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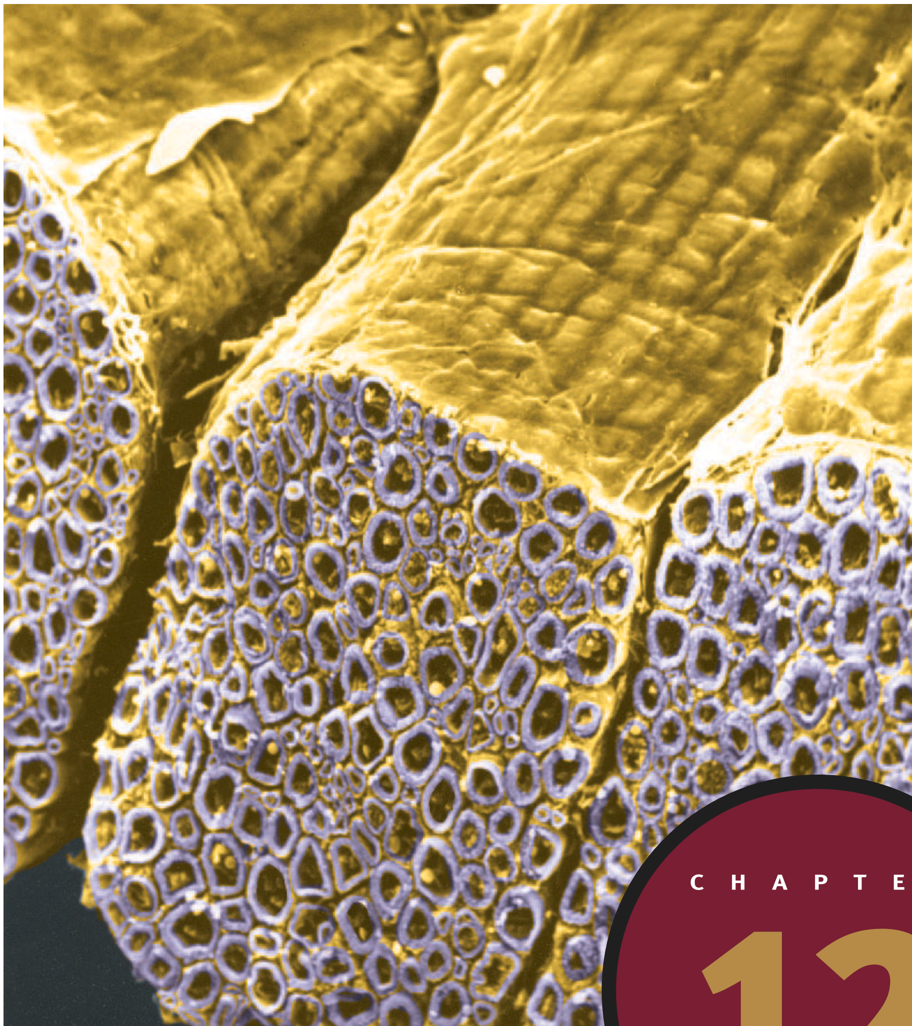


Colorized SEM of nerve fascicles containing bundles of axons.

Spinal Cord and Spinal Nerves

C H A P T E R

12

The **central nervous system (CNS)** consists of the brain and spinal cord, with the division between these two parts of the CNS placed somewhat arbitrarily at the level of the foramen magnum. The **peripheral nervous system (PNS)** consists of nerves and ganglia outside the cranial cavity and vertebral column (see chapter 11). **Nerves** are bundles of axons and their schwann cells, surrounded by connective tissue sheaths. **Ganglia** are accumulations of cell bodies in the PNS. The PNS includes 12 pairs of cranial nerves and 31 pairs of spinal nerves.

The CNS receives sensory information, evaluates that information, stores some information, and initiates reactions. The PNS collects information from numerous sources both inside and outside the body and relays it through axons of sensory neurons to the CNS. Axons of motor neurons in the PNS relay information from the CNS to various parts of the body, primarily to muscles and glands, thereby regulating activity in those structures.

The spinal cord and spinal nerves are described in this chapter. The brain and cranial nerves are considered in the next chapter. The specific topics of this chapter are the *spinal cord* (402), *reflexes* (405), *spinal cord pathways* (410), *structure of peripheral nerves* (410), and *spinal nerves* (410).

Spinal Cord

Objectives

- ***Describe the general structure and location of the spinal cord.***
- ***Describe the spinal cord in cross section, and explain the functions of each area.***

The **spinal cord** is extremely important to the overall function of the nervous system. It is the communication link between the brain and the PNS inferior to the head; it integrates incoming information and produces responses through reflex mechanisms.

General Structure

The spinal cord (figure 12.1) extends from the foramen magnum to the level of the second lumbar vertebra. It's considerably shorter than the vertebral column because it doesn't grow as rapidly as the vertebral column during development. The spinal cord is composed of cervical, thoracic, lumbar, and sacral segments, named according to the portion of the vertebral column from which their nerves enter and exit. The spinal cord gives rise to 31 pairs of spinal nerves, which exit the vertebral column through the intervertebral foramina (see figure 7.15). The nerves from the lower segments descend some distance in the vertebral canal before they exit because the spinal cord is shorter than the vertebral column.

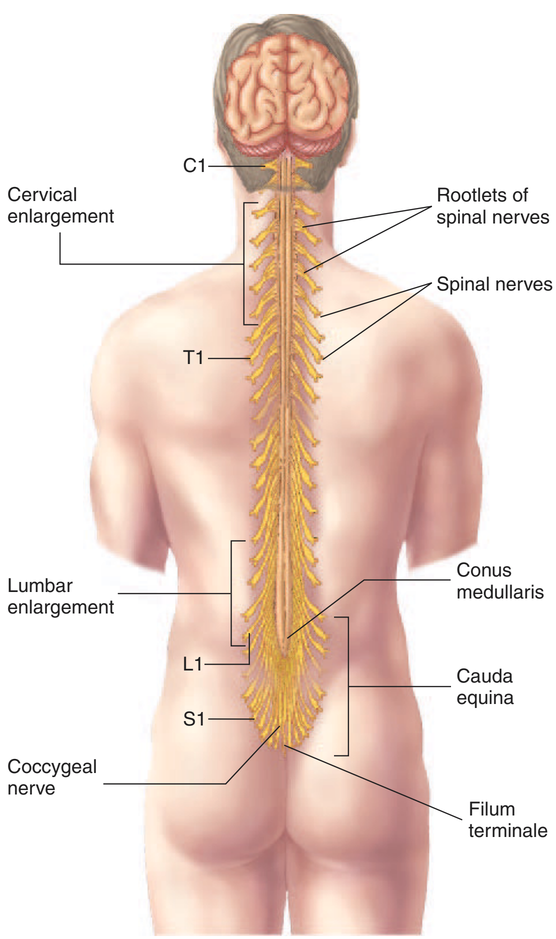


Figure 12.1 Spinal Cord and Spinal Nerve Roots

The spinal cord is not uniform in diameter throughout its length. It's larger in diameter at its superior end, and it gradually decreases in diameter toward its inferior end. Two enlargements occur where nerves supplying the upper and lower limbs enter and leave the cord (see figure 12.1). The **cervical enlargement** in the inferior cervical region corresponds to the location where axons that supply the upper limbs enter and leave the cord. The **lumbar enlargement** in the inferior thoracic and superior lumbar regions is the site where the axons supplying the lower limbs enter or leave the cord.

P R E D I C T 1

Why is the cord enlarged in the cervical and lumbar areas?

Immediately inferior to the lumbar enlargement, the spinal cord tapers to form a conelike region called the **conus medullaris.** Its tip is the inferior end of the spinal cord and extends to the level of the second lumbar vertebra. The nerves supplying the lower limbs and other inferior structures of the body arise from the second lumbar to the fifth sacral nerves. They exit the lumbar enlargement and conus medullaris, course inferiorly through the vertebral canal, and exit through the intervertebral foramina from the second lumbar to the fifth sacral vertebrae. The conus medullaris and the numerous nerves extending inferiorly from it, within the vertebral canal, resemble a horse's tail and are therefore called the **cauda** (kaw′dă, tail) **equina** (ē-kwī′nă, horse; see figure 12.1).

Meninges of the Spinal Cord

The spinal cord and brain are surrounded by connective tissue membranes called **meninges** (mĕ-nin′jēz; figure 12.2). The most superficial and thickest membrane is the **dura mater** (doo′ră mā′ter; tough mother). The dura mater surrounds the spinal cord and is continuous with the epineurium of the spinal nerves (discussed on p. 410). The dura mater around the spinal cord is separated from the periosteum of the vertebral canal by the **epidural space.** This is a true space around the spinal cord that contains blood vessels, areolar connective tissue, and fat. **Epidural anesthesia** of the spinal nerves is induced by injecting anesthetics into this space. Epidural anesthesia is often given to women during childbirth.

The next meningeal membrane is a very thin, wispy **arachnoid** (ă-rak′noyd; spiderlike; i.e., cobwebs) **mater.** The space between this membrane and the dura mater is the **subdural space** and contains only a very small amount of serous fluid.

The third meningeal layer, the **pia** (pī′ă; affectionate) **mater** is bound very tightly to the surface of the brain and spinal cord. Beyond the conus medullaris, the pia mater forms the **filum terminale** (fī′lŭm ter′mi-nal′ē), a connective tissue filament, which extends inferiorly to the coccyx where it anchors the spinal cord.

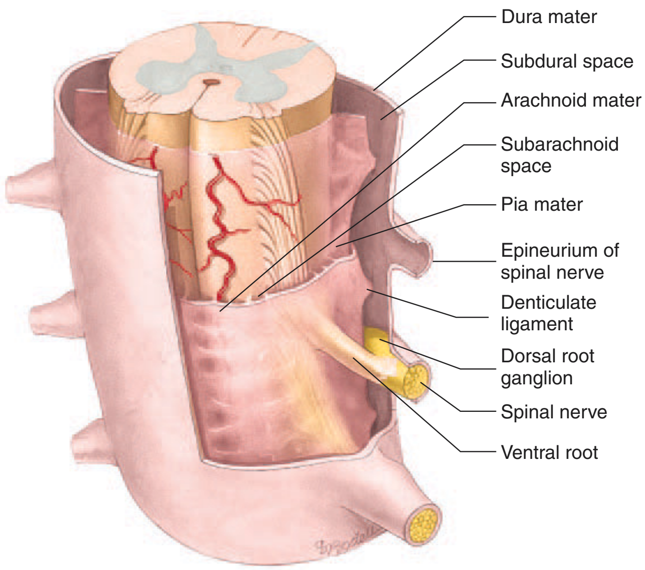


Figure 12.2 Meningeal Membranes Surrounding the Spinal Cord

Between the arachnoid mater and the pia mater is the **subarachnoid space,** which contains weblike strands of the arachnoid mater, blood vessels, and **cerebrospinal** (ser′ĕ-brō-spī-năl, sĕ-rē′brō-spī-nal) **fluid (CSF),** which is described in chapter 13.

The spinal cord is held in place within the vertebral canal by a series of connective tissue strands connecting the pia mater to the dura mater. This causes the arachnoid mater to form points between the upper spinal nerves. Because the points create a "toothed" appearance, these attachments are called **denticulate** (den-tik′ū-lāt) **ligaments** (see figure 12.2).

Introduction of Needles into the Subarachnoid Space

Several clinical procedures involve the insertion of a needle into the subarachnoid space inferior to the level of the second lumbar vertebra. The needle doesn't contact the spinal cord because it extends only approximately to the second lumbar vertebra of the vertebral column, but the subarachnoid space extends to level S2 of the vertebral column. Nor does the needle damage the nerves of the cauda equina located in the subarachnoid space, because the needle quite easily pushes the nerves aside. In **spinal anesthesia,** or spinal block, drugs that block action potential transmission are introduced into the subarachnoid space to prevent pain sensations in the lower half of the body. A **spinal tap** is the removal of CSF from the subarachnoid space. A spinal tap may be performed to examine the CSF for infectious agents (meningitis), for the presence of blood (hemorrhage), or for the measurement of CSF pressure. A radiopaque substance may also be injected into this area, and a **myelogram** (radiograph of the spinal cord) may be taken to visualize spinal cord defects or damage.

Cross Section of the Spinal Cord

A cross section of the spinal cord reveals that the cord consists of a peripheral white portion and a central gray portion (figure 12.3). The white matter consists of myelinated axons forming nerve tracts, and the gray matter consists of neuron cell bodies, dendrites, and axons. An **anterior median fissure** and a **posterior median sulcus** are deep clefts partially separating the two halves of the cord. The white matter in each half of the spinal cord is organized into three **columns,** or **funiculi** (fū-nik′ū-lī), called the **ventral** (anterior), **dorsal** (posterior), and **lateral columns.** Each column is subdivided into **nerve tracts** or **fasciculi** (fă-sik′ū-lī); also referred to as **pathways.** Individual axons ascending to the brain or descending from the brain are usually grouped together within the nerve tracts. Axons within a given nerve tract carry basically the same type of information, although they may overlap to some extent. For example, one ascending nerve tract carries action potentials related to pain and temperature sensations, whereas another functions to carry action potentials related to light touch.

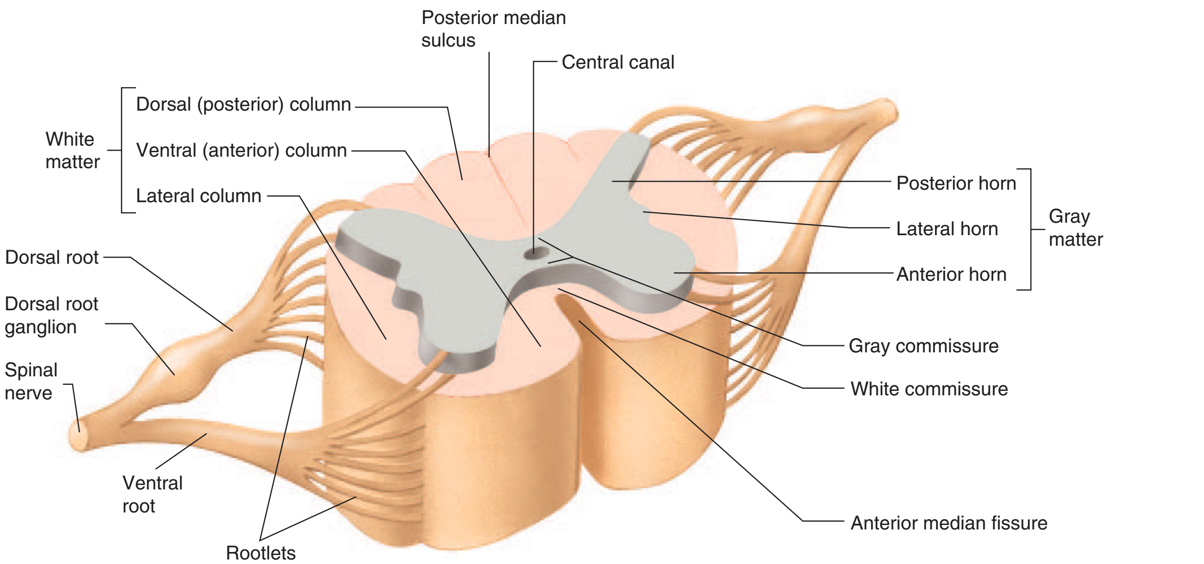
The central gray matter is organized into horns. Each half of the central gray matter of the spinal cord consists of a relatively thin **posterior** (dorsal) **horn** and a larger **anterior** (ventral) **horn.** Small **lateral horns** exist in levels of the cord associated with the autonomic nervous system (see chapter 16). The two halves of the spinal cord are connected by **gray** and **white commissures** (see figure 12.3). The white and gray commissures contain axons that cross from one side of the spinal cord to the other. The **central canal** is in the center of the gray commissure.

Spinal nerves arise from numerous rootlets along the dorsal and ventral surfaces of the spinal cord (see figure 12.3). About six to eight of these rootlets combine to form each **ventral root** on the ventral (anterior) side of the spinal cord, and another six to eight form each **dorsal root** on the dorsal (posterior) side of the cord at each segment. The ventral and dorsal roots join one another just lateral to the spinal cord to form a spinal nerve. Each dorsal root contains a ganglion, called the **dorsal root,** or **spinal, ganglion** (gang′glē-on; a swelling or knot).

