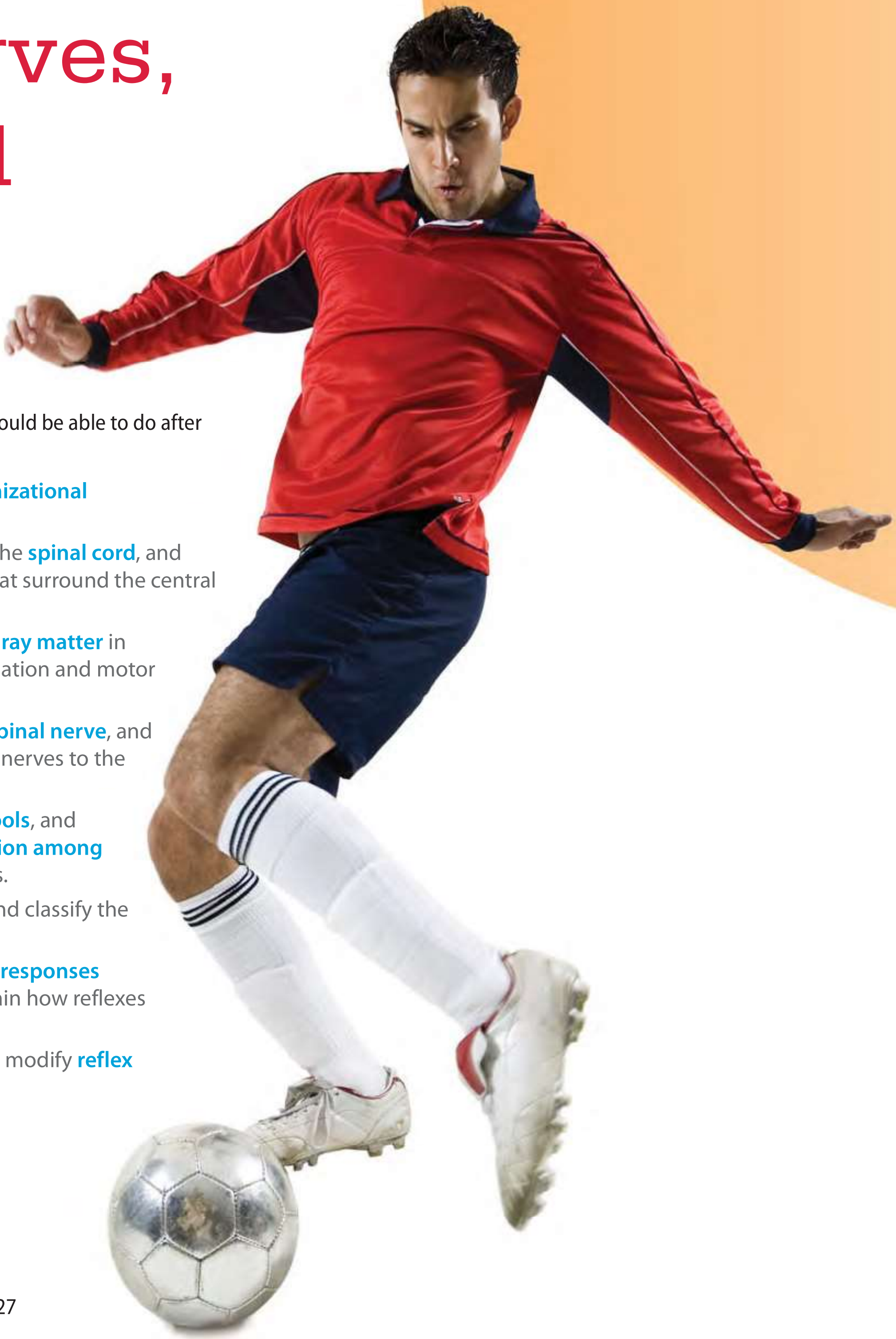
13

The Spinal Cord, Spinal Nerves, and Spinal Reflexes



Learning Outcomes

These Learning Outcomes correspond by number to this chapter's sections and indicate what you should be able to do after completing the chapter.

13-1 Describe the basic structural and **organizational characteristics of the nervous system**.

13-2 Discuss the structure and functions of the **spinal cord**, and describe the three **meningeal layers** that surround the central nervous system.

13-3 Explain the roles of **white matter and gray matter** in processing and relaying sensory information and motor commands.

13-4 Describe the **major components of a spinal nerve**, and relate the distribution pattern of spinal nerves to the regions they innervate.

13-5 Discuss the significance of **neuronal pools**, and describe the major patterns of **interaction among neurons** within and among these pools.

13-6 Describe the **steps in a neural reflex**, and classify the **types of reflexes**.

13-7 Distinguish among the **types of motor responses** produced by various reflexes, and explain how reflexes interact to produce complex behaviors.

13-8 Explain how higher centers control and modify **reflex responses**.

Clinical Notes

Spotlight

An Introduction to the Spinal Cord, Spinal Nerves, and Spinal Reflexes

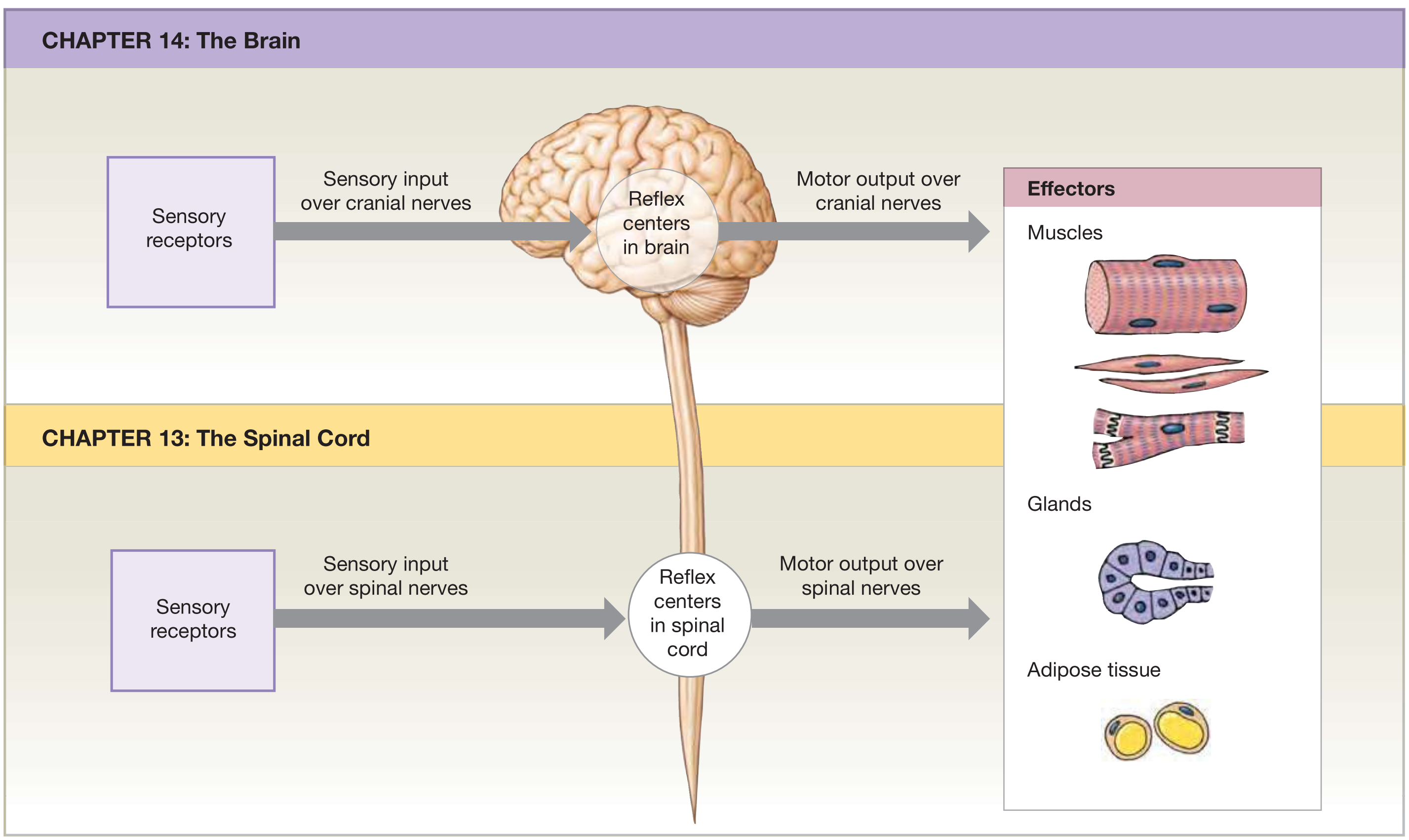
This chapter discusses the functional anatomy and organization of the spinal cord and spinal nerves, and describes simple spinal reflexes. Organization is usually the key to success in any complex environment. A large corporation, for example, has both a system to distribute messages on specific topics and executive assistants who decide whether an issue can be ignored or easily responded to; only the most complex and important problems reach the desk of the president. The nervous system works in much the same way: It has input pathways that route sensations, and processing centers that prioritize and distribute information. There are also several levels that issue motor responses. Your conscious mind (the president) gets involved only in a fraction of the day-to-day activities; the other decisions are handled at lower levels that operate outside your awareness. This very efficient system works only because it is so highly organized.

13-1 The brain and spinal cord make up the central nervous system, and the cranial nerves and spinal nerves constitute the peripheral nervous system

Because the nervous system has so many components and does so much, even a superficial discussion will take four chapters to complete. If our primary interest were the anatomy of this system, we would probably start with an examination of the central nervous system (brain and spinal cord) and then consider the peripheral nervous system (cranial nerves and spinal nerves). But our primary interest is how the nervous system *functions*, so we will consider the system from a functional perspective. The basic approach has been diagrammed in **Figure 13–1**.

In the chapters that follow, we will look at increasing levels of structural and functional complexity. Chapter 12 provided the foundation by considering the function of individual neurons.

Figure 13–1 An Overview of Chapters 13 and 14.



In the current chapter, we consider the spinal cord and spinal nerves, and the basic wiring of simple *spinal reflexes*—rapid, automatic responses triggered by specific stimuli. Spinal reflexes are controlled in the spinal cord; whether they involve a single spinal segment or multiple segments, they can function without any input from the brain. For example, a reflex controlled in the spinal cord makes you drop a frying pan you didn't realize was sizzling hot. Before the information reaches your brain and you become aware of the pain, you've already released the pan. Although there are much more complex spinal reflexes, this functional pattern still applies; a reflex provides a quick, automatic response to a specific stimulus.

Your spinal cord is structurally and functionally integrated with your brain. Chapter 14 provides an overview of the major components and functions of the brain and cranial nerves. It also discusses the *cranial reflexes*, localized reflex responses comparable in organization and complexity to those of the spinal cord.

Chapters 15 and 16 consider the nervous system as an integrated functional unit. Chapter 15 deals with the interplay between centers in the brain and spinal cord that occurs in the processing of sensory information. It then examines the conscious and subconscious control of skeletal muscle activity by the *somatic nervous system* (SNS).

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Chapter 16 continues with a discussion of the control of visceral functions by the *autonomic nervous system* (ANS). The ANS, which has processing centers in the brain, spinal cord, and peripheral nervous system, is responsible for the control of visceral effectors, such as smooth muscles, cardiac muscle, glands, and fat cells. We then conclude this section of the book by examining what are often called *higher-order functions*: memory, learning, consciousness, and personality. These fascinating topics are difficult to investigate, but they can affect activity along the sensory and motor pathways and alter our perception of those activities.

With these basic principles, definitions, and strategies in mind, we can begin our examination of the levels of functional organization in the nervous system.

Checkpoint

1. **Name the components of the central nervous system and of the peripheral nervous system.**
2. **Define spinal reflex.**

See the blue Answers tab at the back of the book.

13-2 ◗ The spinal cord is surrounded by three meninges and conveys sensory and motor information

We begin this section by studying the gross anatomy of the spinal cord. Then we examine the three layers that surround the spinal cord: the spinal meninges.

Gross Anatomy of the Spinal Cord

The adult spinal cord (**Figure 13–2a**) measures approximately 45 cm (18 in.) in length and has a maximum width of roughly 14 mm (0.55 in.). Note that the cord itself is not as long as the vertebral column—instead, the adult spinal cord ends between vertebrae L_1 and L_2. The posterior (dorsal) surface of the spinal cord has a shallow longitudinal groove, the **posterior median sulcus** (**Figure 13–2b**). The **anterior median fissure** is a deeper groove along the anterior (ventral) surface.

