nerves only.
   (b) It contains components of the autonomic nervous system.
   (c) Sensory receptors, nerves, ganglia, and plexuses are all part of the PNS.
2. An inability to cross the eyes would most likely indicate a problem with which cranial nerve?
   (a) the optic nerve
   (b) the oculomotor nerve
   (c) the abducens nerve
   (d) the facial nerve
3. Which cranial nerve innervates the muscle that raises the upper eyelid?
   (a) the trochlear nerve
   (b) the oculomotor nerve
   (c) the abducens nerve
   (d) the facial nerve
4. The inability to walk a straight line may indicate damage to which cranial nerve?
   (a) the trigeminal nerve
   (b) the facial nerve
   (c) the vestibulocochlear nerve
   (d) the vagus nerve
5. Which cranial nerve passes through the stylomastoid foramen?
   (a) the facial nerve
   (b) the glossopharyngeal nerve
   (c) the vagus nerve
   (d) the hypoglossal nerve
6. Which of the following cranial nerves does *not* contain parasympathetic fibers?
   (a) the oculomotor nerve
   (b) the accessory nerve
   (c) the vagus nerve
   (d) the facial nerve
7. Which of the following is *not* a spinal nerve plexus?
   (a) the cervical plexus
   (b) the brachial plexus
   (c) the thoracic plexus
   (d) the lumbar plexus
   (e) the sacral plexus
8. Roots, trunks, divisions, and cords are characteristic of
   (a) the sacral plexus.
   (b) the thoracic plexus.
   (c) the lumbar plexus.
   (d) the brachial plexus.
9. Which of the following nerve-plexus associations is *incorrect?*
   (a) median/sacral
   (b) phrenic/cervical
   (c) axillary/brachial
   (d) femoral/lumbar
10. Extending the knee joint when the patellar ligament is tapped is an example of
    (a) a visceral reflex.
    (b) a flexor reflex.
    (c) an ipsilateral reflex.
    (d) a crossed extensor reflex.

Essay Questions

1. Explain the structural and functional relationships between the central nervous system, the autonomic nervous system, and the peripheral nervous system.
2. List the cranial nerves and describe the major function(s) of each. How is each cranial nerve tested for dysfunction?
3. Describe the structure of a spinal nerve.
4. List the roots of each of the spinal plexuses. Describe where each plexus is located and state the nerves that originate from it.
5. What is a reflex arc? Explain how reflexes are important in maintaining body homeostasis.
6. Distinguish between monosynaptic, polysynaptic, ipsilateral, stretch, and flexor reflexes.

Critical-Thinking Questions

1. A person with quadriplegia from a spinal cord injury at the level of C5 can speak, digest food, breath, and regulate his or her heartbeat, yet the person cannot move muscles from the shoulder down. Explain why.
2. The doctor taps your patellar ligament with a reflex hammer and can't elicit a kick. What's the matter with you? If it's good to have your leg jump a little, is it better to have your leg jump a lot?
3. A 63-year-old truck driver made an appointment with the company doctor because of pain and numbness in his left leg. Following a routine physical exam, the physician scheduled the man for a magnetic resonance imaging of his lumbar region. The MRI indicated a herniated disc in the lumbar region. Explain how such a condition could develop and account for the man's symptoms. Discuss the possible treatment of this condition. (You may have to refer to medical textbooks in your library to find the answer.)
4. After being revived from a knockout punch during the world featherweight championship fight, the ringside physician determined that the boxer had sustained oculomotor and facial nerve damage when his right zygomatic bone was shattered from a hard left hook. What symptoms might the boxer have displayed that would cause the physician to come to this conclusion?



Visit our **Online Learning Center** at http://www.mhhe.com/vdg
for chapter-by-chapter quizzing, additional study resources, and related web links.