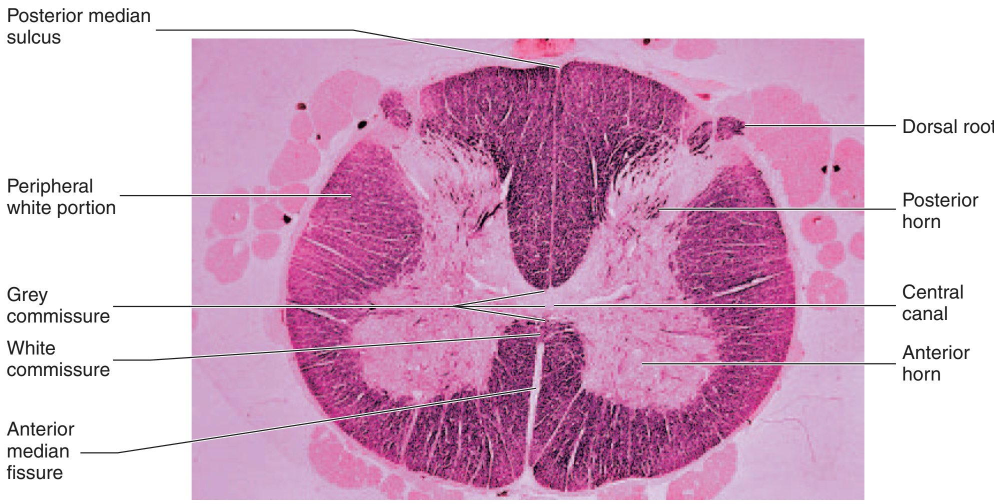
Organization of Neurons in the Spinal Cord and Spinal Nerves

The cell bodies of sensory neurons are in the dorsal root ganglia (figure 12.3c). The axons of these unipolar neurons extend from various parts of the body and pass through spinal nerves to the dorsal root ganglia. The axons do not synapse in the dorsal root ganglion but pass through the dorsal root and project into the posterior horn of the spinal cord gray matter. The axons either synapse with interneurons in the posterior horn or pass into the white matter and ascend or descend in the spinal cord.

The cell bodies of motor neurons, which supply muscles and glands, are located in the anterior and lateral horns of the spinal cord gray matter (see figure 12.3c). Multipolar somatic motor neurons are in the anterior horn, also called the motor horn, and autonomic neurons are in the lateral horn. Axons from the motor neurons form the ventral roots and pass into the spinal nerves. Thus, dorsal roots contain sensory axons, ventral roots contain motor axons, and spinal nerves have both sensory and motor axons.



(a)



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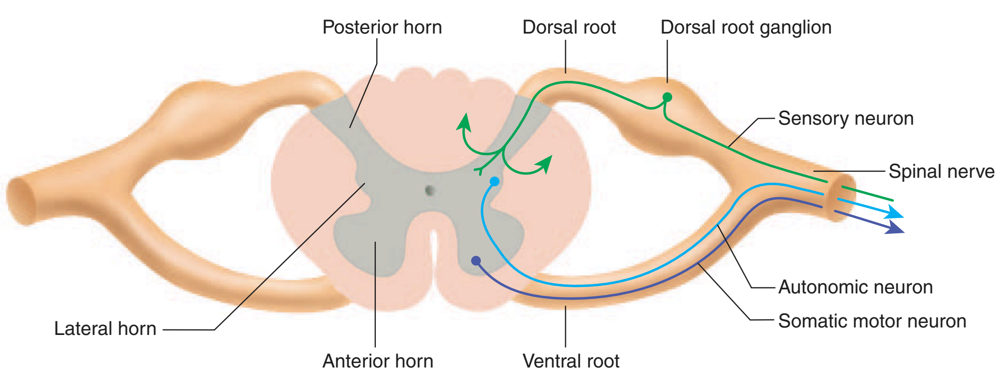


(c)

Figure 12.3 **Cross Section of the Spinal Cord**

(*a*) A 3-D drawing of a segment of the spinal cord showing one dorsal and one ventral root on each side and the rootlets that form them. (*b*) Photograph of a cross section through the midlumbar region. The *darker-colored areas* are white matter, where tracts are located. The *lighter area* is gray matter, where neuron cell bodies are located. (*c*) Relationship of sensory and motor neurons to the spinal cord.

1. *Describe the cervical and lumbar enlargements of the spinal cord, the conus medullaris, and the cauda equina. How many pairs of spinal nerves exit the spinal cord?*
2. *Name the meninges surrounding the spinal cord. What is found within the epidural, subdural, and subarachnoid spaces?*
3. *How is the spinal cord held within the vertebral canal?*
4. *Explain the arrangement of white matter in the spinal cord. What are commissures?*
5. *Describe the spinal cord gray matter. Where are sensory, somatic motor, and autonomic neuron cell bodies located in the gray matter?*
6. *Where do dorsal and ventral roots exit the spinal cord? What kinds of axons are in the dorsal and ventral roots and in the spinal nerves?*

P R E D I C T 2

Explain why the dorsal root ganglia are larger in diameter than the dorsal roots.

Reflexes

Objective

- *List the components and characteristics of a reflex.*

The basic structural unit of the nervous system is the neuron. The **reflex arc** is the basic functional unit of the nervous system and is the smallest, simplest portion capable of receiving a stimulus and producing a response. The reflex arc has five basic components: (1) a sensory receptor, (2) a sensory neuron, (3) an interneuron, (4) a motor neuron, and (5) an effector organ (figure 12.4).

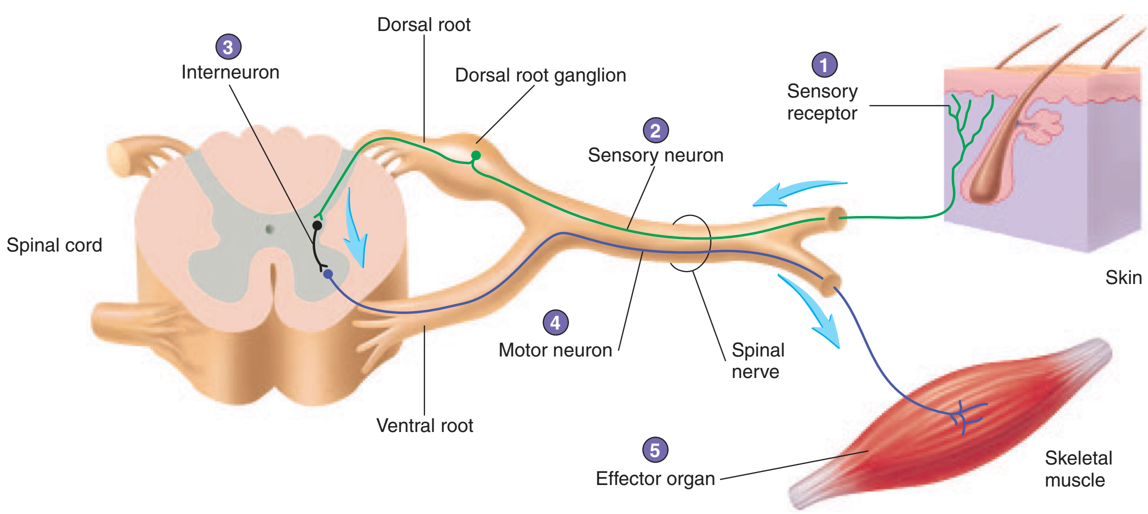
Action potentials initiated in sensory receptors are transmitted along the axons of sensory neurons to the CNS, where the axons usually synapse with interneurons. Interneurons synapse with motor neurons, which send axons out of the spinal cord and through the PNS to muscles or glands, where the action potentials of the motor neurons cause effector organs to respond. The response produced by the reflex arc is called a **reflex.** It's an automatic response to a stimulus that occurs without conscious thought.

Reflexes are, in general, homeostatic. Some function to remove the body from painful stimuli that would cause tissue damage, and others function to keep the body from suddenly falling or moving because of external forces. A number of reflexes are responsible for maintaining relatively constant blood pressure, blood carbon dioxide levels, and water intake.

Individual reflexes vary in their complexity. Some involve simple neuronal pathways and few or even no interneurons, whereas others involve complex pathways and integrative centers. Many are integrated within the spinal cord, and others are integrated within the brain. Some reflexes involve excitatory neurons and result in a response, such as when a muscle contracts (see chapter 11). Other reflexes involve inhibitory neurons and result in inhibition of a response, such as when a muscle relaxes. In addition, higher brain centers influence reflexes by either suppressing or exaggerating them. Major spinal cord reflexes include the stretch reflex, the Golgi tendon reflex, the withdrawal reflex, and the crossed extensor reflex.

Stretch Reflex

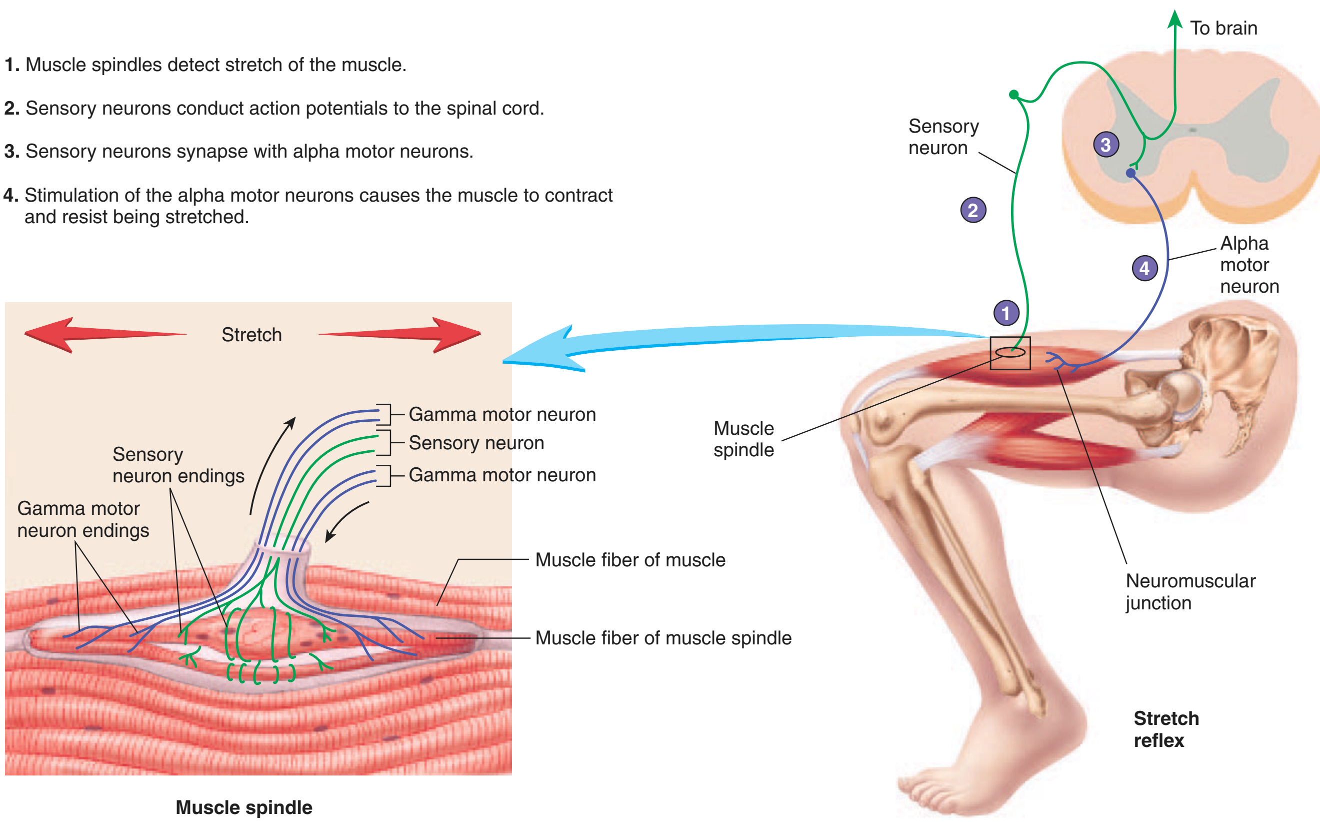
The simplest reflex is the **stretch reflex** (figure 12.5), a reflex in which muscles contract in response to a stretching force applied to them. The sensory receptor of this reflex is the **muscle spindle,** which consists of 3–10 small, specialized skeletal muscle cells. The cells are contractile only at their ends and are innervated by specific motor neurons called **gamma motor neurons** (the term *gamma* refers to motor neurons with small diameter axons) originating from the spinal cord and controlling contraction of the ends of the muscle spindle cells. Sensory neurons



Process Figure 12.4 Reflex Arc

The parts of a reflex arc are labeled in the order in which action potentials pass through them. The five components are the (1) sensory receptor, (2) sensory neuron, (3) interneuron, (4) motor neuron, and (5) effector organ.

1. Muscle spindles detect stretch of the muscle.
2. Sensory neurons conduct action potentials to the spinal cord.
3. Sensory neurons synapse with alpha motor neurons.
4. Stimulation of the alpha motor neurons causes the muscle to contract and resist being stretched.



Process Figure 12.5 Stretch Reflex

innervate the noncontractile centers of the muscle spindle cells. Axons of these sensory neurons synapse directly with motor neurons in the spinal cord called **alpha motor neurons** (the term *alpha* refers to motor neurons with large diameter axons), which in turn innervate the muscle in which the muscle spindle is embedded. The stretch reflex is unique because there is no interneuron between the sensory and motor neurons.

Stretching a muscle also stretches muscle spindles located among the muscle fibers. The stretch stimulates the sensory neurons that innervate the center of each of the muscle spindles. The increased frequency of action potentials in the sensory neurons stimulates the alpha motor neurons in the spinal cord. The alpha motor neurons transmit action potentials to skeletal muscle, causing a rapid contraction of the stretched muscle, which opposes the stretch of the muscle. The postural muscles demonstrate the adaptive nature of this reflex. If a person is standing upright and then bends slightly to one side, the postural muscles associated with the vertebral column on the other side are stretched. As a result, stretch reflexes are initiated in those muscles, which cause them to contract and reestablish normal posture.

Collateral axons from the sensory neurons of the muscle spindles also synapse with neurons whose axons contribute to ascending nerve tracts, which enable the brain to perceive that a muscle has been stretched (see p. 412). Descending neurons within the spinal cord synapse with the neurons of the stretch reflex modifying their activity. This activity is important in maintaining posture and in coordinating muscular activity.

Gamma motor neurons are responsible for regulating the sensitivity of the muscle spindles. As a skeletal muscle contracts, the tension on the centers of muscle spindles within the muscle decreases because the muscle spindles passively shorten as the muscle shortens. The decrease in tension in the centers of the muscle spindles cause them to be less sensitive to stretch. Sensitivity is maintained because at the same time alpha motor neurons are stimulating the muscle to contract, gamma motor neurons stimulate the muscle spindles to contract. The contraction of the muscle fibers at the ends of the muscle spindles pulls on the center part of the muscle spindles and maintains the proper tension. The activity of the muscle spindles help control and coordinate muscular activity, such as posture, muscle tension, and muscle length.

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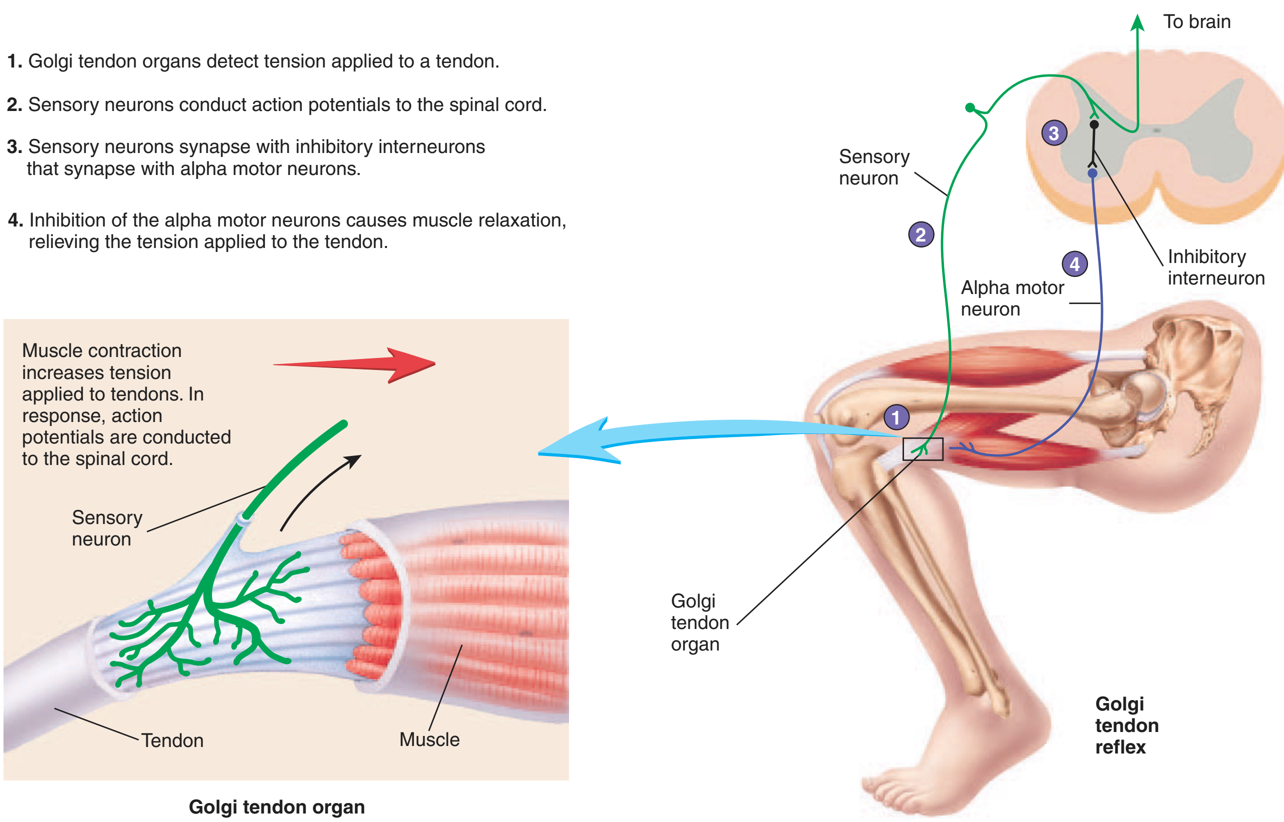
Knee-Jerk Reflex

The **knee-jerk reflex,** or **patellar reflex,** is a classic example of the stretch reflex. Clinicians use this reflex to determine whether the higher CNS centers that normally influence this reflex are functional. When the patellar ligament is tapped, the tendons and muscles of the quadriceps femoris muscle group are stretched. The muscle spindle fibers within these muscles are also stretched, and the stretch reflex is activated. Consequently, contraction of the muscles extends the leg, thus producing the characteristic knee-jerk response. When the stretch reflex is greatly exaggerated, it indicates that the neurons within the brain that innervate the gamma motor neurons and enhance the stretch reflex are overly active. On the other hand, if the neurons that innervate the gamma motor neurons are depressed, the stretch reflex can be suppressed or absent. Absence of the stretch reflex may indicate that the reflex pathway is not intact.