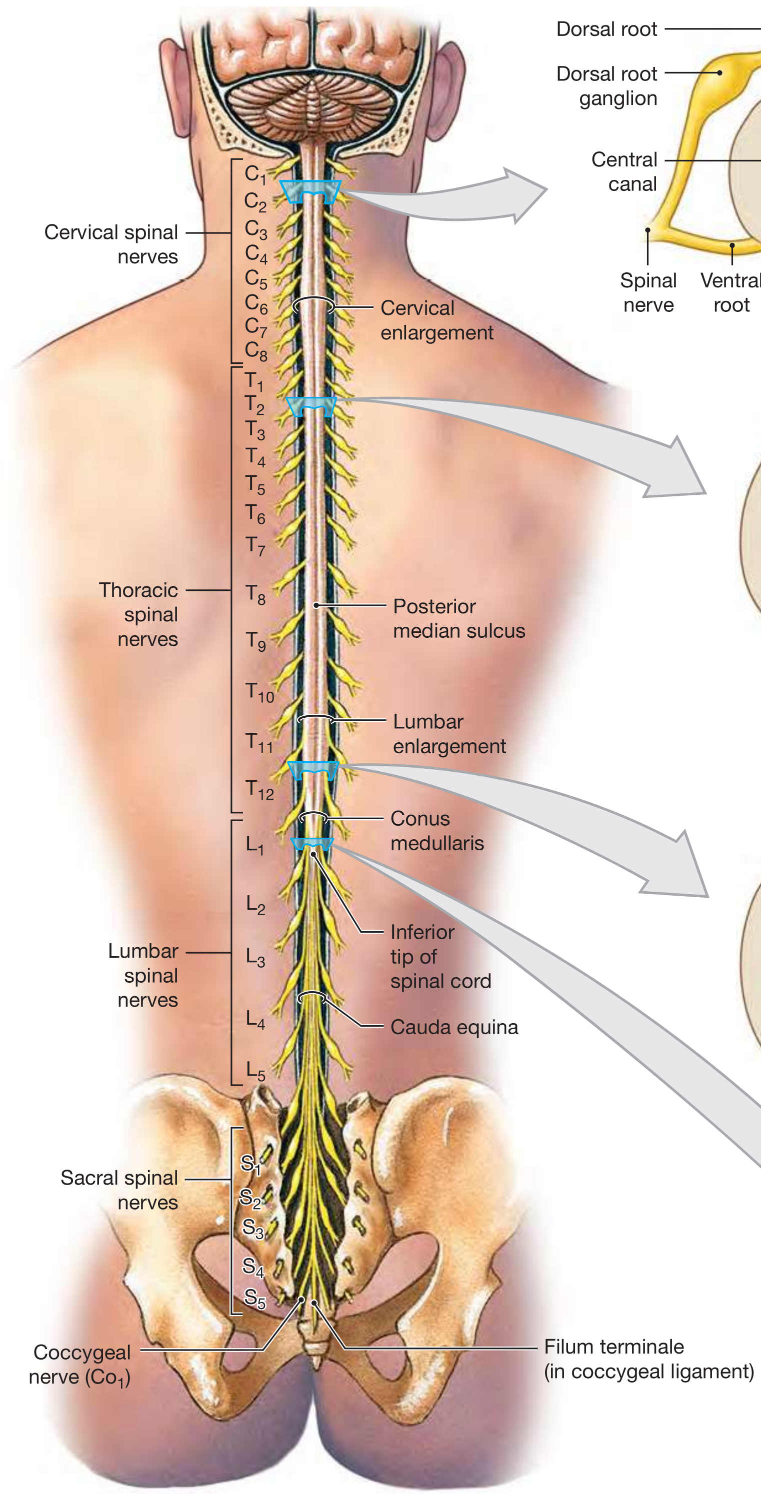
The amount of gray matter is greatest in segments of the spinal cord dedicated to the sensory and motor control of the limbs. These segments are expanded, forming the **enlargements** of the spinal cord. The **cervical enlargement** supplies nerves to the shoulder and upper limbs; the **lumbar enlargement** provides innervation to structures of the pelvis and lower limbs. Inferior to the lumbar enlargement, the spinal cord becomes tapered and conical; this region is the **conus medullaris.** The **filum terminale** ("terminal thread"), a slender strand of fibrous tissue, extends from the inferior tip of the conus medullaris. It continues along the length of the vertebral canal as far as the second sacral vertebra, where it provides longitudinal support to the spinal cord as a component of the *coccygeal ligament*.

The series of sectional views in **Figure 13–2b** illustrate the variations in the proportions of gray matter and white matter in the cervical, thoracic, lumbar, and sacral regions of the spinal cord. The entire spinal cord can be divided into 31 segments on the basis of the origins of the spinal nerves. A letter and number designation, the same method used to identify vertebrae, identify each segment. For example, C_3, the segment in the uppermost section of **Figure 13–2b**, is the third cervical segment.

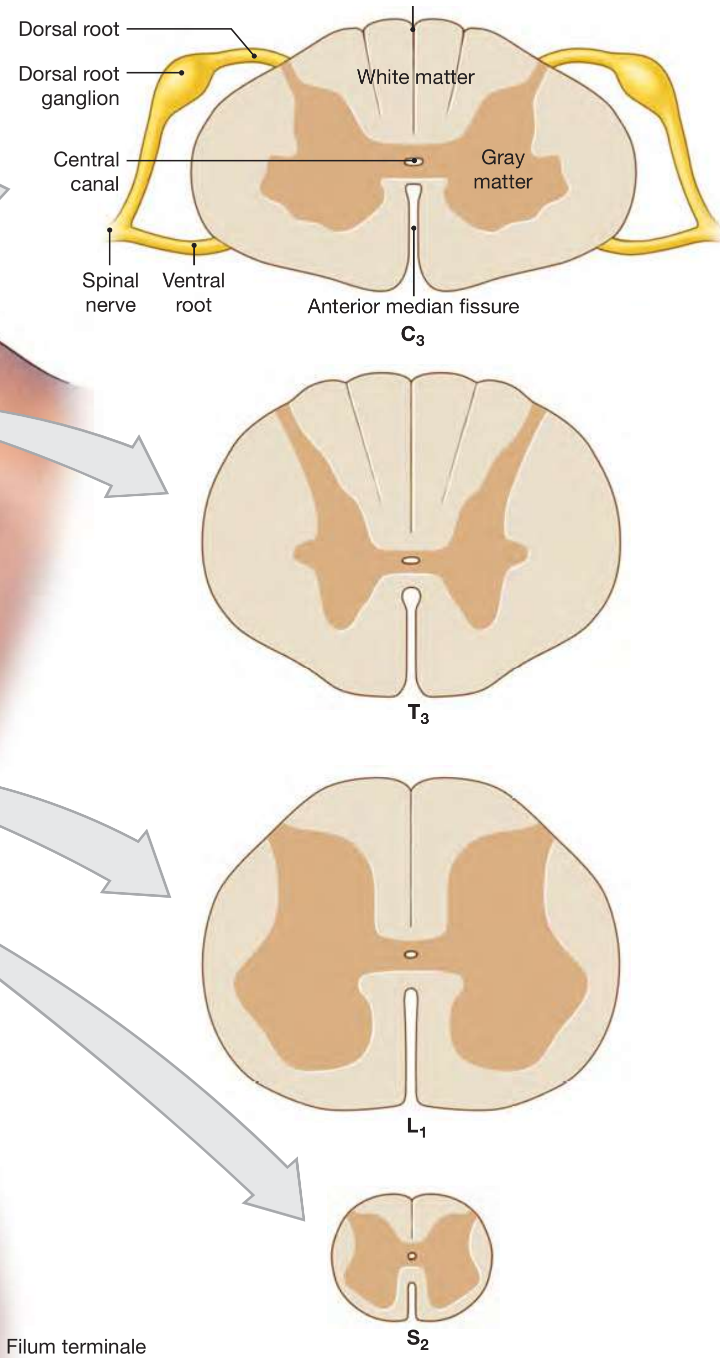
Every spinal segment is associated with a pair of **dorsal root ganglia** (**Figure 13–2b**), located near the spinal cord. These ganglia contain the cell bodies of sensory neurons. The axons of the neurons form the **dorsal roots,** which bring sensory information into the spinal cord. A pair of **ventral roots** contains the axons of motor neurons that extend into the periphery to control somatic and visceral effectors. On both sides, the dorsal and ventral roots of each segment pass between the vertebral canal and the periphery at the *intervertebral foramen* between successive vertebrae. The dorsal root ganglion lies between the pedicles of the adjacent vertebrae. (You can review vertebral anatomy in Chapter 7. ⮌ pp. 217–219)

Distal to each dorsal root ganglion, the sensory and motor roots are bound together into a single **spinal nerve.** Spinal nerves are classified as **mixed nerves**—that is, they contain both afferent (sensory) and efferent (motor) fibers. There are 31 pairs of spinal nerves, each identified by its association with adjacent vertebrae. For example, we may speak of "cervical spinal nerves" or even "cervical nerves" when we make a general reference to spinal nerves of the neck. However, when we indicate specific spinal nerves, it is customary to give them a regional number, as indicated in **Figure 13–2**. Each spinal nerve inferior to the first

Figure 13–2 **Gross Anatomy of the Adult Spinal Cord.** ATLAS: Plates 2a; 20a,b; 24a–c



a The superficial anatomy and orientation of the adult spinal cord. The numbers to the left identify the spinal nerves and indicate where the nerve roots leave the vertebral canal. The spinal cord extends from the brain only to the level of vertebrae L_1–L_2; the spinal segments found at representative locations are indicated in the cross sections.



b Inferior views of cross sections through representative segments of the spinal cord, showing the arrangement of gray matter and white matter.

thoracic vertebra takes its name from the vertebra immediately superior to it. Thus, spinal nerve T_1 emerges immediately inferior to vertebra T_1, spinal nerve T_2 follows vertebra T_2, and so forth.

The arrangement differs in the cervical region, because the first pair of spinal nerves, C_1, passes between the skull and the first cervical vertebra. For this reason, each cervical nerve takes its name from the vertebra immediately inferior to it. In other words, cervical nerve C_2 *precedes* vertebra C_2, and the same system is used for the rest of the cervical series. The transition from one numbering system to another occurs between the last cervical vertebra and first thoracic vertebra. The spinal nerve found at this location has been designated C_8. Therefore, although there are only seven cervical vertebrae, there are *eight* cervical nerves.

The spinal cord continues to enlarge and elongate until an individual is approximately 4 years old. Up to that time, enlargement of the spinal cord keeps pace with the growth of the vertebral column. Throughout this period, the ventral and dorsal roots are very short, and they enter the intervertebral foramina immediately adjacent to their spinal segment. After age 4, the vertebral column continues to elongate, but the spinal cord does not. This vertebral growth moves the intervertebral foramina, and thus the spinal nerves, farther and farther from their original positions relative to the spinal cord. As a result, the dorsal and ventral roots gradually elongate, and the correspondence between the spinal segment and the vertebral segment is lost. For example, in adults, the sacral segments of the spinal cord are at the level of vertebrae L_1–L_2.

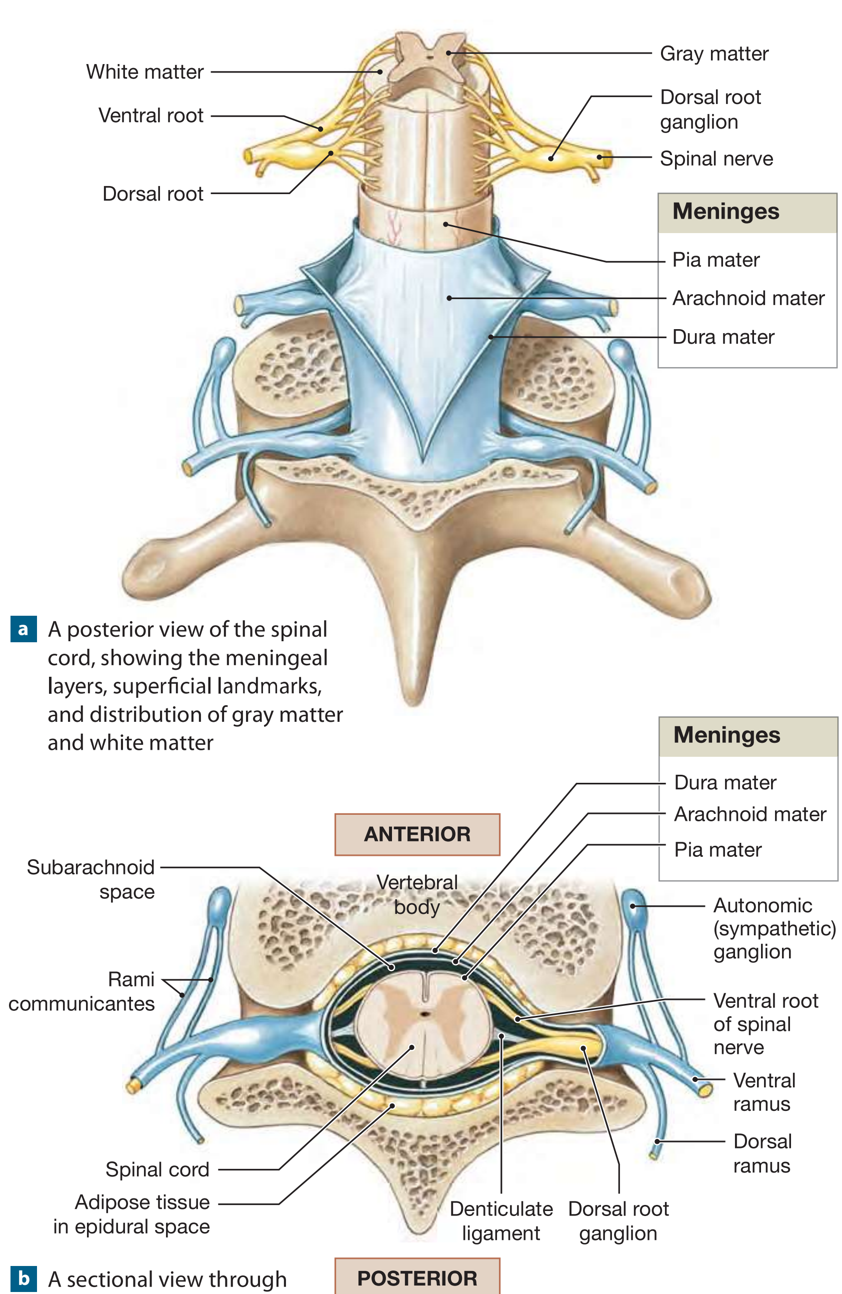
Because the adult spinal cord extends only to the level of the first or second lumbar vertebra, the dorsal and ventral roots of spinal segments L_2 to S_5 extend inferiorly, past the inferior tip of the conus medullaris. When seen in gross dissection, the filum terminale and the long ventral and dorsal roots resemble a horse's tail. As a result, early anatomists called this complex the **cauda equina** (KAW-duh ek-WĪ-nuh; *cauda*, tail + *equus*, horse).