Golgi Tendon Reflex

The **Golgi tendon reflex** prevents contracting muscles from applying excessive tension to tendons. **Golgi tendon organs** are encapsulated nerve endings that have at their ends numerous terminal branches with small swellings associated with bundles of collagen fibers in tendons. The Golgi tendon organs are located within tendons near the muscle–tendon junction (figure 12.6). As a muscle contracts, the attached tendons are stretched, resulting in increased tension in the tendon. The increased tension stimulates action potentials in the sensory neurons from the Golgi tendon organs. Golgi tendon organs have a high threshold and are sensitive only to intense stretch.

The sensory neurons of the Golgi tendon organs pass through the dorsal root to the spinal cord and enter the posterior gray matter, where they branch and synapse with inhibitory interneurons. The interneurons synapse with alpha motor neurons that innervate the muscle to which the Golgi tendon organ is attached. When a great amount of tension is applied to the tendon, the sensory neurons of the Golgi tendon organs are stimulated. The sensory neurons stimulate the interneurons to release inhibitory neurotransmitters which inhibit the alpha motor neurons of the associated muscle and causes it to relax. This reflex protects muscles and tendons from damage caused by excessive tension. The sudden relaxation of the muscle reduces the tension applied to the muscle and tendons. A weight lifter who suddenly drops a heavy weight after straining to lift it does so, in part, because of the effect of the Golgi tendon reflex.



Process Figure 12.6 Golgi Tendon Reflex

Tremendous amounts of tension can be applied to muscles and tendons in the legs. Frequently an athlete's Golgi tendon reflex is inadequate to protect muscles and tendons from excessive tension. The large muscles and sudden movements of football players and sprinters can make them vulnerable to relatively frequent hamstring pulls and calcaneal (Achilles) tendon injuries.

Withdrawal Reflex

The function of the **withdrawal,** or **flexor, reflex** is to remove a limb or other body part from a painful stimulus. The sensory receptors are pain receptors (see chapter 15). Action potentials from painful stimuli are conducted by sensory neurons through the dorsal root to the spinal cord, where they synapse with excitatory interneurons, which in turn synapse with alpha motor neurons (figure 12.7). The alpha motor neurons stimulate muscles, usually flexor muscles, that remove the limb from the source of the painful stimulus. Collateral branches of the sensory neurons synapse with ascending fibers to the brain, providing conscious awareness of the painful stimuli.

Reciprocal Innervation

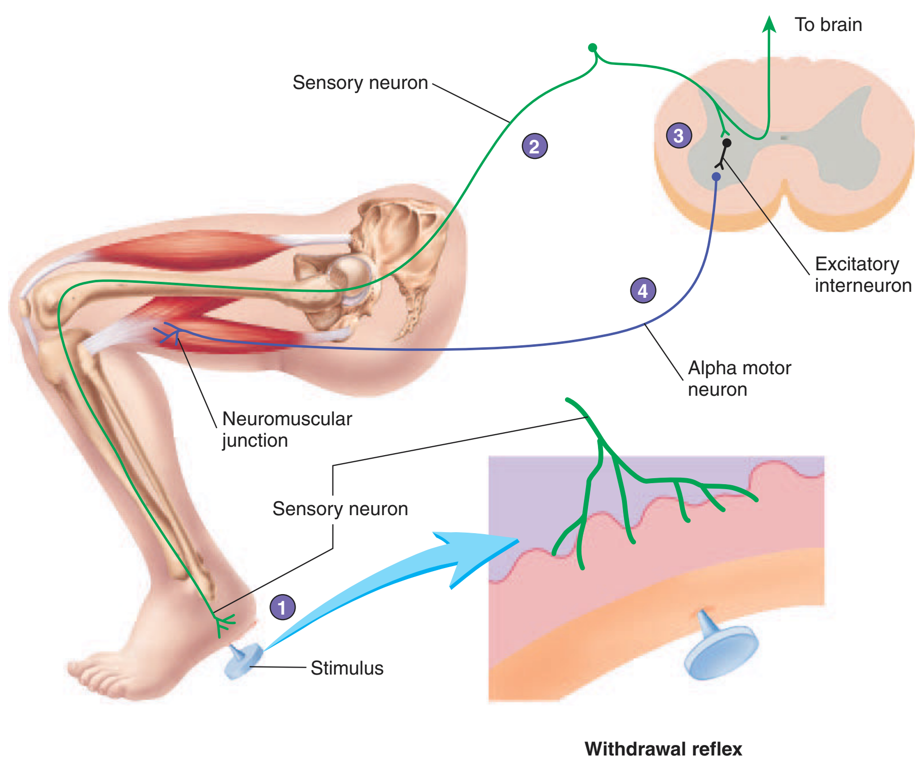
Reciprocal innervation is associated with the withdrawal reflex and reinforces its efficiency (figure 12.8). Collateral axons of sensory neurons that carry action potentials from pain receptors synapse with inhibitory interneurons in the dorsal horn of the spinal cord, which synapse with and inhibit alpha motor neurons of extensor (antagonist) muscles. When the withdrawal reflex is initiated, flexor muscles contract, and reciprocal innervation causes relaxation of the extensor muscles. This reduces the resistance to movement that the extensor muscles would otherwise generate.

Reciprocal innervation is also involved in the stretch reflex. When the stretch reflex causes a muscle to contract, reciprocal innervation causes opposing muscles to relax. In the patellar reflex, for example, the quadriceps femoris muscle contracts and the hamstring muscles relax.

Crossed Extensor Reflex

The **crossed extensor reflex** is another reflex associated with the withdrawal reflex (figure 12.9). Interneurons that stimulate alpha motor neurons, resulting in withdrawal of a limb, have collateral axons that extend through the white commissure to the opposite side of the spinal cord and synapse with alpha motor neurons that innervate extensor muscles in the opposite side of the body. When a withdrawal reflex is initiated in one lower limb, the crossed extensor reflex causes extension of the opposite lower limb.

1. Pain receptors detect a painful stimulus.
2. Sensory neurons conduct action potentials to the spinal cord.
3. Sensory neurons synapse with excitatory interneurons that synapse with alpha motor neurons.
4. Excitation of the alpha motor neurons results in contraction of the flexor muscles and withdrawal of the limb from the painful stimulus.



Process Figure 12.7 Withdrawal Reflex

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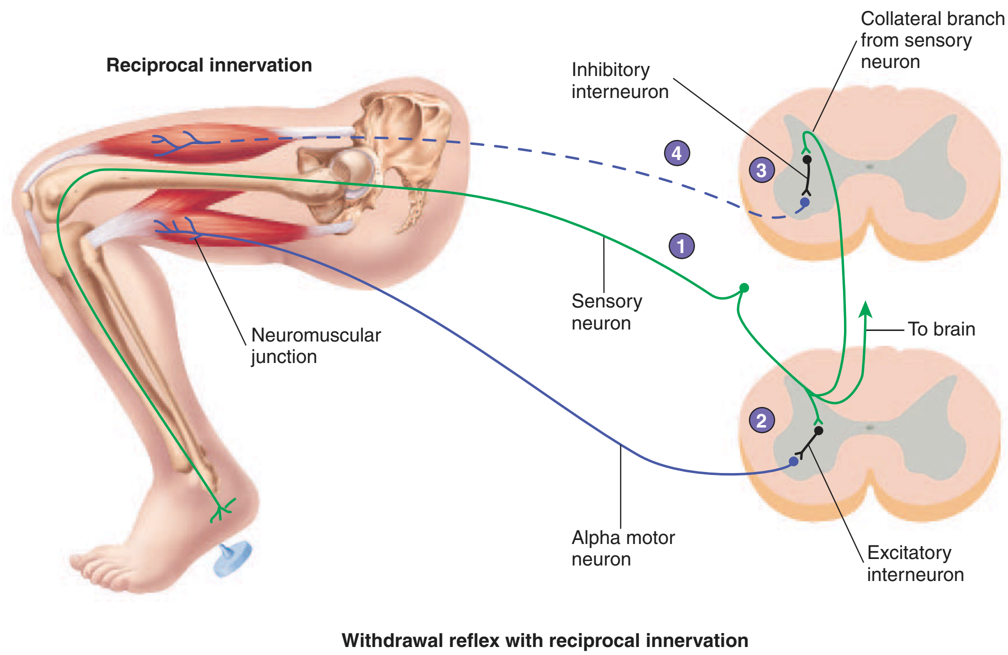
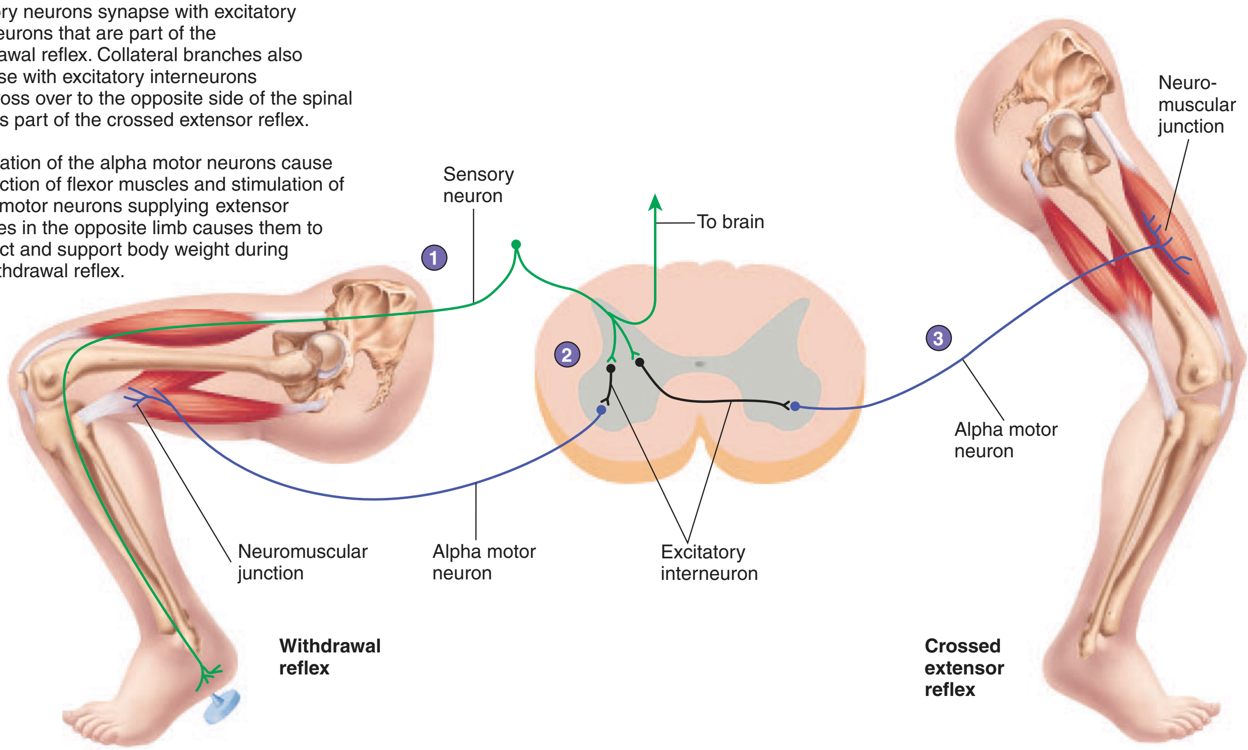
1. During the withdrawal reflex, sensory neurons conduct action potentials to the spinal cord.
2. Sensory neurons synapse with excitatory interneurons that are part of the withdrawal reflex.
3. Collateral branches also synapse with inhibitory interneurons that are part of reciprocal innervation.
4. Inhibition of the alpha motor neurons supplying the extensor muscles causes them to relax and not oppose the flexor muscles of the withdrawal reflex.



Process Figure 12.8 Withdrawal Reflex with Reciprocal Innervation

1. During the withdrawal reflex, sensory neurons conduct action potentials to the spinal cord.
2. Sensory neurons synapse with excitatory interneurons that are part of the withdrawal reflex. Collateral branches also synapse with excitatory interneurons that cross over to the opposite side of the spinal cord as part of the crossed extensor reflex.
3. Stimulation of the alpha motor neurons cause contraction of flexor muscles and stimulation of alpha motor neurons supplying extensor muscles in the opposite limb causes them to contract and support body weight during the withdrawal reflex.



Process Figure 12.9 Withdrawal Reflex with Crossed Extensor Reflex

The crossed extensor reflex is adaptive in that it helps prevent falls by shifting the weight of the body from the affected to the unaffected limb. For example, when a person steps on a sharp object, the affected limb is withdrawn from the stimulus (withdrawal reflex) while the other limb is extended (crossed extensor reflex). Therefore, when a person steps on a sharp object with the right foot, the body weight is shifted from the right to the left lower limb. Initiating a withdrawal reflex in both legs at the same time would cause one to fall.

7. Contrast and give the functions of a stretch reflex and a Golgi tendon reflex. Describe the sensory receptors for each.
8. Describe the operation of gamma motor neurons. What do they accomplish?
9. What is a withdrawal reflex? How do reciprocal innervation and the crossed extensor reflex assist the withdrawal reflex?

Spinal Cord Pathways

Objective

- *Describe and give examples of how convergent and divergent pathways interact with reflexes.*

Reflexes do not operate as isolated entities within the nervous system because of divergent and convergent pathways (see chapter 11). Diverging branches of the sensory neurons or interneurons in a reflex arc send action potentials along ascending nerve tracts to the brain (figure 12.10). A pain stimulus, for example, not only initiates a withdrawal reflex, which removes the affected part of the body from the painful stimulus, but also causes perception of the pain sensation as a result of action potentials sent to the brain.

Axons within descending tracts from the brain carry action potentials to motor neurons in the anterior horn of the spinal cord, converging with neurons of reflex arcs. The neurotransmitters released from the axons of these tracts either stimulate or inhibit the motor neurons in the anterior horn. Neurotransmitters change the sensitivity of the reflex by stimulating (EPSP) or inhibiting (IPSP) the motor neurons. Various ascending and descending tracts occupy specific areas of the spinal cord (figure 12.11).

10. How do ascending and descending pathways relate to reflexes and other neuron functions?

Structure of Peripheral Nerves

Objective

- *Describe the structure of a peripheral nerve.*

Peripheral nerves consist of axon bundles Schwann cells, and connective tissue (figure 12.12). Each axon, or nerve fiber, and its Schwann cell sheath are surrounded by a delicate connective tissue layer, the **endoneurium** (en-dō-noo′rē-ŭm). A heavier connective tissue layer, the **perineurium** (per-i-noo′rē-ŭm), surrounds groups of axons to form nerve **fascicles** (fas′i-klz). A third layer of dense connective tissue, the **epineurium** (ep-i-noo′rē-ŭm), binds the nerve fascicles together to form a nerve. The connective tissue layers of nerves make them tougher than the nerve tracts of the CNS.

11. Describe the structure of peripheral nerves.

Spinal Nerves

Objectives

- *Describe the structure and explain the naming of the spinal nerves.*
- *Describe dorsal roots, ventral roots, dorsal rami, and ventral rami of spinal nerves.*
- *Describe plexuses, and outline the pattern and distribution of intercostal nerves.*
- *Describe the structure, distribution, and function of the cervical, brachial, lumbosacral, and coccygeal plexuses.*

All of the 31 pairs of spinal nerves, except the first pair and those in the sacrum, exit the vertebral column through intervertebral foramena located between adjacent vertebrae. The first pair of spinal nerves exits between the skull and the first cervical vertebra. The nerves of the sacrum exit from the single bone of the sacrum through the sacral foramina (see chapter 7). Eight spinal nerve pairs exit the vertebral column in the cervical region, 12 in the thoracic region, 5 in the lumbar region, 5 in the sacral region, and 1 in the coccygeal region (figure 12.13). For convenience, each of the spinal nerves is designated by a letter and number. The letter indicates the region of the vertebral

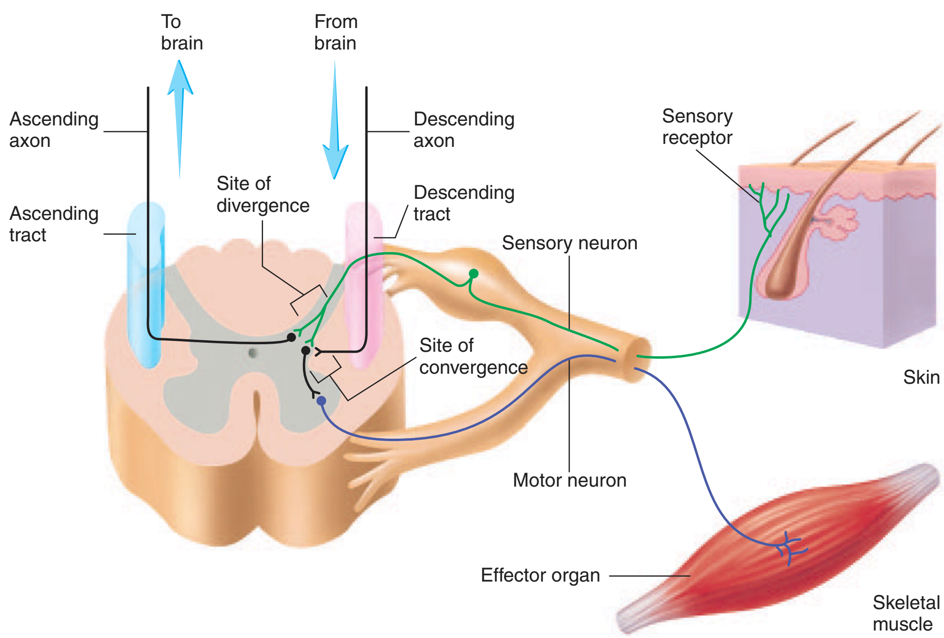


Figure 12.10 Spinal Reflex, with Ascending and Descending Axons

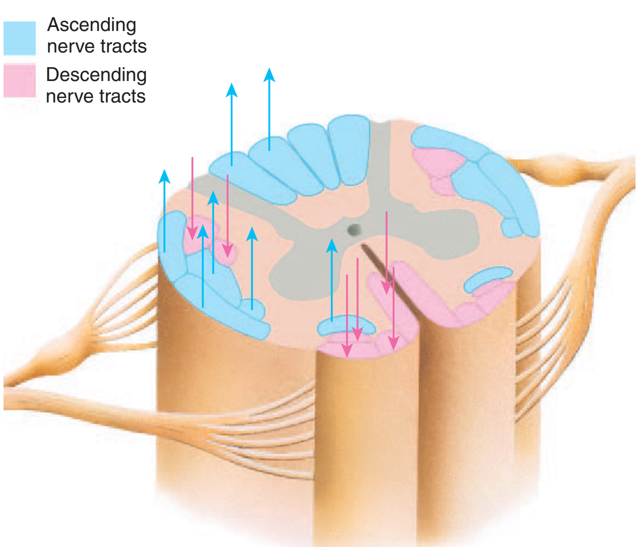


Figure 12.11 Cross Section of the Spinal Cord at the Cervical Level Depicting the Pathways

Ascending nerve tracts are *blue,* descending nerve tracts are *pink.* The arrows indicate the direction of each pathway.

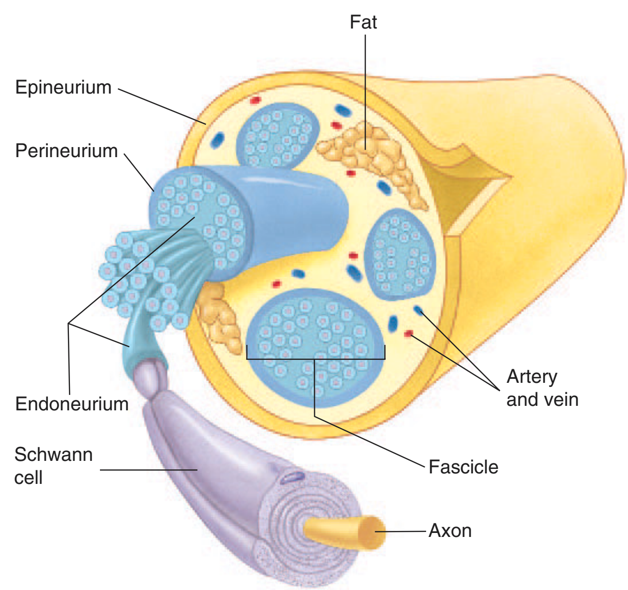


Figure 12.12 Structure of a Peripheral Nerve

Nerve structure illustrating axons surrounded by various layers of connective tissue: epineurium around the whole nerve, perineurium around nerve fascicles, and endoneurium around Schwann cells and axons.

Clinical Focus Spinal Cord Injury

Damage to the spinal cord can disrupt ascending tracts from the spinal cord to the brain, resulting in the loss of sensation, and/or descending tracts from the brain to motor neurons in the spinal cord, resulting in the loss of motor functions. About 10,000 new cases of **spinal cord injury** occur each year in the United States. Automobile and motorcycle accidents are leading causes, followed by gunshot wounds, falls, and swimming accidents. Spinal cord injury is classified according to the vertebral level at which the injury occurred, whether the entire cord is damaged at that level or only a portion of the cord, and the mechanism of injury. Most spinal cord injuries occur in the cervical region or at the thoracolumbar junction and are incomplete. The primary mechanisms include concussion (an injury caused by a blow), contusion (an injury resulting in hemorrhage), or laceration (a tear or cut) and involve excessive flexion, extension, rotation, or compression of the vertebral column. The majority of spinal cord injuries are acute contusions of the cord due to bone or disk displacement into the cord and involve a combination of excessive directional movements, such as simultaneous flexion and compression.

At the time of spinal cord injury, two types of tissue damage occur: (1) primary, mechanical damage and (2) secondary, tissue damage. Secondary spinal cord damage, which begins within minutes of the primary damage, is caused by ischemia, edema, ion imbalances, the release of "excitotoxins" such as glutamate, and inflammatory cell invasion. Secondary damage extends into a much larger region of the cord than the primary damage. It is the primary focus of current research in spinal cord injury. The only treatment for primary damage is prevention, such as wearing seat belts when riding in automobiles and not diving in shallow water. Once an accident occurs, however, little can be done at present about the primary damage. On the other hand, it's now known that much of the secondary damage can be prevented or reversed.

Until the 1950s, spinal cord injuries were often ultimately fatal. Now, with quick treatment, directed at the mechanisms of secondary tissue damage, much of the total damage to the spinal cord can be prevented. Treatment of the damaged spinal cord with large doses of methylprednisolone, a synthetic steroid, within 8 hours of the injury, can dramatically reduce the secondary damage to the cord. The objectives of these treatments are to reduce inflammation and edema. Current treatment includes anatomic realignment and stabilization of the vertebral column, decompression of the spinal cord, and administration of methylprednisolone. Rehabilitation is based on retraining the patient to use whatever residual connections exist across the site of damage.

It had long been thought that the spinal cord is incapable of regeneration following severe damage. It's now known that following injury, most neurons of the adult spinal cord survive and begin to regenerate, growing about 1 mm into the site of damage, but then they regress to an inactive, atrophic state. In addition, fetuses and newborns exhibit considerable regenerative ability and functional improvement. The major block to adult spinal cord regeneration is the formation of a scar, consisting mainly of myelin and astrocytes, at the site of injury. Myelin in the scar is apparently the primary inhibitor of regeneration. Implantation of peripheral nerves, Schwann cells, or fetal CNS tissue can bridge the scar and stimulate some regeneration. Certain growth factors can also stimulate some regeneration. Current research continues to look for the right combination of chemicals and other factors to stimulate regeneration of the spinal cord following injury.

column from which the nerve emerges: C, cervical; T, thoracic; L, lumbar; and S, sacral. The single coccygeal nerve is often not designated, but when it is, the symbol often used is Co. The number indicates the location in each region where the nerve emerges from the vertebral column, with the smallest number always representing the most superior origin. For example, the most superior nerve exiting from the thoracic region of the vertebral column is designated T1. The cervical nerves are designated C1–C8, the thoracic nerves T1–T12, the lumbar nerves L1–L5, and the sacral nerves S1–S5.

Each of the spinal nerves except C1 has a specific cutaneous sensory distribution. Figure 12.14 illustrates the **dermatomal** (der-mă-tō′măl) **map** for the sensory cutaneous distribution of the spinal nerves. A **dermatome** is the area of skin supplied with sensory innervation by a pair of spinal nerves.

P R E D I C T 3

The dermatomal map is important in clinical considerations of nerve damage. Loss of sensation in a dermatomal pattern can provide valuable information about the location of nerve damage. Predict the possible site of nerve damage for a patient who suffered whiplash in an automobile accident and subsequently developed anesthesia (no sensations) in the left arm, forearm, and hand (see figure 12.14 for help).

Figure 12.15 depicts an idealized section through the trunk. Each spinal nerve has a dorsal and a ventral **ramus** (rā′mŭs; branch). Additional rami (rā′mī), called communicating rami, from the thoracic and upper lumbar spinal cord regions carry axons associated with the sympathetic division (see chapter 16). The **dorsal rami** (rā′mī) innervate most of the deep muscles of the dorsal trunk responsible for movement of the vertebral column.

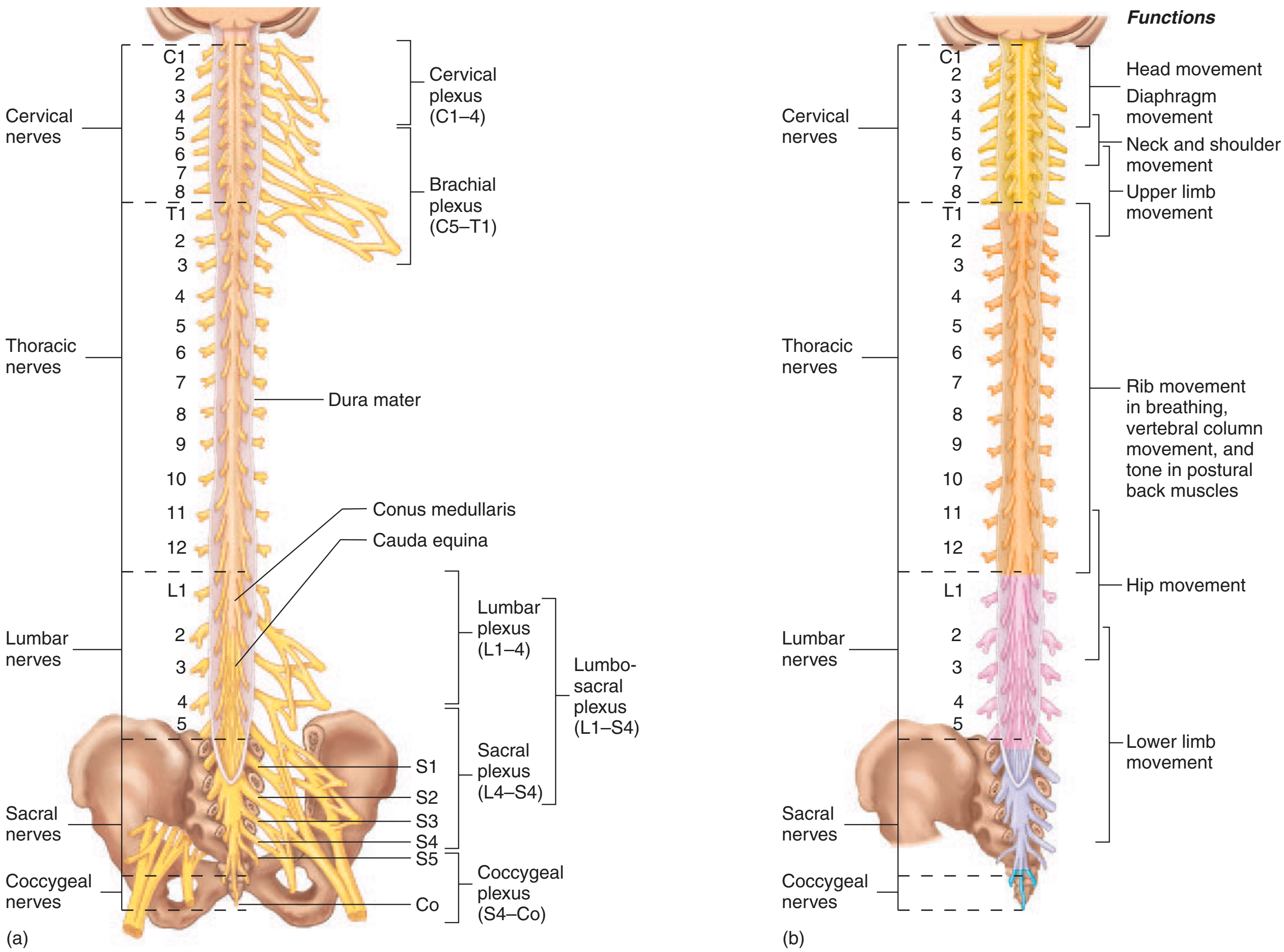


Figure 12.13 **Spinal Nerves**

(*a*) Spinal cord, the spinal nerves, their plexuses, and their branches. (*b*) Regions of the spinal cord and their general functions.

They also innervate the connective tissue and skin near the midline of the back.

The **ventral rami** are distributed in two ways. In the thoracic region, the ventral rami form **intercostal** (between ribs) **nerves,** which extend along the inferior margin of each rib and innervate the intercostal muscles and the skin over the thorax. The ventral rami of the remaining spinal nerves form five **plexuses** (plek′sŭs-ēz). The term *plexus* means braid and describes the organization produced by the intermingling of the nerves. The ventral rami of different spinal nerves, called the **roots** of the plexus, join with each other to form a plexus. These roots should not be confused with the dorsal and ventral roots from the spinal cord, which are more medial. Nerves that arise from plexuses usually have axons from more than one spinal nerve and thus more than one level of the spinal cord. The ventral rami of spinal nerves C1–C4 form the cervical plexus, C5–T1 form the brachial plexus, L1–L4 form the lumbar plexus, L4–S4 form the sacral plexus, and S4, S5, and the coccygeal nerve (Co) form the coccygeal plexus.

Several smaller somatic plexuses, such as the pudendal plexus in the pelvis, are derived from more distal branches of the spinal nerves. Some of the somatic plexuses are mentioned where appropriate in this chapter. Autonomic plexuses (described in chapter 16) also exist in the thorax and abdomen.

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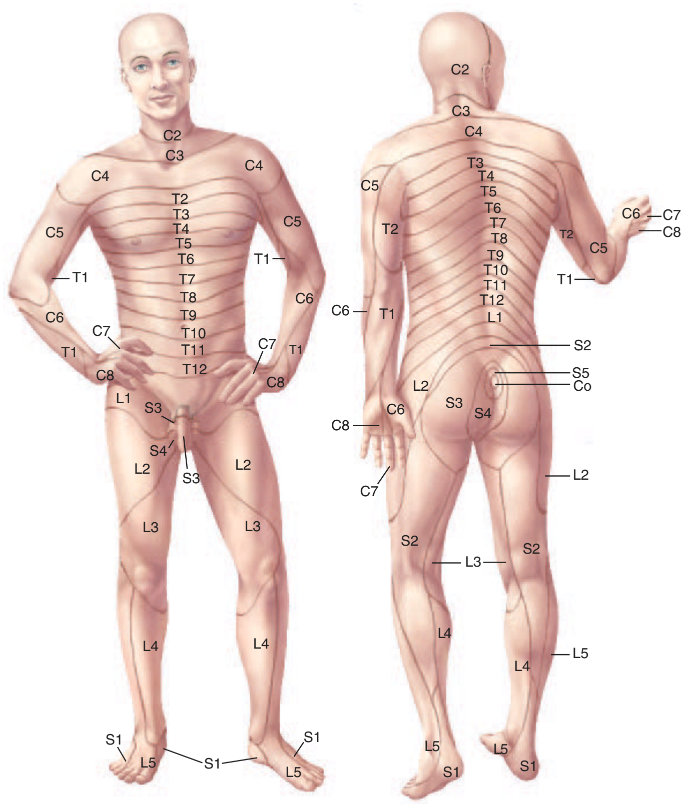

Figure 12.14 Dermatomal Map

Letters and *numbers* indicate the spinal nerves innervating a given region of skin.

12. Describe the connective tissue layers within and surrounding spinal nerves.
13. Differentiate between rootlet, dorsal root, ventral root, and spinal nerve. Indicate whether each contains motor fibers, sensory fibers, or both.
14. List all of the spinal nerves by name and number. Where do they exit the vertebral column?
15. What is a dermatome? Why are dermatomes clinically important?
16. Contrast dorsal and ventral rami of spinal nerves. What muscles do the dorsal rami innervate?
17. Describe the distribution of the ventral rami of the thoracic region.
18. What is a plexus? What happens to the axons of spinal nerves as they pass through a plexus?
19. Name the main spinal plexuses and the spinal nerves associated with each one.

Cervical Plexus

The **cervical plexus** is a relatively small plexus originating from spinal nerves C1–C4 (figure 12.16). Branches derived from this plexus innervate superficial neck structures, including several of the muscles attached to the hyoid bone. The cervical plexus innervates the skin of the neck and posterior portion of the head (see figure 12.14).

One of the most important derivatives of the cervical plexus is the **phrenic** (fren′ik) **nerve,** which originates from spinal nerves C3–C5, derived from both the cervical and brachial plexus. The phrenic nerves descend along each side of the neck to enter the thorax. They descend along the sides of the mediastinum to reach the diaphragm, which they innervate. Contraction of the diaphragm is largely responsible for the ability to breathe.

Phrenic Nerve Damage

Damage to the phrenic nerve severely limits a person’s ability to breathe. Care must be taken not to damage the phrenic nerve during open thoracic surgery or open heart surgery. Cancer of the bronchus is the most common type of cancer in men, accounting for about 30% of all male cancers, and most often occurs in men who smoke cigarettes. Tumors at the base of the lung can compress the phrenic nerve.