Spinal Meninges

The vertebral column and its surrounding ligaments, tendons, and muscles isolate the spinal cord from the rest of the body, and these structures also provide protection against bumps and shocks to the skin of the back. The delicate neural tissues must also be protected from damaging contacts with the surrounding bony walls of the vertebral canal. The **spinal meninges** (me-NIN-jēz; singular, *meninx*, membrane), a series of specialized membranes surrounding the spinal cord, provide the necessary physical stability and shock absorption. Blood vessels branching within these layers deliver oxygen and nutrients to the spinal cord.

The relationships among the spinal meninges are shown in **Figure 13–3a**. The spinal meninges consist of three layers: (1) the *dura mater*, (2) the *arachnoid mater*, and (3) the *pia mater*. At the foramen magnum of the skull, the spinal meninges are

Figure 13–3 The Spinal Cord and Spinal Meninges.



a A posterior view of the spinal cord, showing the meningeal layers, superficial landmarks, and distribution of gray matter and white matter

b A sectional view through the spinal cord and meninges, showing the peripheral distribution of spinal nerves continuous with the **cranial meninges,** which surround the brain. (We discuss the cranial meninges, which have the same three layers, in Chapter 14.)

Bacterial or viral infection can cause **meningitis,** or inflammation of the meningeal membranes. Meningitis is dangerous because it can disrupt the normal circulation of cerebrospinal fluid, damaging or killing neurons and neuroglia in the affected areas. Although an initial diagnosis may specify the meninges of the spinal cord *(spinal meningitis)* or brain *(cerebral meningitis)*, in later stages the entire meningeal system is usually affected.

The Dura Mater

The tough, fibrous **dura mater** (DOO-ruh MĀ-ter; *dura*, hard + *mater*, mother) is the layer that forms the outermost covering of the spinal cord (**Figure 13–3a**). This layer contains dense collagen fibers that are oriented along the longitudinal axis of the cord. Between the dura mater and the walls of the vertebral canal lies the **epidural space,** a region that contains areolar tissue, blood vessels, and a protective padding of adipose tissue (**Figure 13–3b**).

The spinal dura mater does not have extensive, firm connections to the surrounding vertebrae. Attachment sites at either end of the vertebral canal provide longitudinal stability. Cranially, the outer layer of the spinal dura mater fuses with the periosteum of the occipital bone around the margins of the foramen magnum. There, the spinal dura mater becomes continuous with the cranial dura mater. Within the sacral canal, the spinal dura mater tapers from a sheath to a dense cord of collagen fibers that blends with components of the filum terminale to form the **coccygeal ligament** (**Figure 13–2a**). The coccygeal ligament continues along the sacral canal, ultimately blending into the periosteum of the coccyx. Loose connective tissue and adipose tissue within the epidural space support the spinal dura mater. In addition, this dura mater extends between adjacent vertebrae at each intervertebral foramen, fusing with the connective tissues that surround the spinal nerves.

Anesthetics are often injected into the epidural space. Introduced in this way, a drug should affect only the spinal nerves in the immediate area of the injection. The result is an *epidural block*—a temporary sensory loss or a sensory and motor paralysis, depending on the anesthetic selected. Epidural blocks in the inferior lumbar or sacral regions may be used to control pain during childbirth.

The Arachnoid Mater

In most anatomical and tissue specimens, a narrow **subdural space** separates the dura mater from deeper meningeal layers. It is likely, however, that in a living person no such space exists, and that the inner surface of the dura mater is in contact with the outer surface of the **arachnoid** (a-RAK-noyd; *arachne*, spider) **mater,** the middle meningeal layer (**Figure 13–3b**). The inner surface of the dura mater and the outer surface of the arachnoid mater are covered by simple squamous epithelia. The arachnoid mater includes this epithelium, called the *arachnoid membrane*, and the *arachnoid trabeculae*, a delicate network of collagen and elastic fibers that extends between the arachnoid membrane and the outer surface of the pia mater. The region between is called the **subarachnoid space.** It is filled with **cerebrospinal fluid (CSF),** which acts as a shock absorber and a diffusion medium for dissolved gases, nutrients, chemical messengers, and waste products.

The spinal arachnoid mater extends inferiorly as far as the filum terminale, and the dorsal and ventral roots of the cauda equina lie within the fluid-filled subarachnoid space. In adults, the withdrawal of cerebrospinal fluid, a procedure known as a **lumbar puncture** or **spinal tap,** involves the insertion of a needle into the subarachnoid space in the inferior lumbar region.

The Pia Mater

The subarachnoid space extends between the arachnoid epithelium and the innermost meningeal layer, the **pia mater** (*pia*, delicate + *mater*, mother). The pia mater consists of a meshwork of elastic and collagen fibers that is firmly bound to the underlying neural tissue (**Figure 13–3**). These connective-tissue fibers are extensively interwoven with those that span the subarachnoid space, firmly binding the arachnoid to the pia mater. The blood vessels servicing the spinal cord run along the surface of the spinal pia mater, within the subarachnoid space (**Figure 13–4**).

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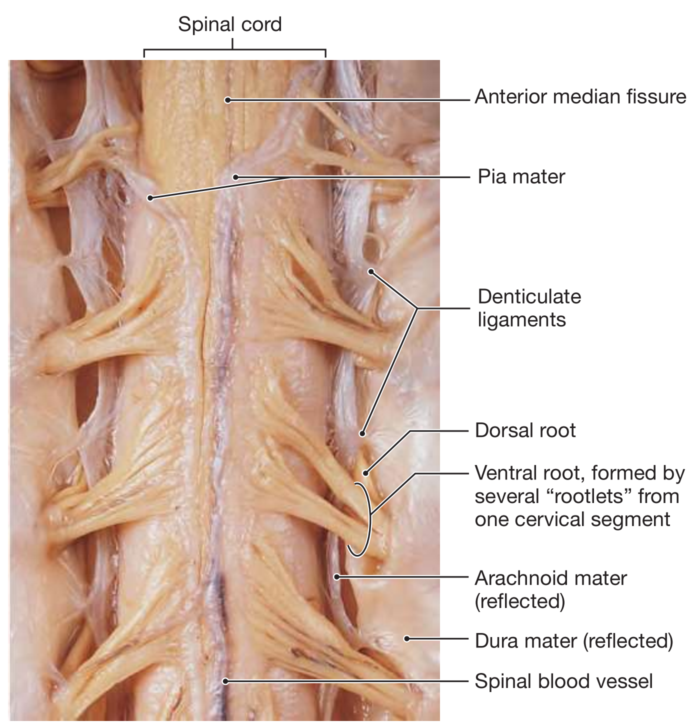
Figure 13–4 The Spinal Cord and Associated Structures. An anterior view of the cervical spinal cord and spinal nerve roots in the vertebral canal. The dura mater and arachnoid mater have been cut and reflected; notice the blood vessels that run in the subarachnoid space, bound to the outer surface of the delicate pia mater.



Clinical Note — Anesthesia

Oh, my **non-aching back**

Injecting a local anesthetic around a nerve produces a temporary blockage of sensory and motor nerve function. This procedure can be done either peripherally, as when skin lacerations are sewn up, or at sites around the spinal cord to obtain more widespread anesthetic effects. An *epidural block*—the injection of an anesthetic into the epidural space—has at least two advantages: (1) It affects only the spinal nerves in the immediate area of the injection, and (2) it provides mainly sensory anesthesia. If a catheter is left in place, continued injection allows sustained anesthesia.

Caudal anesthesia involves the introduction of anesthetics into the epidural space of the sacrum. Injection at this site paralyzes and anesthetizes lower abdominal and perineal structures. Caudal anesthesia can be used to control pain during labor and delivery, but lumbar epidural anesthesia is often preferred.

Local anesthetics can also be introduced as a single dose into the subarachnoid space of the spinal cord. This procedure is commonly called **spinal anesthesia.** The effects include both temporary muscle paralysis and sensory loss, which tend to spread as the movement of cerebrospinal fluid distributes the anesthetic along the spinal cord. Problems with overdosing are seldom serious, because controlling the patient's position during administration can limit the distribution of the drug to some degree. Because the diaphragmatic breathing muscles are controlled by upper cervical spinal nerves, respiration continues even if all thoracic and abdominal segments have been paralyzed.

Along the length of the spinal cord, paired **denticulate ligaments** extend from the pia mater through the arachnoid mater to the dura mater (**Figures 13–3b** and **13–4**). Denticulate ligaments, which originate along either side of the spinal cord, prevent lateral (side-to-side) movement. The dural connections at the foramen magnum and the coccygeal ligament prevent longitudinal (superior–inferior) movement.

The spinal meninges accompany the dorsal and ventral roots as these roots pass through the intervertebral foramina. As the sectional view in **Figure 13–3b** indicates, the meningeal membranes are continuous with the connective tissues that surround the spinal nerves and their peripheral branches.

Checkpoint

3. **Identify the three spinal meninges.**
4. **Damage to which root of a spinal nerve would interfere with motor function?**
5. **Where is the cerebrospinal fluid that surrounds the spinal cord located?**

See the blue Answers tab at the back of the book.

13-3 ◗ Gray matter is the region of integration and command initiation, and white matter carries information from place to place

To understand the functional organization of the spinal cord, you must become familiar with its sectional organization (**Figure 13–5**). Together, the anterior median fissure and the posterior median sulcus divide the spinal cord into left and right sides. The superficial white matter contains large numbers of myelinated and unmyelinated axons. The gray matter, dominated by the cell bodies of neurons, neuroglia, and unmyelinated axons, surrounds the narrow **central canal** and forms an H or butterfly shape. **Horns** are the areas of gray matter on each side of the spinal cord.

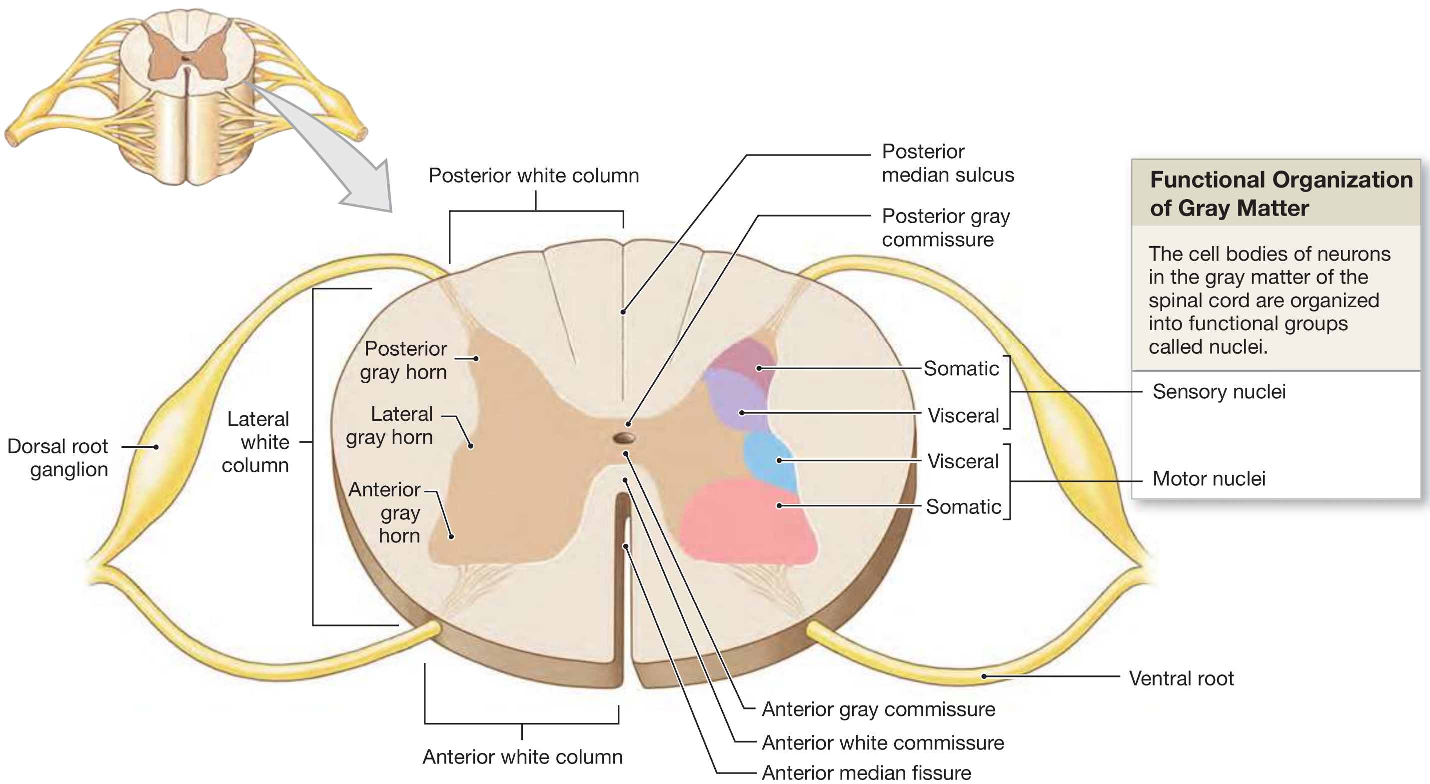
Organization of Gray Matter

Nuclei are masses of gray matter within the central nervous system. **Sensory nuclei** receive and relay sensory information from peripheral receptors. **Motor nuclei** issue motor commands to peripheral effectors. Although sensory and motor nuclei appear small in transverse section, they may extend for a considerable distance along the length of the spinal cord.