PREDICT 4

Explain how damage to or compression of the right phrenic nerve affects the diaphragm. Describe the effect on breathing of a completely severed spinal cord at the level of C2 versus C6.

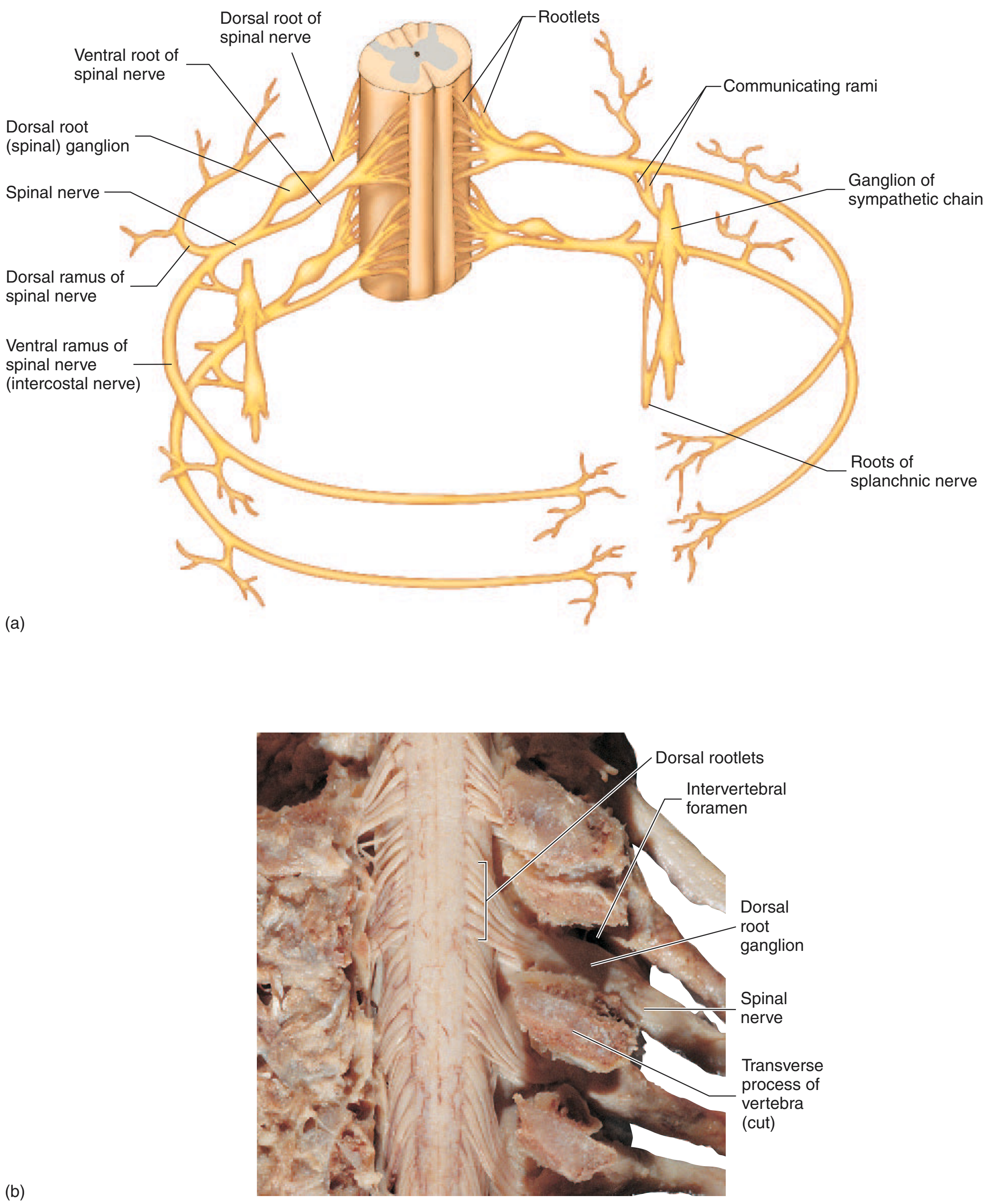

Figure 12.15 Spinal Nerves

(*a*) Typical thoracic spinal nerves. (*b*) Photograph of four dorsal roots in place along the vertebral column.

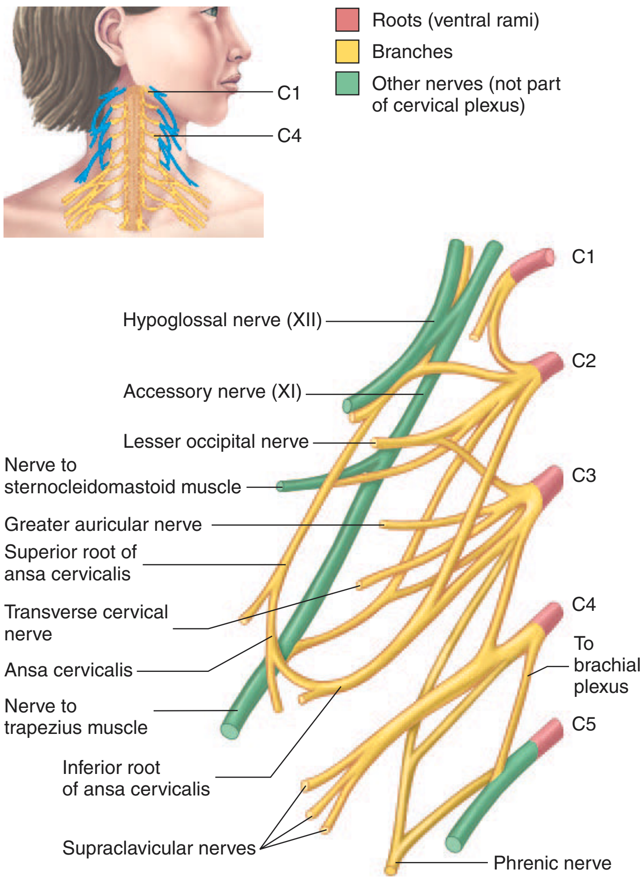

Figure 12.16 **Cervical Plexus, Anterior View**

The roots of the plexus are formed by the ventral rami of the spinal nerves C1–C4.

Brachial Plexus

The **brachial plexus** originates from spinal nerves C5–T1 (figure 12.17). A connection is also present from C4 of the cervical plexus to the brachial plexus. The five ventral rami that constitute the brachial plexus join to form three **trunks,** which separate into six **divisions** and then join again to create three **cords** (posterior, lateral, and medial) from which five **branches,** or nerves of the upper limb, emerge.

The five major nerves emerging from the brachial plexus to supply the upper limb are the axillary, radial, musculocutaneous, ulnar, and median nerves. The axillary nerve innervates part of the shoulder; the radial nerve innervates the posterior arm, forearm, and hand; the musculocutaneous nerve innervates the anterior arm; and the ulnar and median nerves innervate the anterior forearm and hand. Smaller nerves from the brachial plexus innervate the shoulder and pectoral muscles.

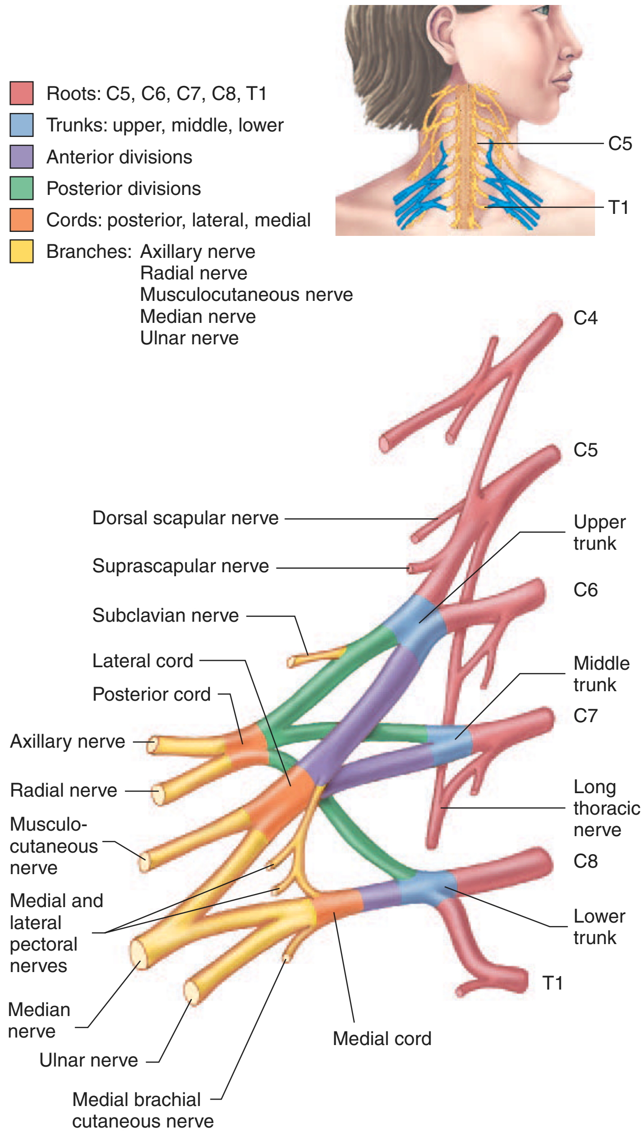

Figure 12.17 **Brachial Plexus, Anterior View**

The roots of the plexus are formed by the ventral rami of the spinal nerves C5–T1 and join to form an upper, middle, and lower trunk. Each trunk divides into anterior and posterior divisions. The divisions join together to form the posterior, lateral, and medial cords from which the major brachial plexus nerves arise.

Brachial Anesthesia

The entire upper limb can be anesthetized by injecting an anesthetic near the brachial plexus. This is called **brachial anesthesia.** The anesthetic can be injected between the neck and the shoulder posterior to the clavicle.

Axillary Nerve

The **axillary** (ak′sil-ār-ē) **nerve** innervates the deltoid and teres minor muscles (figure 12.18). It also provides sensory innervation to the shoulder joint and to the skin over part of the shoulder.

Axillary Nerve

Origin

Posterior cord of brachial plexus, C5–C6

Movements/Muscles Innervated

Laterally rotates arm

- *Teres minor*

Abducts arm

- *Deltoid*

Cutaneous Innervation

Inferior lateral shoulder

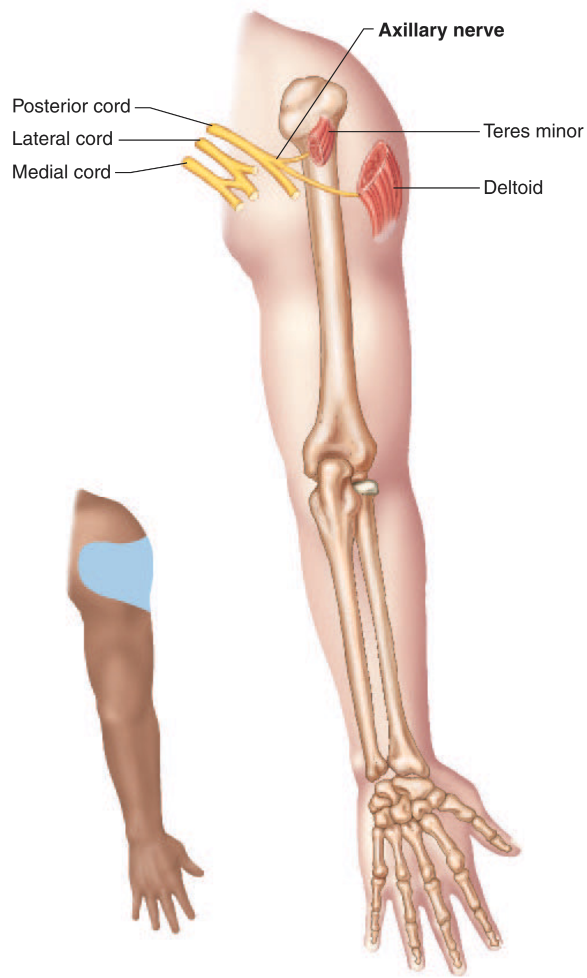

Figure 12.18 **Axillary Nerve**

Route of the axillary nerve and the muscles it innervates. The inset depicts the cutaneous distribution of the nerve (*shaded area*).

Radial Nerve

The **radial nerve** emerges from the posterior cord of the brachial plexus and descends within the deep aspect of the posterior arm (figure 12.19). About midway down the shaft of the humerus, it lies against the bone in the radial groove. The radial nerve innervates all of the extensor muscles of the upper limb, the supinator muscle, and the brachioradialis. Its cutaneous sensory distribution is to the posterior portion of the upper limb, including the posterior surface of the hand.

Radial Nerve Damage

Because the radial nerve lies near the humerus in the axilla, it can be damaged if it's compressed against the humerus. Improper use of crutches (i.e., when the crutch is pushed tightly into the axilla) can result in **"crutch paralysis."** In this disorder, the radial nerve is compressed between the top of the crutch and the humerus. As a result, the radial nerve is damaged, and the muscles it innervates lose their function. The major symptom of crutch paralysis is **"wrist drop"** in which the extensor muscles of the wrist and fingers, which are innervated by the radial nerve, fail to function; as a result, the elbow, wrist, and fingers are constantly flexed.

P R E D I C T 5

Wrist drop can also result from a compound fracture of the humerus. Explain how and where damage to the nerve may occur.

Radial Nerve

Origin

Posterior cord of brachial plexus, C5–T1

Movements/Muscles Innervated

Extends elbow
- *Triceps brachii*
- *Anconeus*

Flexes elbow
- *Brachialis (part; not shown; sensory only)*
- *Brachioradialis*

Extends and abducts wrist
- *Extensor carpi radialis longus*
- *Extensor carpi radialis brevis*

Supinates forearm
- *Supinator*

Extends fingers
- *Extensor digitorum*
- *Extensor digiti minimi*
- *Extensor indicis*

Extends and adducts wrist
- *Extensor carpi ulnaris*

Abducts thumb
- *Abductor pollicis longus*

Extends thumb
- *Extensor pollicis longus*
- *Extensor pollicis brevis*

Cutaneous Innervation

Posterior surface of arm and forearm, lateral two-thirds of dorsum of hand

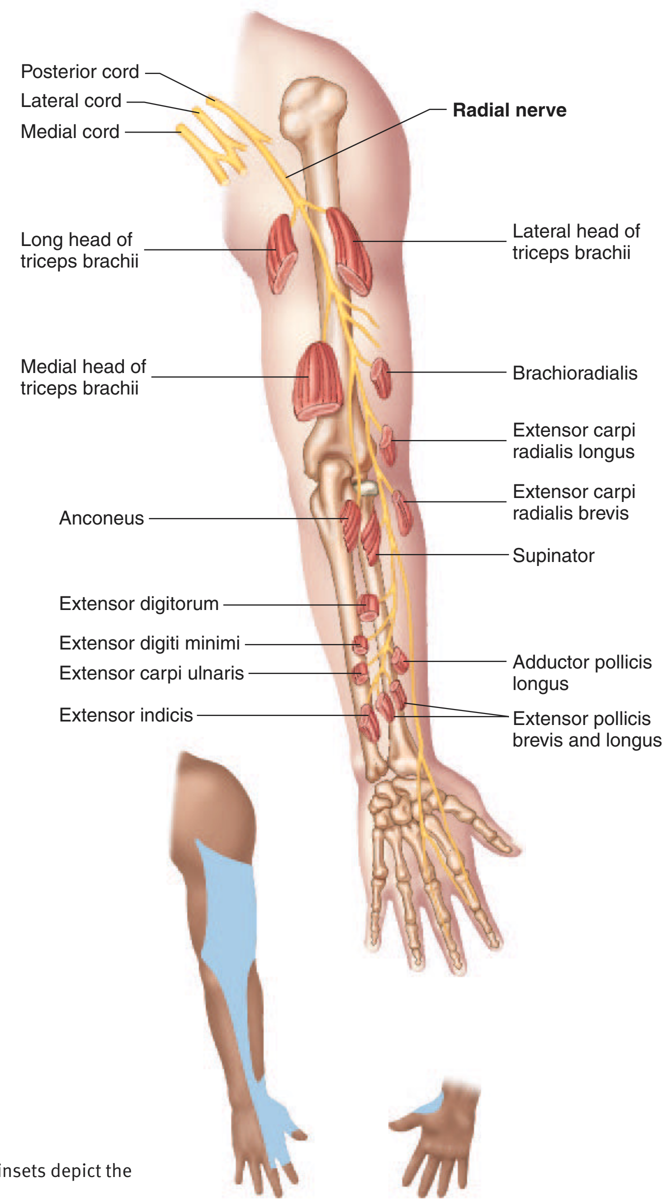

Figure 12.19 Radial Nerve

Route of the radial nerve and the muscles it innervates. The insets depict the cutaneous distribution of the nerve (*shaded area*).

Musculocutaneous Nerve

The **musculocutaneous** (mŭs′kū-lō-kū-tā′nē-ŭs) **nerve** provides motor innervation to the anterior muscles of the arm as well as cutaneous sensory innervation to part of the forearm (figure 12.20).

Musculocutaneous Nerve

Origin

Lateral cord of brachial plexus, C5–C7

Movements/Muscles Innervated

Flexes shoulder
- *Biceps brachii*
- *Coracobrachialis*

Flexes elbow and supinates forearm
- *Biceps brachii*

Flexes elbow
- *Brachialis (also small amount of innervation from radial nerve)*

Cutaneous Innervation

Lateral surface of forearm

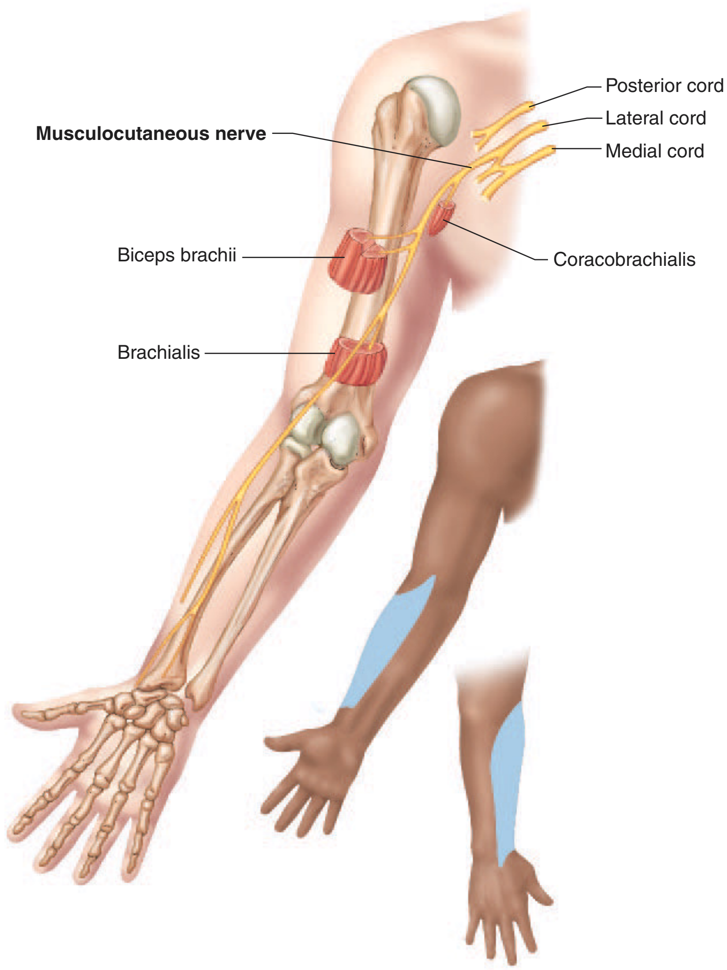

Figure 12.20 Musculocutaneous Nerve

Route of the musculocutaneous nerve and the muscles it innervates. The inset depicts the cutaneous distribution of the nerve (*shaded area*).

Ulnar Nerve

The **ulnar nerve** innervates two forearm muscles plus most of the intrinsic hand muscles, except some associated with the thumb. Its sensory distribution is to the ulnar side of the hand (figure 12.21).

Ulnar Nerve Damage

The ulnar nerve is the most easily damaged of all the peripheral nerves, but such damage is almost always temporary. Slight damage to the ulnar nerve may occur where it passes posterior to the medial epicondyle of the humerus. The nerve can be felt just below the skin at this point, and, if this region of the elbow is banged against a hard object, temporary ulnar nerve damage may occur. This damage results in painful tingling sensations radiating down the ulnar side of the forearm and hand. Because of this sensation, this area of the elbow is often called the **"funny bone"** or **"crazy bone."**

Ulnar Nerve

Origin

Medial cord of brachial plexus, C8–T1

Movements/Muscles Innnervated

Flexes and adducts wrist
- *Flexor carpi ulnaris*

Flexes fingers
- *Part of the flexor digitorum profundus controlling the distal phalanges of little and ring fingers*

Adducts thumb
- *Adductor pollicis*

Controls hypothenar muscles
- *Flexor digiti minimi brevis*
- *Abductor digiti minimi*
- *Opponens digiti minimi*

Flexes metacarpophalangeal joints and extends interphalangeal joints
- *Two medial (ulnar) lumbricales*

Abducts and adducts fingers
- *Interossei*

Cutaneous Innervation

Medial third of hand, little finger, and medial half of ring finger

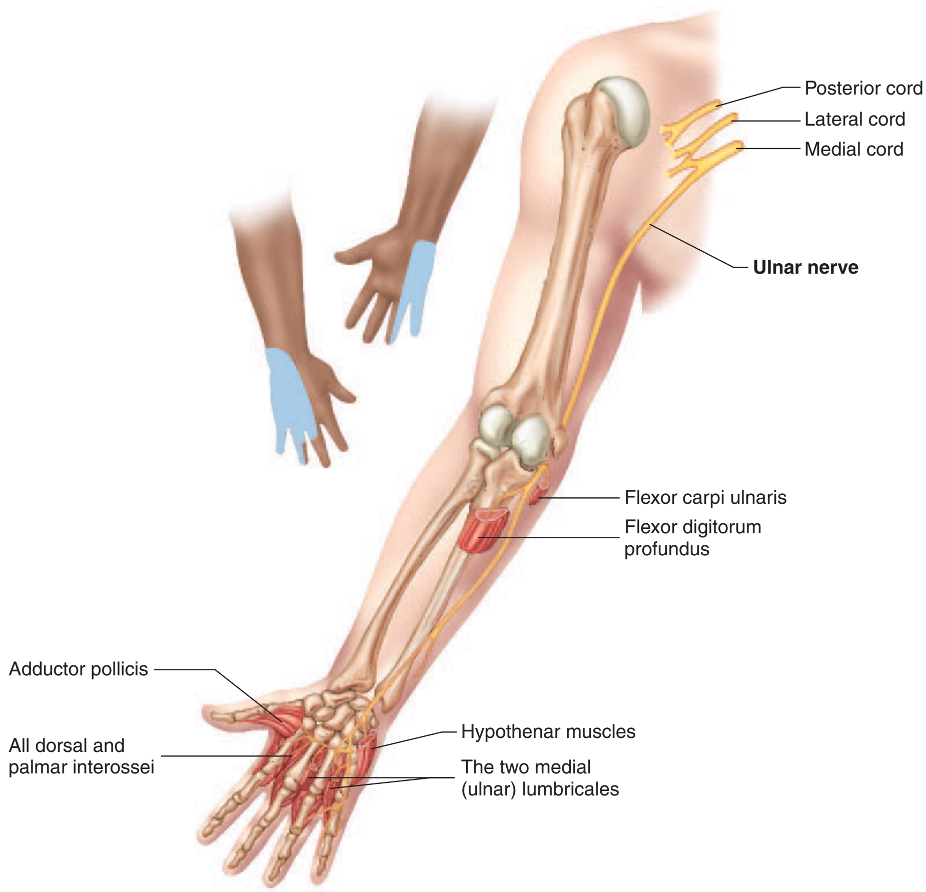

Figure 12.21 Ulnar Nerve

Route of the ulnar nerve and the muscles it innervates. The inset depicts the cutaneous distribution of the nerve (*shaded area).*

Median Nerve

The **median nerve** innervates all but one of the flexor muscles of the forearm and most of the hand muscles at the base of the thumb, called the thenar area of the hand. Its cutaneous sensory distribution is to the radial portion of the palm of the hand (figure 12.22).

Median Nerve Damage

Damage to the median nerve occurs most commonly where it enters the wrist through the **carpal tunnel.** This tunnel is created by the concave organization of the carpal bones and the flexor retinaculum on the anterior surface of the wrist. None of the connective tissue components of the carpal tunnel expands readily. Inflammation in the wrist or an increase in the size of the tendons in the carpal tunnel can produce pressure within it, thereby compressing the median nerve and resulting in numbness, tingling, and pain in the fingers. This condition is referred to as **carpal tunnel syndrome.** Carpal tunnel syndrome is common among people who perform repetative movements of the wrists and fingers, such as keyboard operators. Surgery is often required to relieve the pressure.

People attempting suicide by cutting the wrists commonly cut the median nerve proximal to the carpal tunnel.

Median Nerve

Origin

Medial and lateral cords of brachial plexus, C5–T1

Movements/Muscles Innervated

Pronates forearm
- *Pronator teres*
- *Pronator quadratus*

Flexes and abducts wrist
- *Flexor carpi radialis*

Flexes wrist
- *Palmaris longus*

Flexes fingers
- *Part of flexor digitorum profundus controlling the distal phalanx of the middle and index fingers*
- *Flexor digitorum superficialis*

Controls thumb muscle
- *Flexor pollicis longus*

Controls thenar muscles
- *Abductor pollicis brevis*
- *Opponens pollicis*
- *Flexor pollicis brevis*

Flexes metacarpophalangeal joints and extends interphalangeal joints
- *Two lateral (radial) lumbricales*

Cutaneous Innervation

Lateral two-thirds of palm of hand, thumb, index and middle fingers, and the lateral half of ring finger and dorsal tips of the same fingers

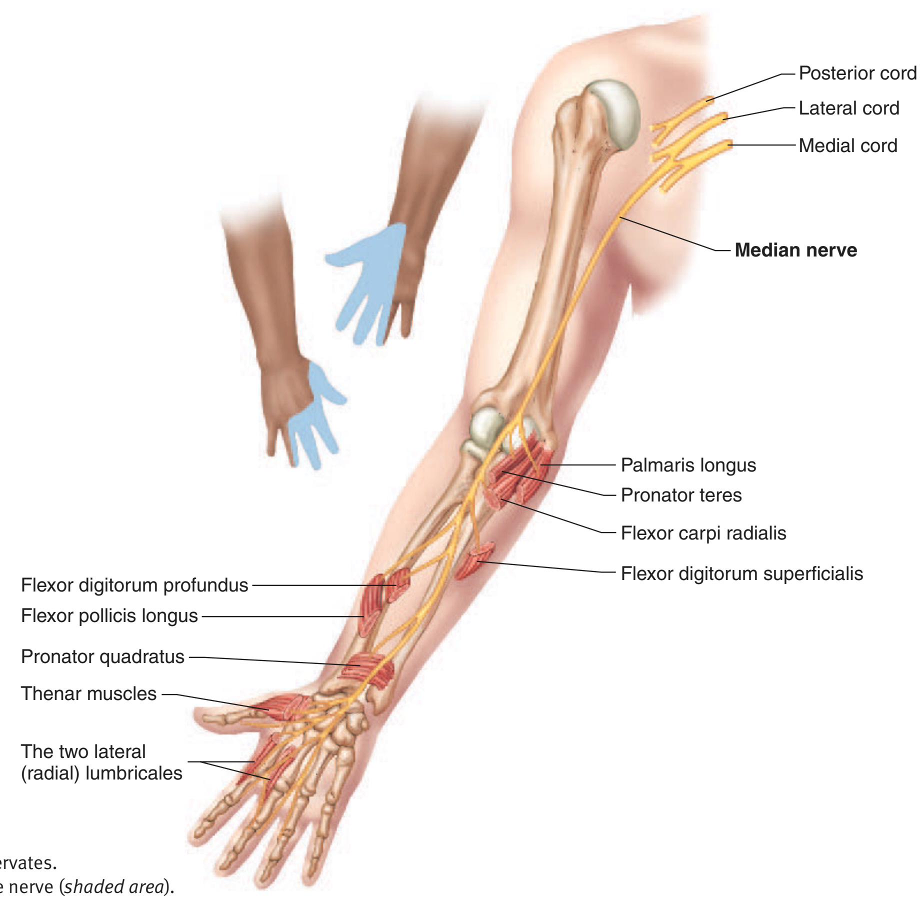

Figure 12.22 Median Nerve

Route of the median nerve and the muscles it innervates.
The inset depicts the cutaneous distribution of the nerve (*shaded area*).

Other Nerves of the Brachial Plexus

Several nerves, other than the five just described, arise from the brachial plexus (see figure 12.16). They supply most of the muscles acting on the scapula and arm and include the pectoral, long thoracic, thoracodorsal, subscapular, and suprascapular nerves. In addition, brachial plexus nerves supply the cutaneous innervation of the medial arm and forearm.

20. Name the structures innervated by the cervical plexus. Describe the innervation of the phrenic nerve.

21. Name the five major nerves that emerge from the brachial plexus. List the muscles they innervate and the areas of the skin they supply. In addition to these five nerves, name the muscles and skin areas supplied by the remaining brachial plexus nerves.

Lumbar and Sacral Plexuses

The **lumbar plexus** originates from the ventral rami of spinal nerves L1–L4 and the **sacral plexus** from L4–S4. Because of their close, overlapping relationship and their similar distribution, however, the two plexuses often are considered together as a single **lumbosacral plexus** (L1–S4; figure 12.23). Four major nerves exit the lumbosacral plexus and enter the lower limb: the obturator, femoral, tibial, and common fibular (peroneal). The obturator nerve innervates the medial thigh; the femoral nerve innervates the anterior thigh; the tibial nerve innervates the posterior thigh, the leg, and foot; and the common fibular nerve innervates the posterior thigh, the anterior and lateral leg, and the foot. Other lumbosacral nerves supply the lower back, the hip, and the lower abdomen.

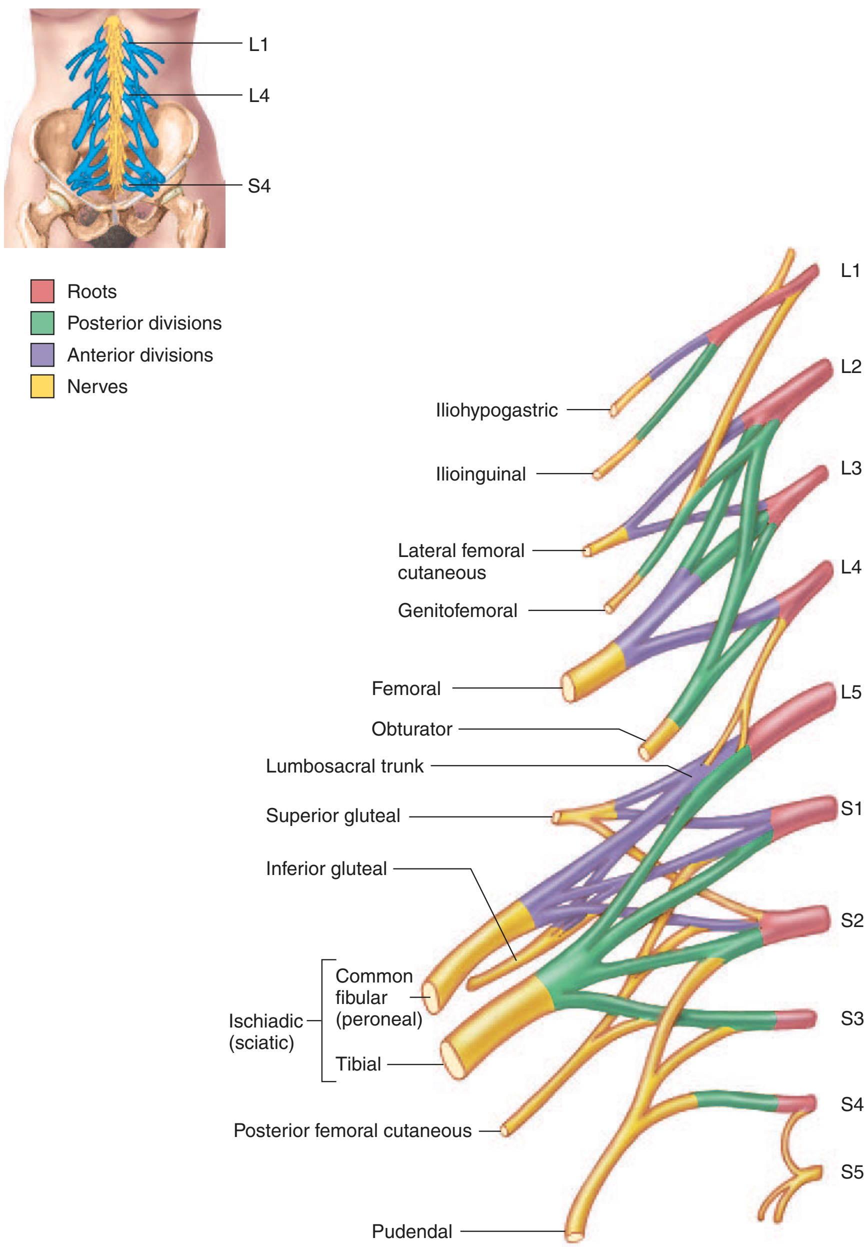

Figure 12.23 **Lumbosacral Plexus, Anterior View**

The roots of the plexus are formed by the ventral rami of the spinal nerves L1–S4 and form anterior and posterior divisions, which give rise to the lumbrosacral nerves. The lumbo sacral trunk joins the lumbar and sacral plexuses.

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Obturator Nerve

The **obturator** (ob′too-rā-tōr) **nerve** supplies the muscles that adduct the thigh. Its cutaneous sensory distribution is to the medial side of the thigh (figure 12.24).