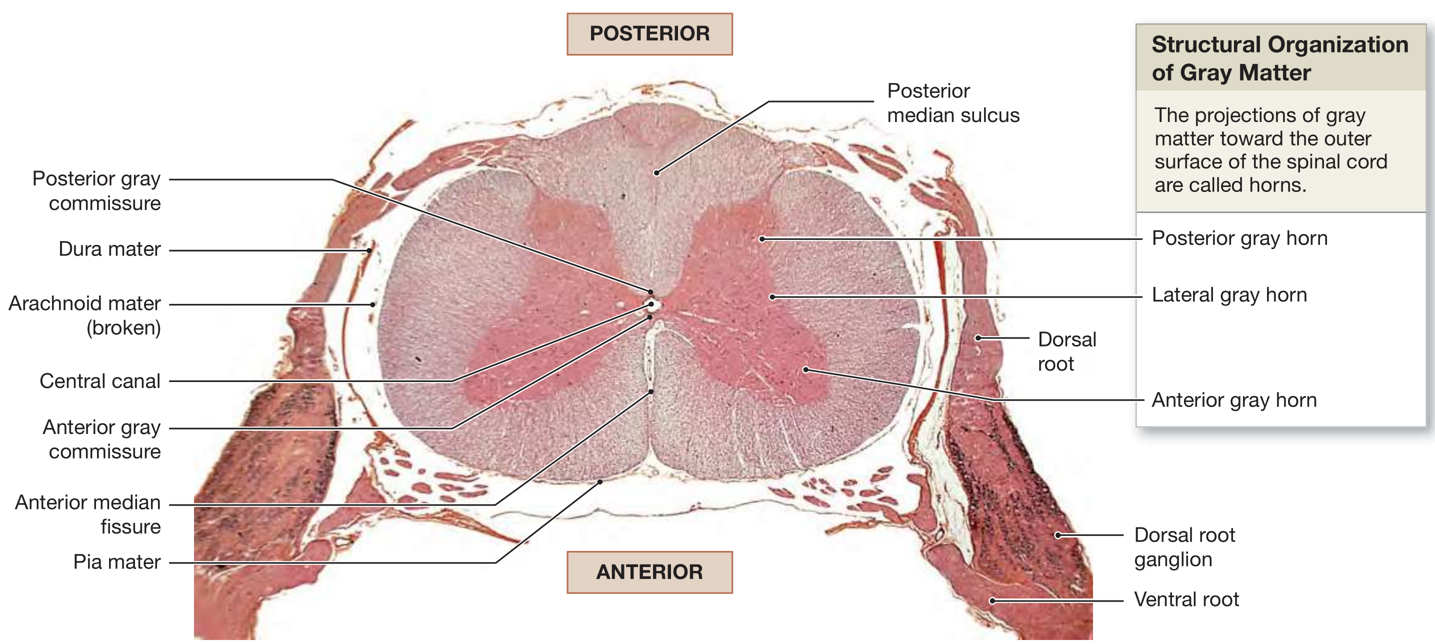
A frontal section along the length of the central canal of the spinal cord separates the sensory (posterior, or dorsal) nuclei from the motor (anterior, or ventral) nuclei. The **posterior gray horns** contain somatic and visceral sensory nuclei, whereas the **anterior gray horns** contain somatic motor nuclei. The **lateral gray horns,** located only in the thoracic and lumbar segments, contain visceral motor nuclei. The **gray commissures** (*commissura*, a joining together) posterior to and anterior to the central canal contain axons that cross from one side of the cord to the other before they reach an area in the gray matter.

Figure 13–5a shows the relationship between the function of a particular nucleus (sensory or motor) and its position in

Figure 13–5 The Sectional Organization of the Spinal Cord.



a The left half of this sectional view shows important anatomical landmarks, including the three columns of white matter. The right half indicates the functional organization of the nuclei in the anterior, lateral, and posterior gray horns.



b A micrograph of a section through the spinal cord, showing major landmarks in and surrounding the cord.

the gray matter of the spinal cord. The nuclei within each gray horn are also spatially organized. In the cervical enlargement, for example, the anterior gray horns contain nuclei whose motor neurons control the muscles of the upper limbs. On each side of the spinal cord, in medial to lateral sequence, are somatic motor nuclei that control (1) muscles that position the pectoral girdle, (2) muscles that move the arm, (3) muscles that move the forearm and hand, and (4) muscles that move the hand and fingers. Within each of these regions, the motor neurons that control flexor muscles are grouped separately from those that control extensor muscles. Because the spinal cord is so highly organized, we can predict which muscles will be affected by damage to a specific area of gray matter.

Organization of White Matter

The white matter on each side of the spinal cord can be divided into three regions called **columns**, or *funiculi* (**Figure 13–5a**). The **posterior white columns** lie between the posterior gray horns and the posterior median sulcus. The **anterior white columns** lie between the anterior gray horns and the anterior median fissure. The anterior white columns are interconnected by the **anterior white commissure,** a region where axons cross from one side of the spinal cord to the other. The white matter between the anterior and posterior columns on each side makes up the **lateral white column.**

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Each column contains tracts whose axons share functional and structural characteristics. A **tract,** or *fasciculus* (fa-SIK-ū-lus ; bundle), is a bundle of axons in the CNS that is somewhat uniform with respect to diameter, myelination, and conduction speed. All the axons within a tract relay the same type of information (sensory or motor) in the same direction. Short tracts carry sensory or motor signals between segments of the spinal cord, and longer tracts connect the spinal cord with the brain. **Ascending tracts** carry *sensory* information toward the brain, and **descending tracts** convey *motor* commands to the spinal cord. We describe the major tracts and their functions in Chapters 15 and 16. Because spinal tracts have very specific functions, damage to one produces a characteristic loss of sensation or motor control.

Checkpoint

6. **Differentiate between sensory nuclei and motor nuclei.**
7. **A person with polio has lost the use of his leg muscles. In which area of his spinal cord would you expect the virus-infected motor neurons to be?**
8. **A disease that damages myelin sheaths would affect which portion of the spinal cord?**

See the blue Answers tab at the back of the book.

13-4 Spinal nerves form plexuses that are named according to their level of emergence from the vertebral canal

In this section we consider the structure and function of spinal nerves. After we examine the anatomy and distribution of spinal nerves, we explore the interwoven networks of spinal nerves called nerve plexuses.

Anatomy of Spinal Nerves

Every segment of the spinal cord is connected to a pair of spinal nerves. Surrounding each spinal nerve is a series of connective tissue layers continuous with those of the associated peripheral nerves (**Figure 13–6**). These layers, best seen in sectional view, are comparable to those associated with skeletal muscles. ⮌ p. 280 The **epineurium,** or outermost layer, consists of a dense network of collagen fibers. The fibers of the **perineurium,** the middle layer, extend inward from the epineurium. These connective tissue partitions divide the nerve into a series of compartments that contain bundles of axons, or *fascicles*. Delicate connective tissue fibers of the **endoneurium,** the innermost layer, extend from the perineurium and surround individual axons.

Arteries and veins penetrate the epineurium and branch within the perineurium. Capillaries leaving the perineurium branch in the endoneurium and supply the axons and Schwann cells of the nerve and the fibroblasts of the connective tissues.

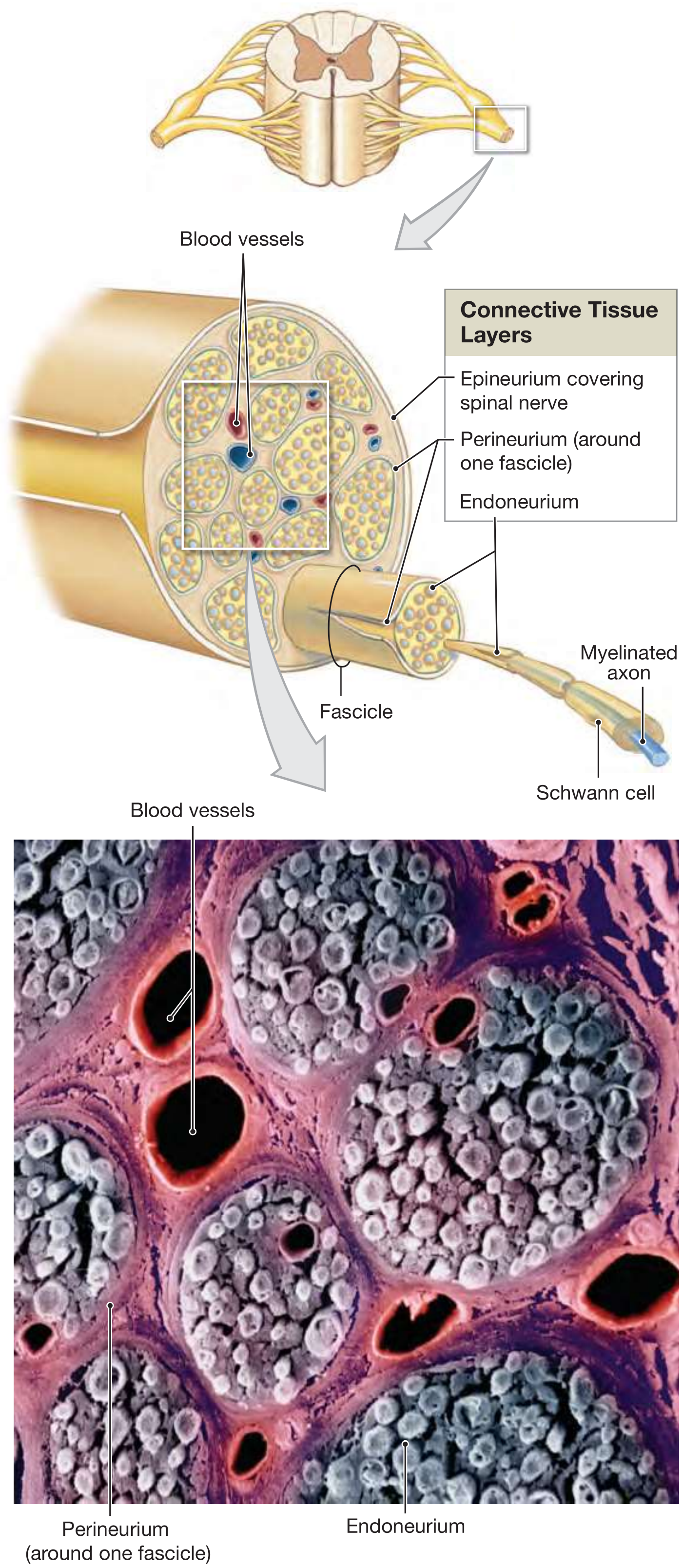
As they extend into the periphery, the spinal nerves branch and interconnect, forming the peripheral nerves that innervate body tissues and organs. The connective tissue sheaths of peripheral nerves are the same as, and continuous with, those of spinal nerves.

If a peripheral axon is severed but not displaced, normal function may eventually return as the cut stump grows across the site of injury, away from the cell body and along its former path. ⮌ p. 385 Repairs made after an entire peripheral *nerve* has been damaged are generally incomplete, primarily because of problems with axon alignment and regrowth. Various technologically sophisticated procedures designed to improve nerve regeneration and repair are currently under evaluation.

Peripheral Distribution of Spinal Nerves

Spotlight Figure 13–7 shows the distribution, or pathway, of a typical spinal nerve that originates from the thoracic or superior lumbar segments of the spinal cord. The spinal nerve forms just lateral to the intervertebral foramen, where the dorsal and ven-

Figure 13–6 A Peripheral Nerve. A diagrammatic view and an electron micrograph of a typical spinal nerve. Note the connective tissue layers that are continuous with the associated spinal nerve. (SEM × 340) [Image by © Dr. Richard Kessel & Dr. Randy Kardon/Tissues & Organs/Visuals Unlimited/Corbis]



tral roots unite. We consider the pathways of both the sensory information and the motor commands.

The specific bilateral region of the skin surface monitored by a single pair of spinal nerves is known as a **dermatome.** Each pair of spinal nerves services its own dermatome (**Figure 13–8**), although the boundaries of adjacent dermatomes overlap to some degree. Dermatomes are clinically important because damage or infection of a spinal nerve or dorsal root ganglion will produce a loss of sensation in the corresponding region of the skin. Additionally, characteristic signs may appear on the skin supplied by that specific nerve.

Peripheral *nerve palsies*, or **peripheral neuropathies,** are regional losses of sensory and motor function most often resulting from nerve trauma or compression. (You have experienced a mild, temporary palsy if your arm or leg has ever "fallen asleep" after you leaned or sat in an uncomfortable position.) The location of the affected dermatomes provides clues to the location of injuries along the spinal cord, but the information is not precise. More exact conclusions can be drawn if there is loss of motor control, based on the origin and distribution of the peripheral nerves originating at nerve plexuses.

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Nerve Plexuses

The simple distribution pattern of dorsal and ventral rami in **Figure 13–7** applies to spinal nerves T_1–T_{12}. But in segments controlling the skeletal musculature of the neck, upper limbs, or lower limbs, the situation is more complicated. During development, small skeletal muscles innervated by different ventral rami typically fuse to form larger muscles with compound origins. The anatomical distinctions between the component muscles may disappear, but separate ventral rami continue to provide sensory innervation and motor control to each part of the compound muscle. As they converge, the ventral rami of adjacent spinal nerves blend their fibers, producing a series of compound nerve trunks. Such a complex interwoven network of nerves is called a **nerve plexus** (PLEK-sus; *plexus*, braid). The ventral rami form four major plexuses: (1) the *cervical plexus*, (2) the *brachial plexus*, (3) the *lumbar plexus*, and (4) the *sacral plexus* (**Figure 13–10**). Because they form from the fusion of ventral rami, the nerves arising at these plexuses contain sensory as well as motor fibers (**Figure 13–7**).

In Chapter 11, we introduced the peripheral nerves that control the major axial and appendicular muscles. As we proceed, you may find it helpful to refer to the related tables in that chapter. ⮌ pp. 334–366

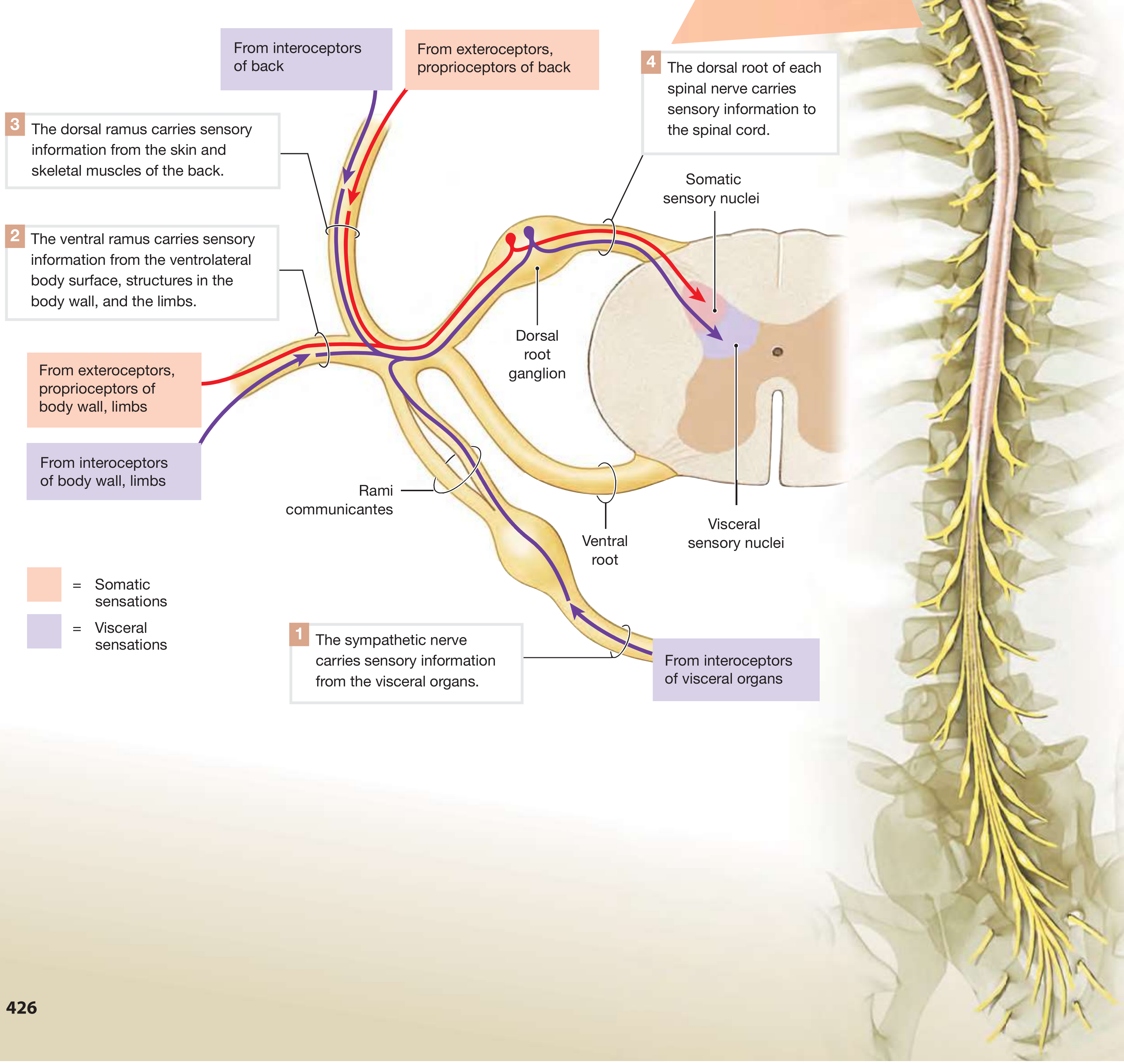
Spotlight

Figure 13–7

Peripheral Distribution of Spinal Nerves

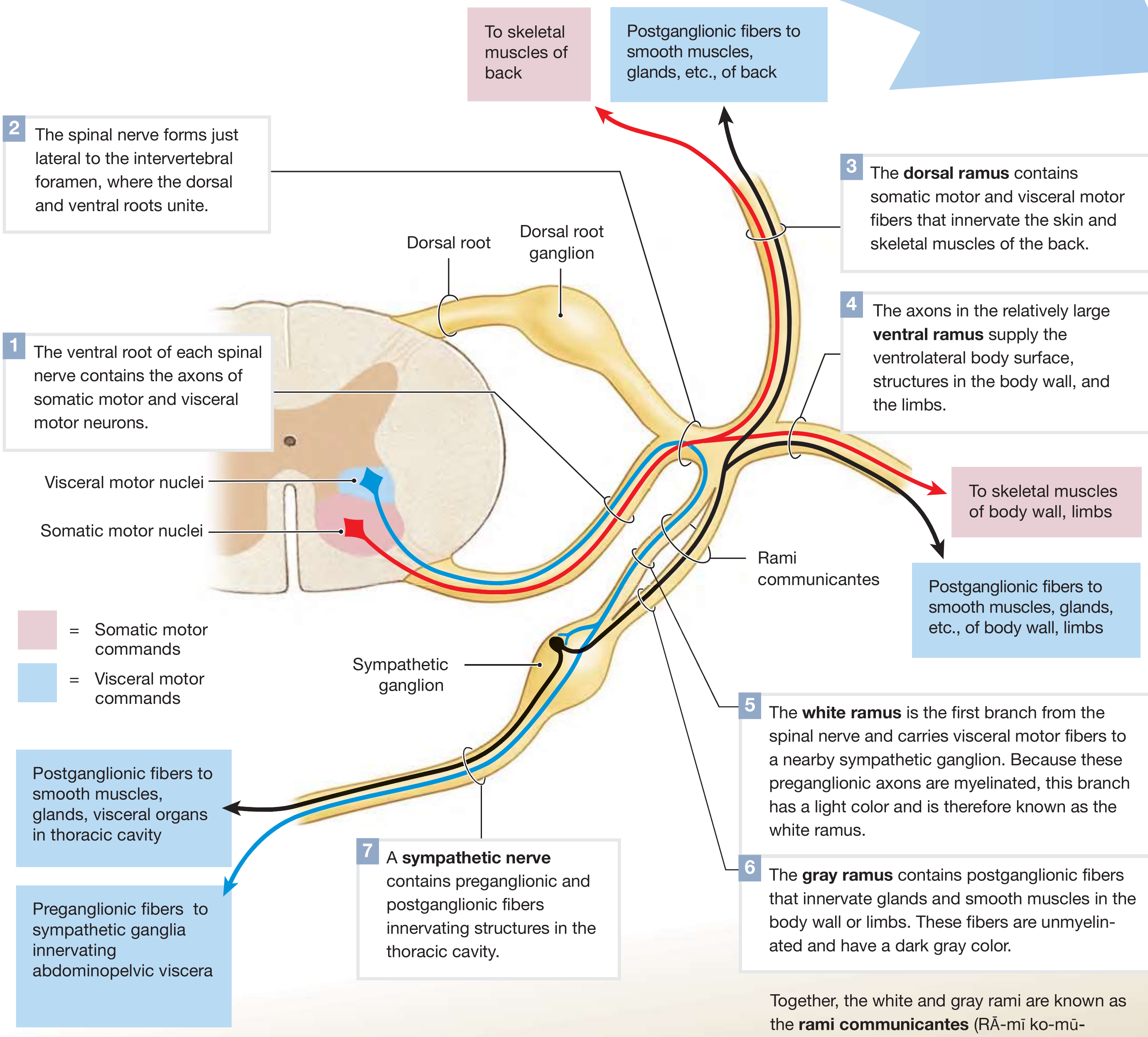
SENSORY INFORMATION

A spinal nerve collects sensory information from peripheral structures and delivers it to sensory nuclei in the thoracic or superior lumbar segments of the spinal cord. The dorsal, ventral, and white rami also contain sensory fibers.



MOTOR COMMANDS

A spinal nerve distributes motor commands that originate in motor nuclei of the thoracic or superior lumbar segments of the spinal cord.



1 The ventral root of each spinal nerve contains the axons of somatic motor and visceral motor neurons.

2 The spinal nerve forms just lateral to the intervertebral foramen, where the dorsal and ventral roots unite.

3 The **dorsal ramus** contains somatic motor and visceral motor fibers that innervate the skin and skeletal muscles of the back.

4 The axons in the relatively large **ventral ramus** supply the ventrolateral body surface, structures in the body wall, and the limbs.

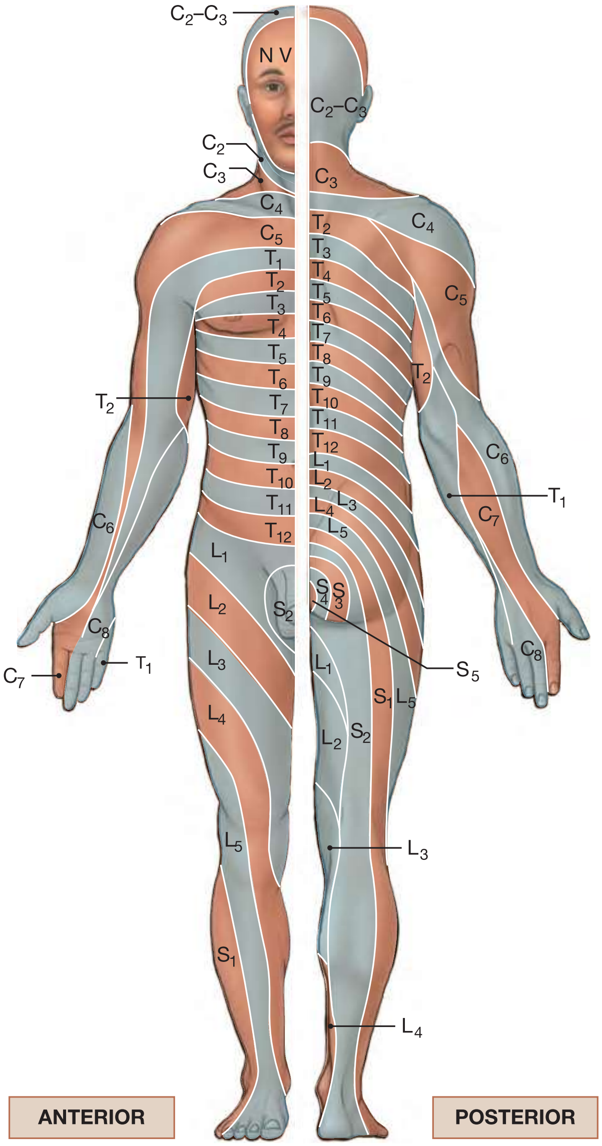
5 The **white ramus** is the first branch from the spinal nerve and carries visceral motor fibers to a nearby sympathetic ganglion. Because these preganglionic axons are myelinated, this branch has a light color and is therefore known as the white ramus.

6 The **gray ramus** contains postganglionic fibers that innervate glands and smooth muscles in the body wall or limbs. These fibers are unmyelinated and have a dark gray color.