Obturator Nerve

Origin
Lumbosacral plexus, L2–L4

Movements/Muscles Innervated

Rotates thigh laterally
- *Obturator externus*

Adducts thigh
- *Adductor magnus (partial)*
- *Adductor longus*
- *Adductor brevis*

Adducts thigh and flexes knee
- *Gracilis*

Cutaneous Innervation
Superior medial side of thigh

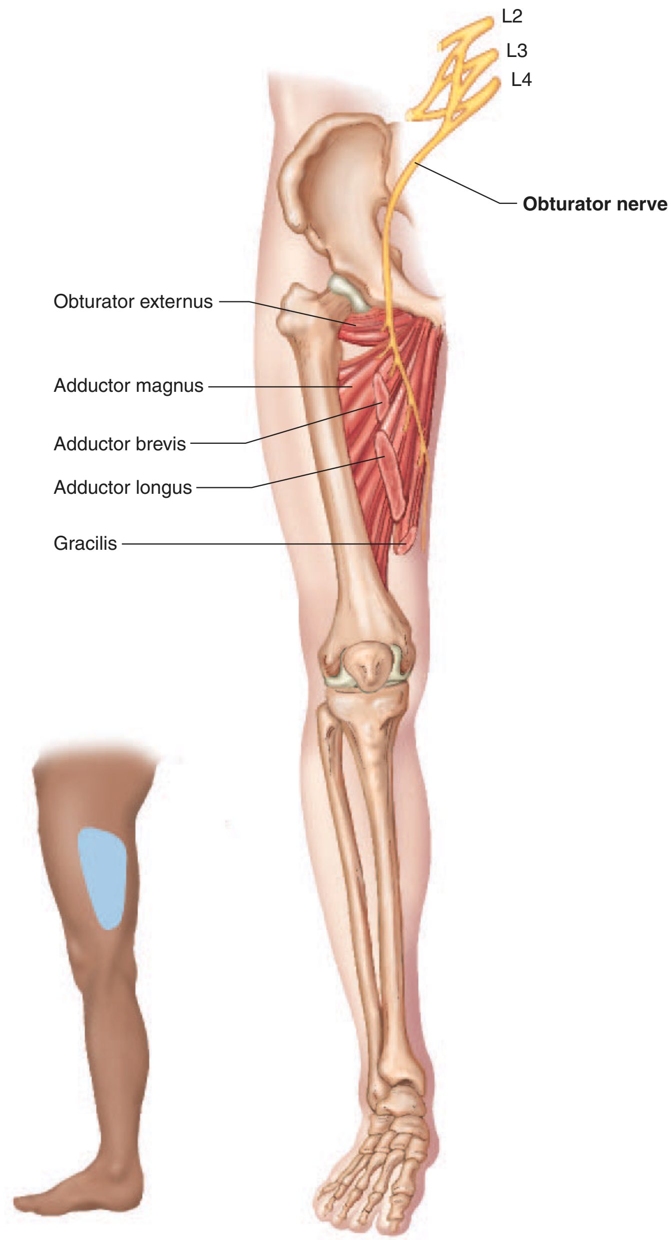

Figure 12.24 Obturator Nerve
Route of the obturator nerve and the muscles it innervates. The inset depicts the cutaneous distribution of the nerve (*shaded area*).

Femoral Nerve

The **femoral nerve** innervates the iliopsoas and sartorius muscles and the quadriceps femoris group. Its cutaneous sensory distribution is the anterior and lateral thigh and the medial leg and foot (figure 12.25).

Femoral Nerve

Origin

Lumbosacral plexus, L2–L4

Movements/Muscles Innervated

Flexes hip
- *Psoas major*
- *Iliacus*
- *Pectineus*

Flexes hip and flexes knee
- *Sartorius*

Extends knee
- *Vastus lateralis*
- *Vastus intermedius*
- *Vastus medialis*

Extends knee and flexes hip
- *Rectus femoris*

Cutaneous Innervation

Anterior and lateral branches supply the anterior and lateral thigh; saphenous branch supplies the medial leg and foot

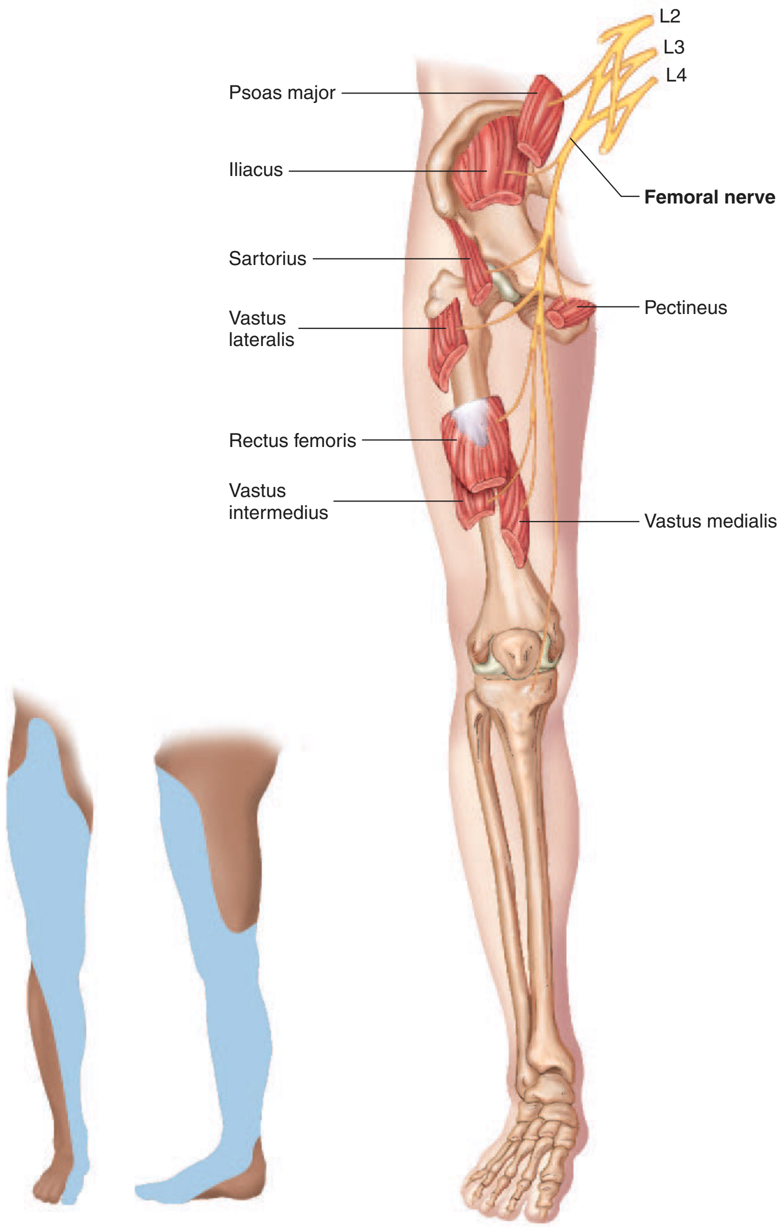

Figure 12.25 Femoral Nerve

Route of the femoral nerve and the muscles it innervates. The inset depicts the cutaneous distribution of the nerve (*shaded area*).

Tibial and Common Fibular Nerves

The **tibial** and **common fibular (peroneal)** (per-ō-nē′ăl) **nerves** originate from spinal segments L4–S3 and are bound together within a connective tissue sheath for the length of the thigh (figures 12.26 and 12.27; see figure 12.23). These two nerves, combined within the same sheath, are referred to jointly as the **ischiadic** (is-kē-ad′ik) **nerve** (see figure 12.23). The ischiadic nerve is commonly called the **sciatic** (sī-at′ik) **nerve.** The term *sciatic* originated as a degenerate form of ischiadic, and the International Conference of Anatomists has recently decided to begin using the correct term. The ischiadic nerve, by far the largest peripheral nerve in the body, passes through the greater ischiadic notch in the pelvis and descends in the posterior thigh to the popliteal fossa, where the two portions of the ischiadic nerve separate.

The tibial nerve innervates most of the posterior thigh and leg muscle (see figure 12.26). It branches in the foot to form the **medial** and **lateral plantar** (plan′tăr) **nerves,** which innervate the plantar muscles of the foot and the skin over the sole of the foot. Another branch, the **sural** (soo′ răl) **nerve,** supplies part of the cutaneous innervation over the calf of the leg and the plantar surface of the foot.

Tibial Nerve

Origin
Lumbosacral plexus, L4–S3

Movements/Muscles Innervated
Extends hip and flexes knee
- *Biceps femoris (long head)*
- *Semitendinosus*
- *Semimembranosus*

Adducts thigh and extends hip
- *Adductor magnus (partial)*

Plantar flexes foot
- *Plantaris*
- *Gastrocnemius*
- *Soleus*
- *Tibialis posterior*

Flexes knee
- *Popliteus*

Flexes toes
- *Flexor digitorum longus*
- *Flexor hallucis longus*

Cutaneous Innervation
None

Medial and Lateral Plantar Nerves

Origin
Tibial nerve

Movements/Muscles Innervated
Flex and adduct toes
- *Plantar muscles of foot*

Cutaneous Innervation
Sole of foot

Sural Nerve (not shown)

Origin
Tibial nerve

Movements/Muscles Innervated
None

Cutaneous Innervation
Lateral and posterior one-third of leg and lateral side of foot

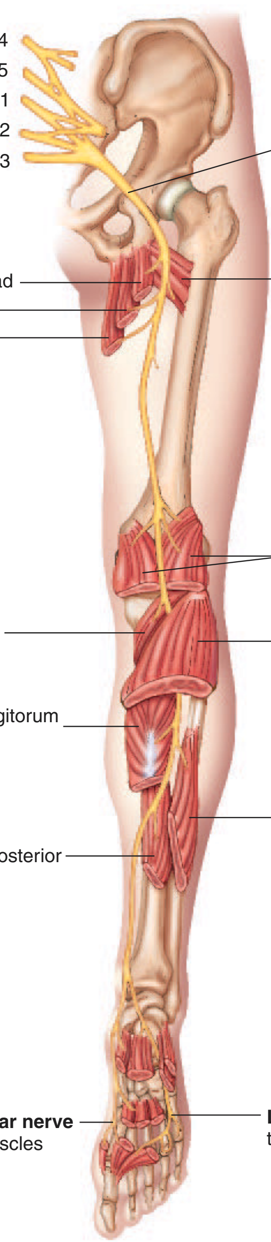

Figure 12.26 Tibial Nerve

Route of the tibial nerve and the muscles it innervates. The inset depicts the cutaneous distribution of the nerve (*shaded area*).

The common fibular nerve divides into the **deep** and **superficial fibular (peroneal) nerves.** These branches innervate the anterior and lateral muscles of the leg and foot. The cutaneous distribution of the common fibular nerve and its branches is the lateral and anterior leg and the dorsum of the foot (see figure 12.27).

Common Fibular (Peroneal) Nerve

Origin
Lumbosacral plexus, L4–S2

Movements/Muscles Innervated
Extends hip and flexes knee
- *Biceps femoris (short head)*

Cutaneous Innervation
Lateral surface of knee

Deep Fibular (Peroneal) Nerve

Origin
Common fibular (peroneal) nerve

Movements/Muscles Innervated
Dorsiflexes foot
- *Tibialis anterior*
- *Peroneus tertius*

Extends toes
- *Extensor digitorum longus*
- *Extensor hallucis longus*

Cutaneous Innervation
Great and second toe

Superficial Fibular (Peroneal) Nerve

Origin
Common fibular (peroneal) nerve

Movements/Muscles Innervated
Plantar flexes and everts foot
- *Peroneus longus*
- *Peroneus brevis*

Extends toes
- *Extensor digitorum brevis*

Cutaneous Innervation
Dorsal anterior third of leg and dorsum of foot

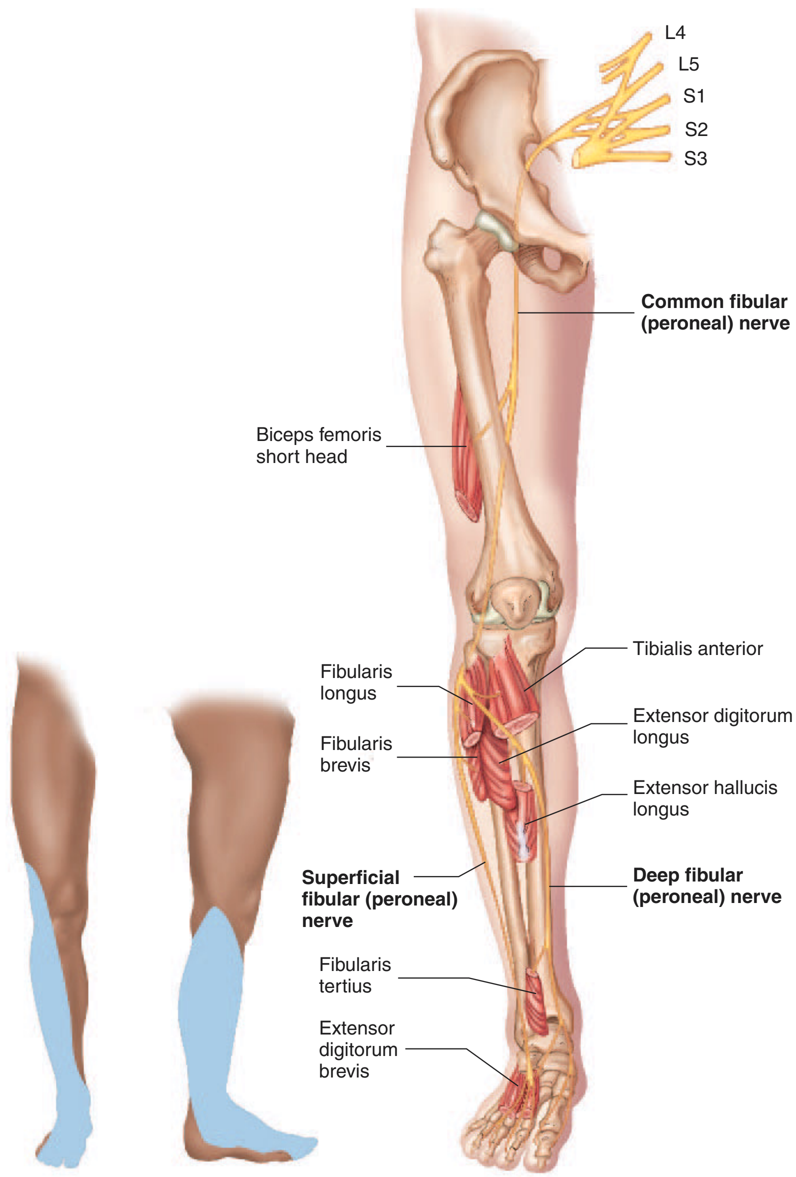

Figure 12.27 Fibular Nerve
Route of the common fibular (peroneal) nerve and the muscles it innervates. The inset depicts the cutaneous distribution of the nerve (*shaded area*).

Clinical Focus Nerve Replacement

Patients paralyzed by strokes or spinal cord lesions are now able to regain certain limited functions. Microcomputers are being perfected that stimulate certain programmed activities, such as grasping and walking. The microcomputer initiates electric impulses that are conveyed through fine wire leads to either peripheral nerves or directly to the muscles responsible for the desired movement. The subtle movement of muscles not affected by the paralysis initiate the program. Sensors connected to the microcomputer are attached to the skin overlying functional muscles and are able to detect electrical activity associated with movement of the underlying muscles. For example, a person with both legs paralyzed may have such a sensor attached to the abdomen. The abdominal muscles normally involved in stabilizing and moving the pelvis during walking are stimulated by descending tracts when walking is initiated by CNS centers. The resultant abdominal muscle activity is detected by the sensor, which activates the program that stimulates the appropriate sequence of muscles in the lower limbs, and the paralyzed person walks. Similarly, a quadriplegic using subtle movements of the shoulder, neck, or face, where specific sensors can be placed, can initiate certain upper limb and grasping actions.

Ischiadic Nerve Damage

If a person sits on a hard surface for a considerable time, the ischiadic (sciatic) nerve may be compressed against the ischial portion of the coxa. When the person stands up, a tingling sensation described as "pins and needles" can be felt throughout the lower limb, and the limb is said to have "gone to sleep."

The ischiadic nerve may be seriously injured in a number of ways. A ruptured intervertebral disk or pressure from the uterus during pregnancy may compress the roots of the ischiadic nerve. Other possibilities for causing ischiadic nerve damage include hip injury or an improperly administered injection in the hip region.

Other Lumbosacral Plexus Nerves

In addition to the nerves just described, the lumbosacral plexus gives rise to nerves that supply the lower abdominal muscles (iliohypogastric nerve), the hip muscles that act on the femur (gluteal nerves), and the muscles of the abdominal floor (pudendal nerve; see figure 12.23). The **iliohypogastric** (il′ē-ō-hī-pō-gas′trik), **ilioinguinal** (il′ē-ō-ing′gwi-năl), **genitofemoral** (jen′i-tō-fem′ŏ-răl), **cutaneous femoral,** and **pudendal** (pū-den′dăl) **nerves** innervate the skin of the suprapubic area, the external genitalia, the superior medial thigh, and the posterior thigh. The pudendal nerve plays a vital role in sexual stimulation and response.

Pudendal Nerve Anesthesia

Branches of the pudendal nerve are anesthetized before a doctor performs an episiotomy for childbirth. An **episiotomy** (e-piz-ē-ot′ō-mē, e-pis-ē-ot′ō-mē) is a cut in the perineum that makes the opening of the birth canal larger.

Coccygeal Plexus

The **coccygeal** (kok-sij′ē-ăl) **plexus** is a very small plexus formed from the ventral rami of spinal nerves S4, S5, and the coccygeal nerve. This small plexus supplies motor innervation to muscles of the pelvic floor and sensory cutaneous innervation to the skin over the coccyx. The dorsal rami of the coccygeal nerves innervate some skin over the coccyx.

22. Name the four major nerves that arise from the lumbosacral plexus, and describe the muscles and skin area they supply. What is the name applied to the tibial and common fibular nerves bound together?

23. Describe the structures innervated by the remaining lumbosacral nerves.

24. What structures are innervated by the coccygeal plexus?

Clinical Focus Peripheral Nervous System Disorders—Spinal Nerves

General Types of PNS Disorders

Anesthesia is the loss of sensation (the Greek word *esthesis* means sensation). It may be a pathologic condition if it happens spontaneously, or it may be induced to facilitate surgery or some other medical treatment.

Hyperesthesia (hī′per-es-thē′zē-ă) is an abnormal acuteness to sensation, especially an increased sensitivity to pain, pressure, or light.

Paresthesia (par-es-the′zē-ă) is an abnormal spontaneous sensation, such as tingling, prickling, or burning.

Neuralgia (noo-ral′jē-ă) consists of severe spasms of throbbing or stabbing pain resulting from inflammation or damage along the pathway of a nerve.

Ischiadica (is′kē-ad′i-kă), or **sciatica,** is a neuralgia of the ischiadic nerve, with pain radiating down the back of the thigh and leg. The most common cause is a herniated lumbar disk, resulting in pressure on the spinal nerves contributing to the lumbar plexus. Ischiadica may also be produced by ischiadic neuritis arising from a number of causes, including mechanical stretching of the nerve during exertion, vitamin deficiency, or metabolic disorders (such as gout or diabetes).

Neuritis (noo-rī′tis) is a general term referring to inflammation of a nerve that has a wide variety of causes, including mechanical injury or pressure, viral or bacterial infection, poisoning by drugs or other chemicals, and vitamin deficiencies. Neuritis in sensory nerves is characterized by neuralgia or may result in anesthesia and loss of reflexes in the affected area. Neuritis in motor nerves results in loss of motor function.

Infections

Herpes is a family of diseases characterized by skin lesions, which are caused by a group of closely related viruses (the herpes viruses). The term is derived from the Greek word *herpo,* meaning to creep, and indicates a spreading skin eruption. The viruses apparently reside in the ganglia of sensory nerves and cause lesions along the course of the nerve. **Herpes simplex II,** or genital herpes, is usually responsible for a sexually transmitted disease causing lesions on the external genitalia.

The varicella-zoster virus causes the diseases chicken pox in children and **shingles** in older adults, a disease also called **herpes zoster.** Normally, this virus first enters the body in childhood to cause chicken pox. The virus then lies dormant in the spinal ganglia for many years and can become active during a time of reduced resistance to cause **shingles,** a unilateral patch of skin blisters and discoloration along the path of one or more spinal nerves, most commonly around the waist. The symptoms can persist for 3–6 months.

Poliomyelitis (pō′lē-ō-mī′ĕ-lī′tis; "polio" or infantile paralysis; the Greek word *polio* means gray matter) is a disease caused by an *Enterovirus.* It's actually a CNS infection, but its major effect is on the peripheral nerves and the muscles they supply. The virus infects the motor neurons in the anterior horn of the spinal cord. The infection causes degeneration of the motor neurons, which results in paralysis and atrophy of the muscles innervated by those nerves.

Anesthetic leprosy is a bacterial infection of the peripheral nerves caused by *Mycobacterium leprae.* The infection results in anesthesia, paralysis, ulceration, and gangrene.

Genetic and Autoimmune Disorders

Myotonic dystrophy is an autosomal dominant hereditary disease characterized by muscle weakness, dysfunction, and atrophy and by visual impairment as a result of nerve degeneration.

Myasthenia (mī-as-thē′nē-ă) **gravis** is an autoimmune disorder resulting in a reduction in the number of functional acetylcholine receptors in neuromuscular junctions. T cells of the immune system break down acetylcholine receptor proteins into two fragments, which trigger antibody production by the immune system. Myasthenia gravis results in fatigue and progressive muscular weakness because of the neuromuscular dysfunction.

S U M M A R Y

Spinal Cord (p. 402)

General Structure

1. The spinal cord gives rise to 31 pairs of spinal nerves. The spinal cord has cervical and lumbar enlargements where nerves of the limbs enter and leave.
2. The spinal cord is shorter than the vertebral column. Nerves from the end of the spinal cord form the cauda equina.

Meninges of the Spinal Cord

Three meningeal layers surround the spinal cord: the dura mater, arachnoid mater, and pia mater.

Cross Section of the Spinal Cord

1. The cord consists of peripheral white matter and central gray matter.
2. White matter is organized into funiculi, which are subdivided into fasciculi, or nerve tracts, which carry action potentials to and from the brain.
3. Gray matter is divided into horns.
   - The dorsal horns contain sensory axons that synapse with interneurons. The ventral horns contain the neuron cell bodies of somatic motor neurons, and the lateral horns contain the neuron cell bodies of autonomic neurons.
   - The gray and white commissures connect each half of the spinal cord.
4. The dorsal root conveys sensory input into the spinal cord, and the ventral root conveys motor output away from the spinal cord.

Reflexes (p. 405)

1. A reflex arc is the functional unit of the nervous system.
   - Sensory receptors respond to stimuli and produce action potentials in sensory neurons.
   - Sensory neurons propagate action potentials to the CNS.
   - Interneurons in the CNS synapse with sensory neurons and with motor neurons.
   - Motor neurons carry action potentials from the CNS to effector organs.
   - Effector organs such as muscles or glands respond to the action potentials.
2. Reflexes don't require conscious thought, and they produce a consistent and predictable result.
3. Reflexes are homeostatic.
4. Reflexes are integrated within the brain and spinal cord. Higher brain centers can suppress or exaggerate reflexes.

Stretch Reflex

Muscle spindles detect stretch of skeletal muscles and cause the muscle to shorten reflexively.

Golgi Tendon Reflex

Golgi tendon organs respond to increased tension within tendons and cause skeletal muscles to relax.

Withdrawal Reflex

1. Activation of pain receptors causes contraction of muscles and the removal of some part of the body from a painful stimulus.
2. Reciprocal innervation causes relaxation of muscles that would oppose the withdrawal movement.
3. In the crossed extensor reflex, during flexion of one limb caused by the withdrawal reflex, the opposite limb is stimulated to extend.

Spinal Cord Pathways (p. 410)

Convergent and divergent pathways interact with reflexes.

Structure of Peripheral Nerves (p. 410)

In the PNS, individual axons are surrounded by the endoneurium. Groups of axons, called fascicles, are bound together by the perineurium. The fascicles form the nerve and are held together by the epineurium.

Spinal Nerves (p. 410)

1. Eight cervical, 12 thoracic, 5 lumbar, 5 sacral pairs, and 1 coccygeal pair make up the spinal nerves.
2. Spinal nerves have specific cutaneous distributions called dermatomes.
3. Spinal nerves branch to form rami.
   - The dorsal rami supply the muscles and skin near the midline of the back.
   - The ventral rami in the thoracic region form intercostal nerves, which supply the thorax and upper abdomen. The remaining ventral rami join to form plexuses (see following summary sections). Communicating rami supply sympathetic nerves (see chapter 16).

Cervical Plexus

Spinal nerves C1–C4 form the cervical plexus, which supplies some muscles and the skin of the neck and shoulder. The phrenic nerves innervate the diaphragm.

Brachial Plexus

1. Spinal nerves C5–T1 form the brachial plexus, which supplies the upper limb.
2. The axillary nerve innervates the deltoid and teres minor muscles and the skin of the shoulder.
3. The radial nerve supplies the extensor muscles of the arm and forearm and the skin of the posterior surface of the arm, forearm, and hand.
4. The musculocutaneous nerve supplies the anterior arm muscles and the skin of the lateral surface of the forearm.
5. The ulnar nerve innervates most of the intrinsic hand muscles and the skin on the ulnar side of the hand.
6. The median nerve innervates the pronator and most of the flexor muscles of the forearm, most of the thenar muscles, and the skin of the radial side of the palm of the hand.
7. Other nerves supply most of the muscles that act on the arm, the scapula, and the skin of the medial arm and forearm.

Lumbar and Sacral Plexuses

1. Spinal nerves L1–S4 form the lumbosacral plexus.
2. The obturator nerve supplies the muscles that adduct the thigh and the skin of the medial thigh.
3. The femoral nerve supplies the muscles that flex the thigh and extend the leg and the skin of the anterior and lateral thigh and the medial leg and foot.
4. The tibial nerve innervates the muscles that extend the thigh and flex the leg and the foot. It also supplies the plantar muscles and the skin of the posterior leg and the sole of the foot.
5. The common fibular nerve supplies the short head of the biceps femoris, the muscles that dorsiflex and plantar flex the foot, and the skin of the lateral and anterior leg and the dorsum of the foot.
6. In the thigh, the tibial nerve and the common fibular nerve are combined as the ischiadic (sciatic) nerve.
7. Other lumbosacral nerves supply the lower abdominal muscles, the hip muscles, and the skin of the suprapubic area, external genitalia, and upper medial thigh.

Coccygeal Plexus

Spinal nerves S4, S5, and Co form the coccygeal plexus, which supplies the muscles of the pelvic floor and the skin over the coccyx.

REVIEW AND COMPREHENSION

1. The spinal cord extends from the
   a. medulla oblongata to the coccyx.
   b. level of the third cervical vertebra to the coccyx.
   c. level of the axis to the lowest lumbar vertebra.
   d. medulla oblongata to the level of the second lumbar vertebra.
   e. axis to the sacral hiatus.
2. The structure that anchors the inferior end of the spinal cord to the coccyx is the
   a. conus medullaris.
   b. cauda equina.
   c. filum terminale.
   d. lumbar enlargement.
   e. posterior median sulcus.

3. Axons of sensory neurons synapse with the cell bodies of interneurons in the ____________ of spinal cord gray matter.
   a. anterior horn
   b. lateral horn
   c. posterior horn
   d. gray commissure
   e. lateral funiculi
4. Cell bodies for sensory neurons are located in the
   a. anterior horn of spinal cord gray matter.
   b. lateral horn of spinal cord gray matter.
   c. posterior horn of spinal cord gray matter.
   d. dorsal root ganglia.
   e. posterior columns.
5. Given these components of a reflex arc:
   1. effector organ
   2. interneuron
   3. motor neuron
   4. sensory neuron
   5. sensory receptor

   Choose the correct order an action potential follows after a sensory receptor is stimulated.
   a. 5,4,3,2,1
   b. 5,4,2,3,1
   c. 5,3,4,1,2
   d. 5,2,4,3,1
   e. 5,3,2,1,4
6. A reflex response accompanied by the conscious sensation of pain is possible because of
   a. convergent pathways.
   b. divergent pathways.
   c. a reflex arc that contains only one neuron.
   d. sensory perception in the spinal cord.
7. Several of the events that occurred between the time that a physician struck a patient's patellar tendon with a rubber hammer and the time the quadriceps femoris contracted (knee-jerk reflex) are listed below:
   1. increased frequency of action potentials in sensory neurons
   2. stretch of the muscle spindles
   3. increased frequency of action potentials in the alpha motor neurons
   4. stretch of the quadriceps femoris
   5. contraction of the quadriceps femoris

   Which of these lists most closely describes the sequence of events as they normally occur?
   a. 4,1,2,3,5
   b. 4,1,3,2,5
   c. 1,4,3,2,5
   d. 4,2,1,3,5
   e. 4,2,3,1,5
8. ____________ are responsible for regulating the sensitivity of the muscle spindle.
   a. Alpha motor neurons
   b. Sensory neurons
   c. Gamma motor neurons
   d. Golgi tendon organs
   e. Inhibitory interneurons
9. Which of these events occurs when a person steps on a tack with the right foot?
   a. The right foot is pulled away from the tack because of the Golgi tendon reflex.
   b. The left leg is extended to support the body because of the stretch reflex.
   c. The flexor muscles of the right thigh contract, and the extensor muscles of the right thigh relax because of reciprocal innervation.
   d. Extensor muscles contract in both thighs because of the crossed extensor reflex.
10. Which of these is a correct count of the spinal nerves?
    a. 9 cervical, 12 thoracic, 5 lumbar, 5 sacral, 1 coccygeal
    b. 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, 1 coccygeal
    c. 7 cervical, 12 thoracic, 5 lumbar, 5 sacral, 1 coccygeal
    d. 8 cervical, 11 thoracic, 4 lumbar, 6 sacral, 1 coccygeal
    e. 7 cervical, 11 thoracic, 5 lumbar, 6 sacral, 1 coccygeal
11. Given these structures:
    1. dorsal ramus
    2. dorsal root
    3. plexus
    4. ventral ramus
    5. ventral root

    Choose the arrangement that lists the structures in the order that an action potential passes through them, given that the action potential originates in the spinal cord and propagates to a peripheral nerve.
    a. 2,1,3
    b. 2,3,1
    c. 3,4,5
    d. 5,3,4
    e. 5,4,3
12. Damage to the dorsal ramus of a spinal nerve results in
    a. loss of sensation.
    b. loss of motor function.
    c. both a and b.
13. A collection of spinal nerves that join together after leaving the spinal cord is called a
    a. ganglion.
    b. nucleus.
    c. projection nerve.
    d. plexus.
14. A dermatome
    a. is the area of skin supplied by a pair of spinal nerves.
    b. may be supplied by more than one nerve from a plexus.
    c. can be used to locate the site of spinal cord injury.
    d. all of the above.
15. Which of these nerves arises from the cervical plexus?
    a. median
    b. musculocutaneous
    c. phrenic
    d. obturator
    e. ulnar
16. The skin on the posterior surface of the hand is supplied by the
    a. median nerve.
    b. musculocutaneous nerve.
    c. ulnar nerve.
    d. axillary nerve.
    e. radial nerve.

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17. The thenar muscles and most of the flexor muscles of the forearm are supplied by the
    a. musculocutaneous nerve.
    b. radial nerve.
    c. median nerve.
    d. ulnar nerve.
    e. axillary nerve.
18. The intrinsic hand muscles, other than those that move the thumb, are supplied by the
    a. musculocutaneous nerve.
    b. radial nerve.
    c. median nerve.
    d. ulnar nerve.
    e. axillary nerve.
19. The ischiadic (sciatic) nerve is actually two nerves combined within the same sheath. The two nerves are the
    a. femoral and obturator.
    b. femoral and gluteal.
    c. common fibular (peroneal) and tibial.
    d. common fibular (peroneal) and obturator.
    e. tibial and gluteal.
20. The muscles of the anterior compartment of the thigh are supplied by the
    a. obturator nerve.
    b. gluteal nerve.
    c. ischiadic (sciatic) nerve.
    d. femoral nerve.
    e. ilioinguinal nerve.

Answers in Appendix F

CRITICAL THINKING

1. Describe how stimulation of a neuron that has its cell body in the cerebrum could inhibit a reflex that is integrated within the spinal cord.
2. A cancer patient has his left lung removed. To reduce the space remaining where the lung is removed, the diaphragm on the left side is paralyzed to allow the abdominal viscera to push the diaphragm upward. What nerve is cut? Where is a good place to cut it, and when would the surgery be done?
3. Based on sensory response to pain in the skin of the hand, how could you distinguish between damage to the ulnar, median, and radial nerves?
4. During a difficult delivery, the baby's arm delivered first. The attending physician grasped the arm and forcefully pulled it. Later a nurse observed that the baby could not abduct or adduct the medial four fingers and flexion of the wrist was impaired. What nerve was damaged?
5. Two patients are admitted to the hospital. According to their charts, both have herniated disks that are placing pressure on the roots of the ischiadic nerve. One patient has pain in the buttocks and the posterior aspect of the thigh. The other patient experiences pain in the posterior and lateral aspects of the leg and the lateral part of the ankle and foot. Explain how the same condition, a herniated disk, could produce such different symptoms.
6. In an automobile accident a woman suffers a crushing hip injury. For each of the conditions given here, state what nerve is damaged.
    a. Unable to adduct the thigh
    b. Unable to extend the leg
    c. Unable to flex the leg
    d. Loss of sensation from the skin of the anterior thigh
    e. Loss of sensation from the skin of the medial thigh

Answers in Appendix G

ANSWERS TO PREDICT QUESTIONS

1. The cord is enlarged in the inferior cervical and superior lumbar regions because of the large numbers of motor nerve fibers exiting from the cord to the limbs and sensory nerve fibers entering the cord from the limbs. Also, more neuron cell bodies in the spinal cord regions are associated with the increased numbers of sensory and motor fibers.
2. Dorsal root ganglia contain neuron cell bodies, which are larger in diameter than the axons of the dorsal roots.
3. Nerves C5–T1, which innervate the left arm, forearm, and hand, are damaged.
4. Damage to the right phrenic nerve results in the absence of muscular contraction in the right half of the diaphragm. Because the phrenic nerves originate from C3–C5, damage to the upper cervical region of the spinal cord eliminates their functions; damage in the lower cord below the point where the spinal nerves originate doesn't affect the nerves to the diaphragm. Breathing is affected, however, because the intercostal nerves to the intercostal muscles, which move the ribs, are paralyzed.
5. The radial nerve lies along the shaft of the humerus about midway along its length. If the humerus is fractured, the radial nerve can be lacerated by bone fragments or, more commonly, pinched between two fragments of bone, decreasing or eliminating the function of the nerve.

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