7 A **sympathetic nerve** contains preganglionic and postganglionic fibers innervating structures in the thoracic cavity.

Together, the white and gray rami are known as the **rami communicantes** (RĀ-mī ko-mū-ni-KAN-tēz), or “communicating branches” (singular, *ramus communicans*).

Figure 13–8 Dermatomes. Anterior and posterior distributions of dermatomes on the surface of the skin. N V = fifth cranial nerve (trigeminal nerve).



The Cervical Plexus

The **cervical plexus** consists of the ventral rami of spinal nerves $C_1–C_5$ (**Figures 13–10, 13–11**; **Table 13–1**).The branches of the cervical plexus innervate the muscles of the neck and extend into the thoracic cavity, where they control the diaphragmatic muscles. The **phrenic nerve,** the major nerve of

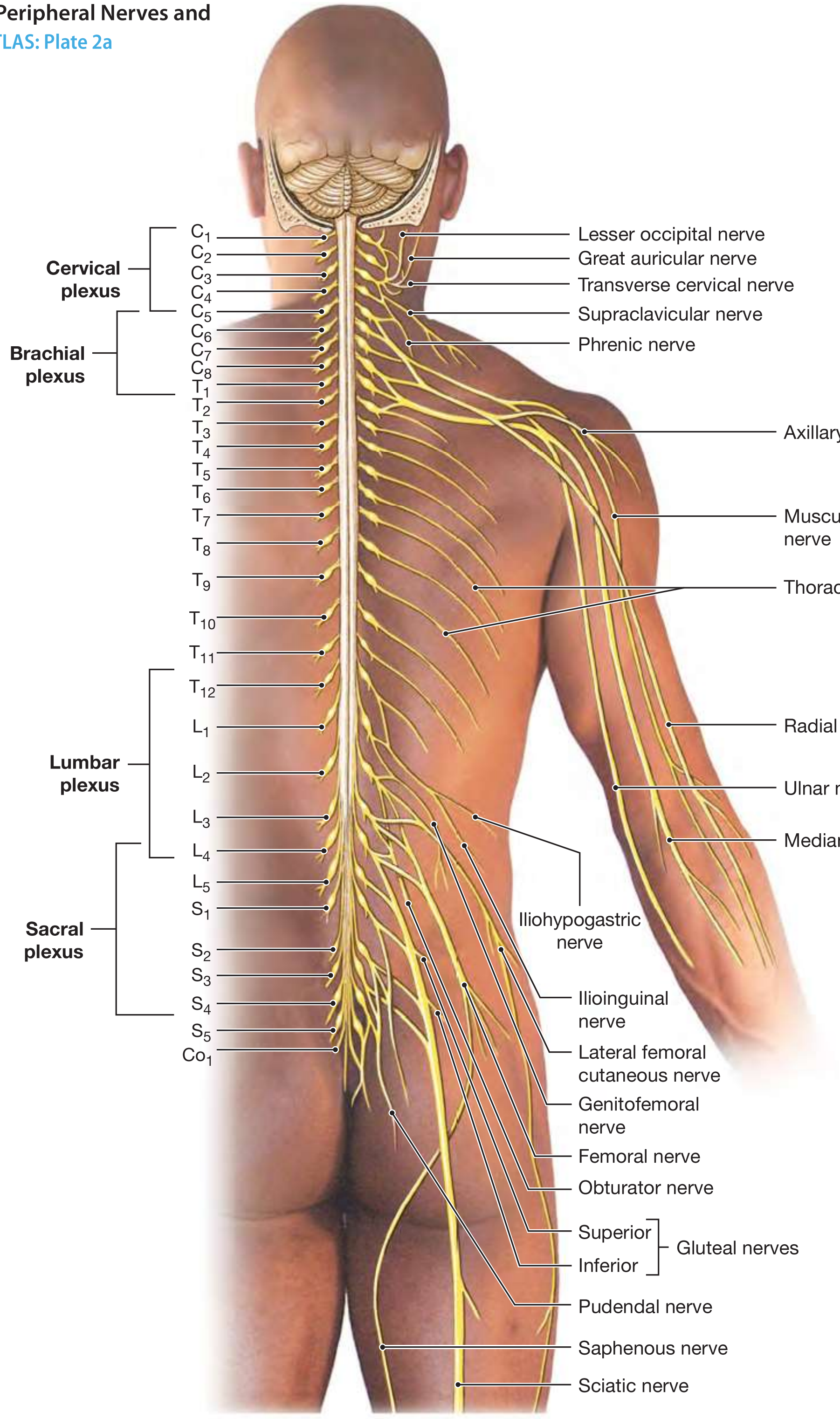
Clinical Note

Shingles **Shingles** (derived from the Latin *cingulum*, girdle) is caused by the varicella-zoster virus (VZV), the same virus that causes chickenpox. This herpes virus attacks neurons within the dorsal roots of spinal nerves and sensory ganglia of cranial nerves. The disorder produces a painful rash and blisters whose distribution corresponds to that of the affected sensory nerves and follows its dermatome (**Figure 13–9**). Anyone who has had chickenpox is at risk of developing shingles. After the initial encounter, the virus remains dormant within neurons of the anterior gray horns of the spinal cord. It is not known what triggers the reactivation of this pathogen. Fortunately for those affected, attacks of shingles usually heal and leave behind only unpleasant memories.

Most people who contract shingles suffer just a single episode in their adult lives. *Postherpetic neuralgia* is a painful condition experienced by some after a bout of shingles. Moreover, the problem can recur in people with weakened immune systems, including the elderly and individuals with AIDS or some forms of cancer. Treatment for shingles typically involves large doses of antiviral drugs. In 2006, the U.S. Food and Drug Administration approved a VZV vaccine (Zostavax) for use in people ages 60 and above who have had chickenpox.

Figure 13–9 Shingles. The skin eruptions follow the distribution of the dermatomal innervation.

Figure 13–10 Peripheral Nerves and Nerve Plexuses. ATLAS: Plate 2a



the cervical plexus, provides the entire nerve supply to the diaphragm, a key respiratory muscle. Other branches of this nerve plexus are distributed to the skin of the neck and the superior part of the chest.

The Brachial Plexus

The **brachial plexus** innervates the pectoral girdle and upper limb, with contributions from the ventral rami of spinal nerves C_5–T_1 (**Figures 13–10** and **13–12**; **Table 13–2**). The brachial

Figure 13–11 The Cervical Plexus. ATLAS: Plates 3c,d; 18a–c

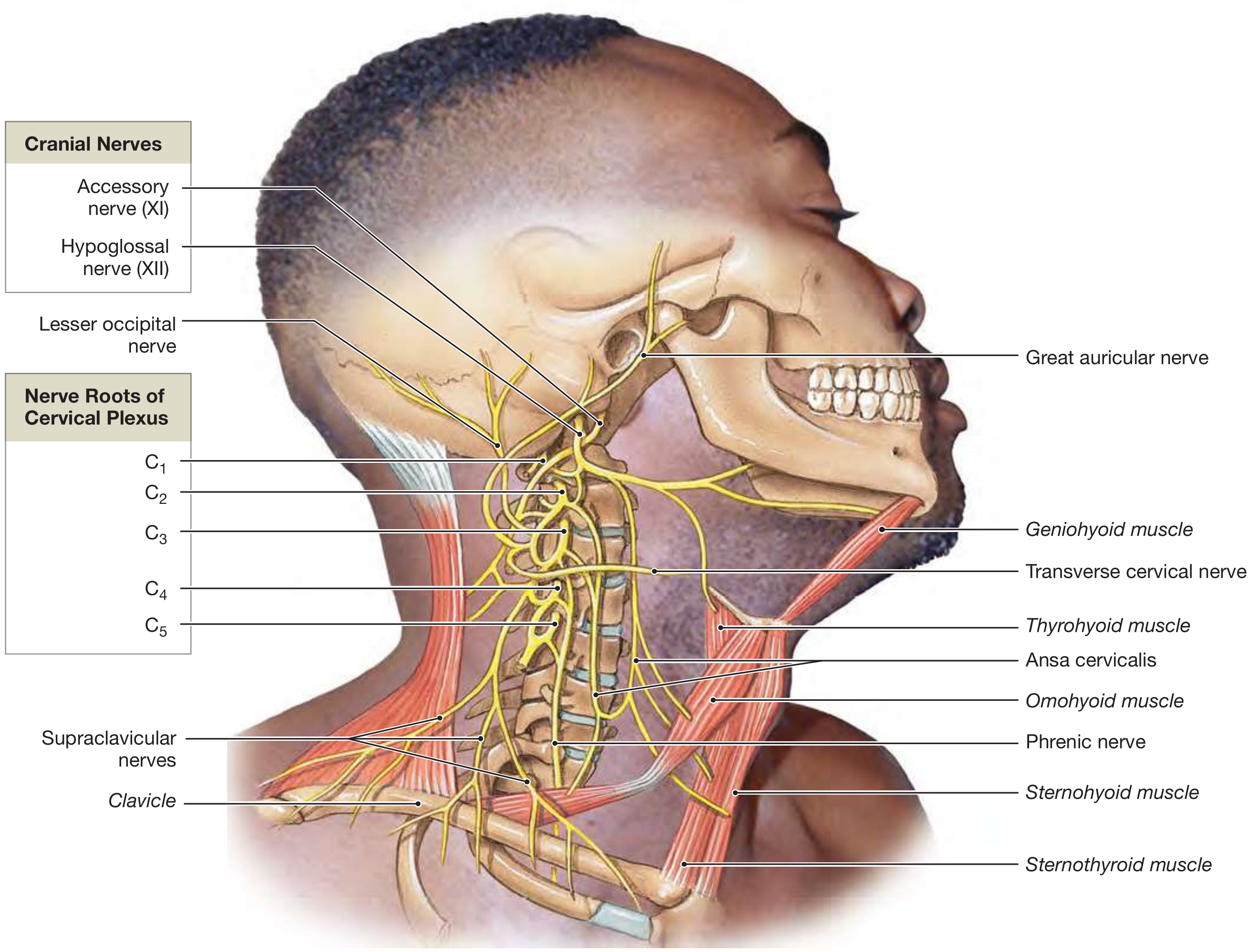
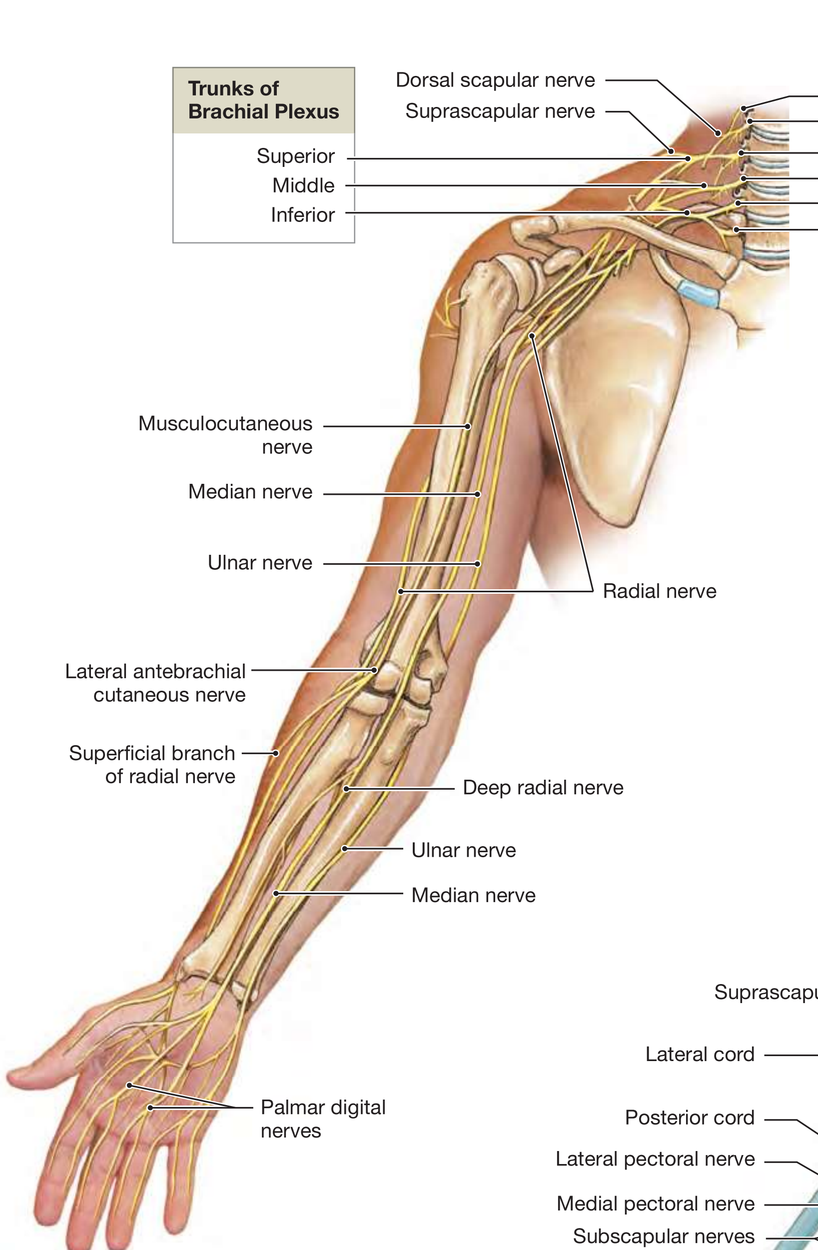


Table 13–1 The Cervical Plexus

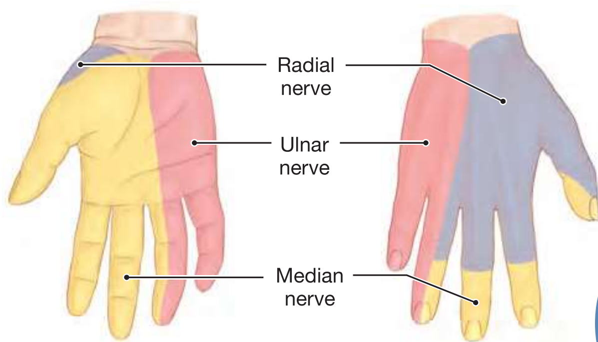
Nerve	Spinal Segments	Distribution
Ansa cervicalis (superior and inferior branches)	C_1–C_4	Five of the extrinsic laryngeal muscles: sternothyroid, sternohyoid, omohyoid, geniohyoid, and thyrohyoid muscles (via N XII)
Lesser occipital, transverse cervical, supraclavicular, and great auricular nerves	C_2–C_3	Skin of upper chest, shoulder, neck, and ear
Phrenic nerve	C_3–C_5	Diaphragm
Cervical nerves	C_1–C_5	Levator scapulae, scalene, sternocleidomastoid, and trapezius muscles (with N XI)

plexus can also have fibers from C_4, T_2, or both. The nerves that form this plexus originate from trunks and cords. **Trunks** are large bundles of axons contributed by several spinal nerves. **Cords** are smaller branches that originate at trunks. Both trunks and cords are named according to their location relative to the *axillary artery*, a large artery supplying the upper limb. Hence we have *superior*, *middle*, and *inferior trunks*, and *lateral*, *medial*, and *posterior cords*. The lateral cord forms the **musculocutaneous nerve** exclusively and, together with the medial cord, contributes to the **median nerve.** The **ulnar nerve** is the other major nerve

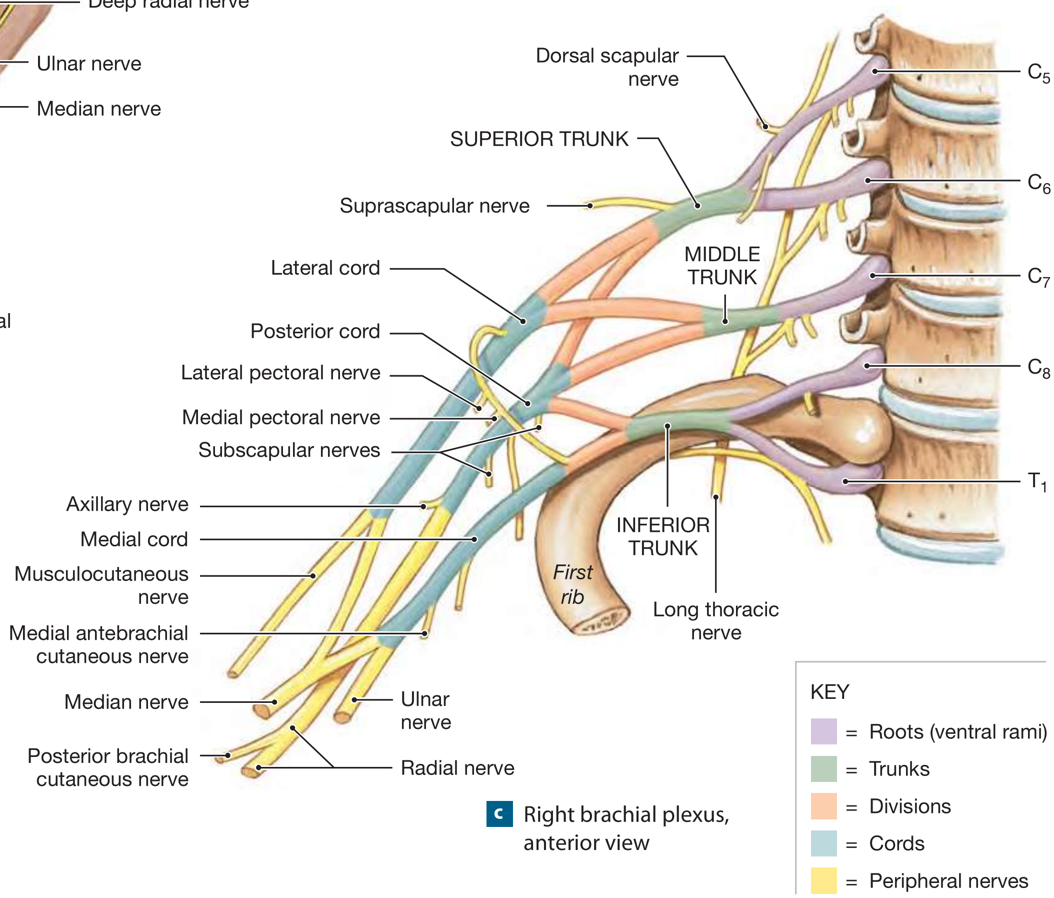
Figure 13–12 **The Brachial Plexus.** ATLAS: Plates 27a–c; 29b,c; 30



a Major nerves originating at the right brachial plexus, anterior view



b Areas of the hands serviced by nerves of the right brachial plexus



c Right brachial plexus, anterior view

13

Table 13–2 The Brachial Plexus

Nerve	Spinal Segments	Distribution
Nerve to subclavius	C_4–C_6	Subclavius muscle
Dorsal scapular nerve	C_5	Rhomboid and levator scapulae muscles
Long thoracic nerve	C_5–C_7	Serratus anterior muscle
Suprascapular nerve	C_5, C_6	Supraspinatus and infraspinatus muscles; sensory from shoulder joint and scapula
Pectoral nerves (medial and lateral)	C_5–T_1	Pectoralis muscles
Subscapular nerves	C_5, C_6	Subscapularis and teres major muscles
Thoracodorsal nerve	C_6–C_8	Latissimus dorsi muscle
Axillary nerve	C_5, C_6	Deltoid and teres minor muscles; sensory from the skin of the shoulder
Medial antebrachial cutaneous nerve	C_8, T_1	Sensory from skin over anterior, medial surface of arm and forearm
Radial nerve	C_5–T_1	Many extensor muscles on the arm and forearm (triceps brachii, anconeus, extensor carpi radialis, extensor carpi ulnaris, and brachioradialis muscles); supinator muscle, digital extensor muscles, and abductor pollicis muscle via the *deep branch*; sensory from skin over the posterolateral surface of the limb through the *posterior brachial cutaneous nerve* (arm), *posterior antebrachial cutaneous nerve* (forearm), and the *superficial branch* (radial half of hand)
Musculocutaneous nerve	C_5–T_1	Flexor muscles on the arm (biceps brachii, brachialis, and coracobrachialis muscles); sensory from skin over lateral surface of the forearm through the *lateral antebrachial cutaneous nerve*
Median nerve	C_6–T_1	Flexor muscles on the forearm (flexor carpi radialis and palmaris longus muscles); pronator quadratus and pronator teres muscles; digital flexors (through the *anterior interosseous nerve*); sensory from skin over anterolateral surface of the hand
Ulnar nerve	C_8, T_1	Flexor carpi ulnaris muscle, flexor digitorum profundus muscle, adductor pollicis muscle, and small digital muscles via the *deep branch*; sensory from skin over medial surface of the hand through the *superficial branch*

of the medial cord. The posterior cord gives rise to the **axillary nerve** and the **radial nerve.** Table 13–2 provides further information about these and other major nerves of the brachial plexus.

The Lumbar and Sacral Plexuses

The **lumbar plexus** and the **sacral plexus** arise from the lumbar and sacral segments of the spinal cord, respectively. The nerves arising at these plexuses innervate the pelvic girdle and lower limbs (**Figures 13–10** and **13–13**). The individual nerves that form the lumbar and sacral plexuses are listed in **Table 13–3**.

The lumbar plexus contains axons from the ventral rami of spinal nerves T_{12}–L_4. The major nerves of this plexus are the **genitofemoral nerve,** the **lateral femoral cutaneous nerve,** and the **femoral nerve.** The sacral plexus contains axons from the ventral rami of spinal nerves L_4–S_4. Two major nerves arise at this plexus: the **sciatic nerve** and the **pudendal nerve.** The sciatic nerve passes posterior to the femur, deep to the long head of the biceps femoris muscle. As it approaches the knee, the sciatic nerve divides into two branches: the **fibular nerve** (or *peroneal nerve*) and the **tibial nerve.** The *sural nerve*, formed by branches of the fibular nerve, is a sensory nerve innervating the lateral portion of the foot. A section of this nerve is often removed for use in nerve grafts.

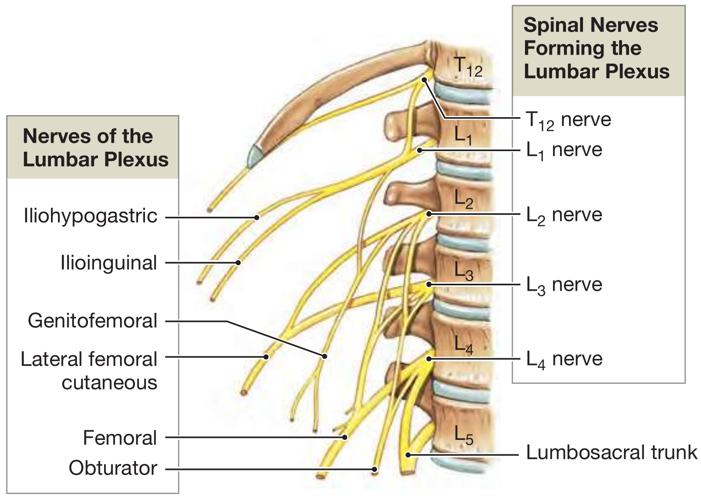
In discussions of motor performance, a distinction is usually made between the conscious ability to control motor function—something that requires communication and feedback between the brain and spinal cord—and automatic motor responses coordinated entirely within the spinal cord. These automatic responses, called *reflexes*, are motor responses to specific stimuli. The rest of this chapter looks at how sensory neurons, interneurons, and motor neurons interconnect, and how these interconnections produce both simple and complex reflexes. ATLAS: Embryology Summary 11: The Development of the Spinal Cord and Spinal Nerves

Checkpoint

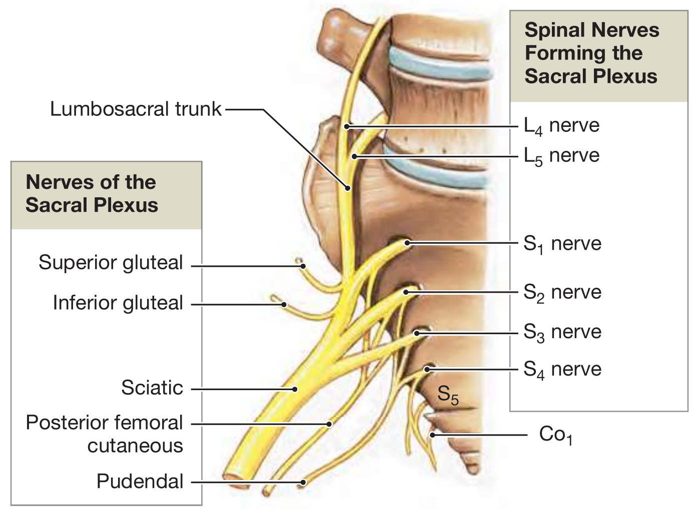
9. **Identify the major networks of nerves known as plexuses.**
10. **An anesthetic blocks the function of the dorsal rami of the cervical spinal nerves. Which areas of the body will be affected?**
11. **Injury to which of the nerve plexuses would interfere with the ability to breathe?**
12. **Compression of which nerve produces the sensation that your leg has "fallen asleep"?**

See the blue Answers tab at the back of the book.

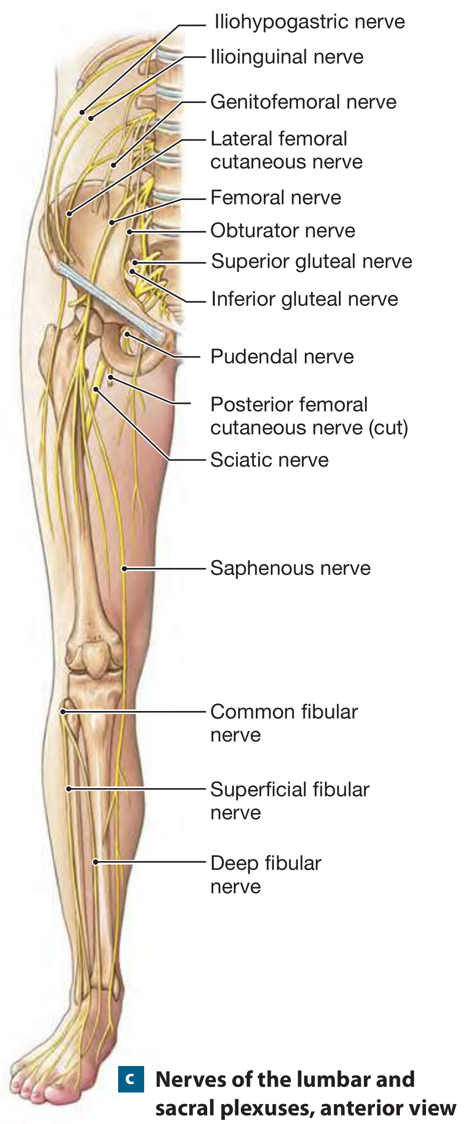
Figure 13–13 **The Lumbar and Sacral Plexuses.** ATLAS: Plates 70b; 76b; 82b



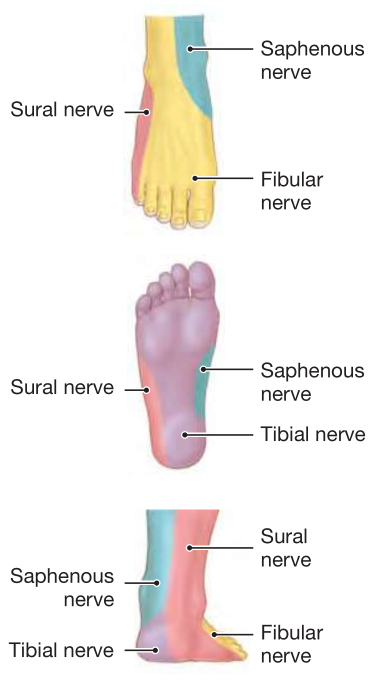
a **Lumbar plexus, anterior view**



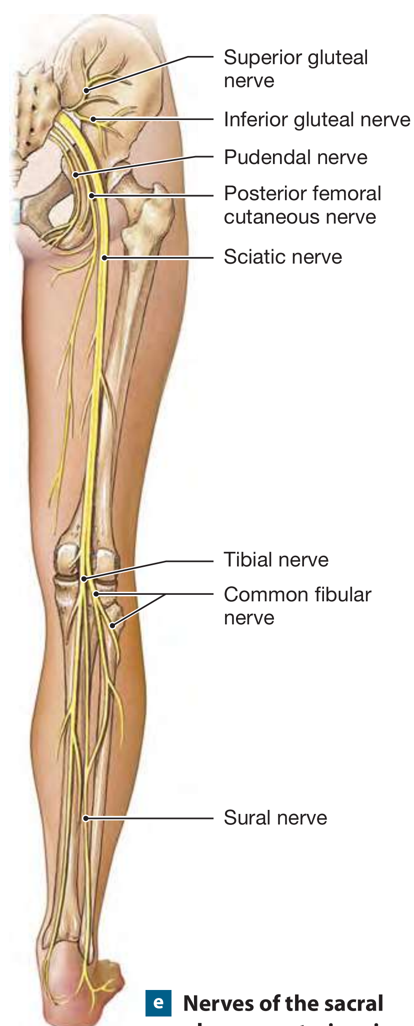
b **Sacral plexus, anterior view**



c **Nerves of the lumbar and sacral plexuses, anterior view**



d **Cutaneous distribution of the nerves in the foot and ankle**



e **Nerves of the sacral plexus, posterior view**

Table 13–3	The Lumbar and Sacral Plexuses	
Nerve	**Spinal Segment**	**Distribution**
LUMBAR PLEXUS		
Iliohypogastric nerve	T_{12}, L_1	Abdominal muscles (external and internal oblique muscles, transversus abdominis muscle); skin over inferior abdomen and buttocks
Ilioinguinal nerve	L_1	Abdominal muscles (with iliohypogastric nerve); skin over superior, medial thigh and portions of external genitalia
Genitofemoral nerve	L_1, L_2	Skin over anteromedial surface of thigh and portions of external genitalia
Lateral femoral cutaneous nerve	L_2, L_3	Skin over anterior, lateral, and posterior surfaces of thigh
Femoral nerve	L_2–L_4	Anterior muscles of thigh (sartorius muscle and quadriceps group); flexors and adductors of hip (pectineus and iliopsoas muscles); skin over anteromedial surface of thigh, medial surface of leg and foot
Obturator nerve	L_2–L_4	Adductors of hip (adductors magnus, brevis, and longus muscles); gracilis muscle; skin over medial surface of thigh
Saphenous nerve	L_2–L_4	Skin over medial surface of leg
SACRAL PLEXUS		
Gluteal nerves:	L_4–S_2	
Superior		Abductors of hip (gluteus minimus, gluteus medius, and tensor fasciae latae muscles)
Inferior		Extensor of hip (gluteus maximus muscle)
Posterior femoral cutaneous nerve	S_1–S_3	Skin of perineum and posterior surfaces of thigh and leg
Sciatic nerve:	L_4–S_3	Two of the hamstrings (semimembranosus and semitendinosus muscles); adductor magnus muscle (with obturator nerve)
Tibial nerve		Flexors of knee and extensors (plantar flexors) of ankle (popliteus, gastrocnemius, soleus, and tibialis posterior muscles and the long head of the biceps femoris muscle); flexors of toes; skin over posterior surface of leg, plantar surface of foot
Fibular nerve		Biceps femoris muscle (short head); fibularis muscles (brevis and longus) and tibialis anterior muscle; extensors of toes; skin over anterior surface of leg and dorsal surface of foot; skin over lateral portion of foot (through the *sural nerve*)
Pudendal nerve	S_2–S_4	Muscles of perineum, including urogenital diaphragm and external anal and urethral sphincter muscles; skin of external genitalia and related skeletal muscles (bulbospongiosus and ischiocavernosus muscles)

13

13-5 ◗ Neuronal pools are functional groups of interconnected neurons

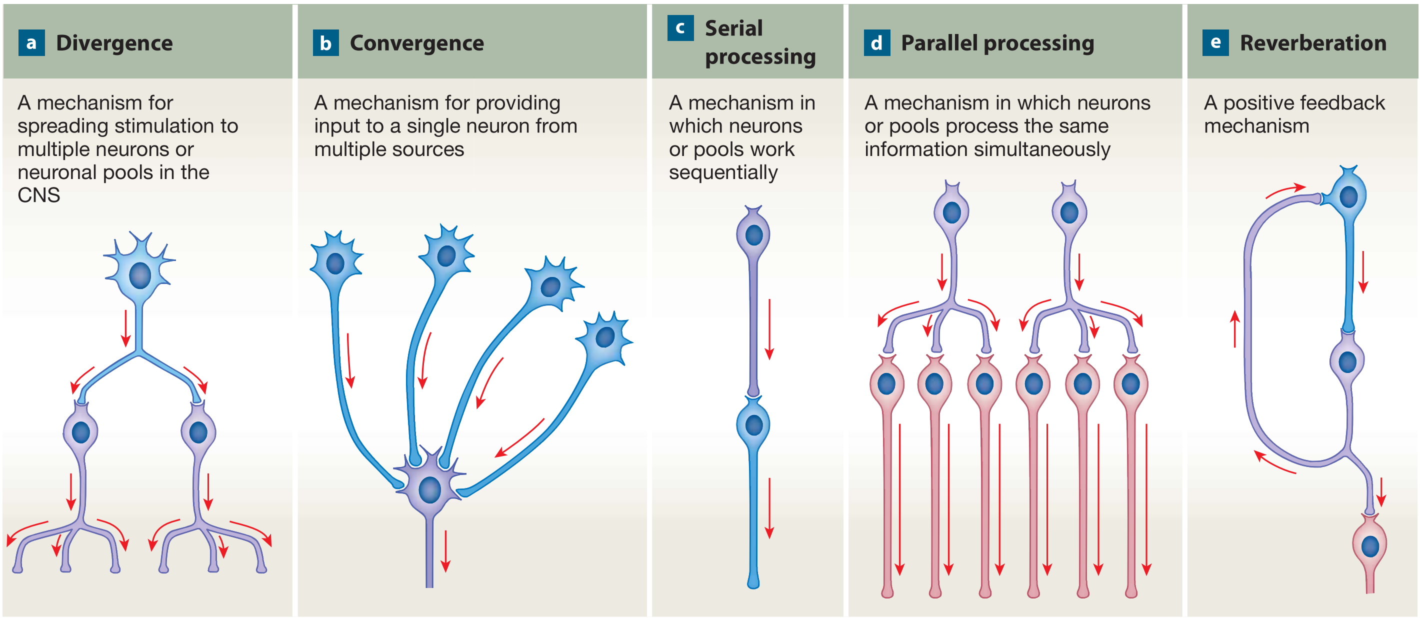
The human body has about 10 million sensory neurons, one-half million motor neurons, and 20 *billion* interneurons. The sensory neurons deliver information to the CNS; the motor neurons distribute commands to peripheral effectors, such as skeletal muscles; and interactions among interneurons provide the interpretation, planning, and coordination of incoming and outgoing signals.

The billions of interneurons of the CNS are organized into a much smaller number of **neuronal pools**—functional groups of interconnected neurons. A neuronal pool may be scattered, involving neurons in several regions of the brain, or localized, with neurons restricted to one specific location in the brain or spinal cord. Estimates of the actual number of neuronal pools range between a few hundred and a few thousand. Each has a limited number of input sources and output destinations, and each may contain both excitatory and inhibitory neurons. The output of the entire neuronal pool may stimulate or depress activity in other parts of the brain or spinal cord, affecting the interpretation of sensory information or the coordination of motor commands.

The pattern of interaction among neurons provides clues to the functional characteristics of a neuronal pool. It is customary to refer to the "wiring diagrams" in **Figure 13–14** as *neural circuits*, just as we refer to electrical circuits in the wiring of a house. We can distinguish five circuit patterns:

1. **Divergence** is the spread of information from one neuron to several neurons (**Figure 13–14a**), or from one pool to multiple pools. Divergence permits the broad distribution of a specific input. Considerable divergence occurs when sensory neurons bring information into the CNS, because the information is distributed to neuronal pools through-

Figure 13–14 Neural Circuits: The Organization of Neuronal Pools.



out the spinal cord and brain. Visual information arriving from the eyes, for example, reaches your consciousness at the same time it is distributed to areas of the brain that control posture and balance at the subconscious level.

2. In **convergence,** several neurons synapse on a single postsynaptic neuron (**Figure 13–14b**). Several patterns of activity in the presynaptic neurons can therefore have the same effect on the postsynaptic neuron. Through convergence, the same motor neurons can be subject to both conscious and subconscious control. For example, the movements of your diaphragm and ribs are now being controlled by your brain at the subconscious level. But the same motor neurons can also be controlled consciously, as when you take a deep breath and hold it. Two neuronal pools are involved, both synapsing on the same motor neurons.
3. In **serial processing,** information is relayed in a stepwise fashion, from one neuron to another or from one neuronal pool to the next (**Figure 13–14c**). This pattern occurs as sensory information is relayed from one part of the brain to another. For example, pain sensations en route to your consciousness make stops at two neuronal pools along the pain pathway.
4. **Parallel processing** occurs when several neurons or neuronal pools process the same information simultaneously (**Figure 13–14d**). Divergence must take place before parallel processing can occur. Thanks to parallel processing, many responses can occur simultaneously. For example, stepping on a sharp object stimulates sensory neurons that distribute the information to several neuronal pools. As a result of parallel processing, you might withdraw your foot, shift your weight, move your arms, feel the pain, and shout "Ouch!" at about the same time.
5. In **reverberation,** collateral branches of axons somewhere along the circuit extend back toward the source of an impulse and further stimulate the presynaptic neurons (**Figure 13–14e**). Reverberation is like a positive feedback loop involving neurons: Once a reverberating circuit has been activated, it will continue to function until synaptic fatigue or inhibitory stimuli break the cycle. Reverberation can occur within a single neuronal pool, or it may involve a series of interconnected pools. Highly complicated examples of reverberation among neuronal pools in the brain may help maintain consciousness, muscular coordination, and normal breathing.

The functions of the nervous system depend on the interactions among neurons organized in neuronal pools. The most complex neural processing steps occur in the spinal cord and brain. The simplest, which occur within the PNS and the spinal cord, control reflexes that are a bit like Legos: Individually, they are quite simple, but they can be combined in a great variety of ways to create very complex responses. For this reason, reflexes are the basic building blocks of neural function, as you will see in the next section.

Checkpoint

13. **Define neuronal pool.**
14. **List the five circuit patterns found in neuronal pools.**

See the blue Answers tab at the back of the book.

13

13-6 Reflexes are rapid, automatic responses to stimuli

Conditions inside or outside the body can change rapidly and unexpectedly. **Reflexes** are rapid, automatic responses to specific stimuli. Reflexes preserve homeostasis by making rapid adjustments in the function of organs or organ systems. The response shows little variability: Each time a particular reflex is activated, it normally produces the same motor response. Chapter 1 introduced the basic functional components involved in all types of homeostatic regulation: a *receptor*, an *integration center*, and an *effector*. p. 11 Here we consider *neural reflexes*, in which sensory fibers deliver information from peripheral receptors to an integration center in the CNS, and motor fibers carry motor commands to peripheral effectors. We examine *endocrine reflexes*, in which the commands to peripheral tissues and organs are delivered by hormones in the bloodstream, in Chapter 18.

13

The Reflex Arc

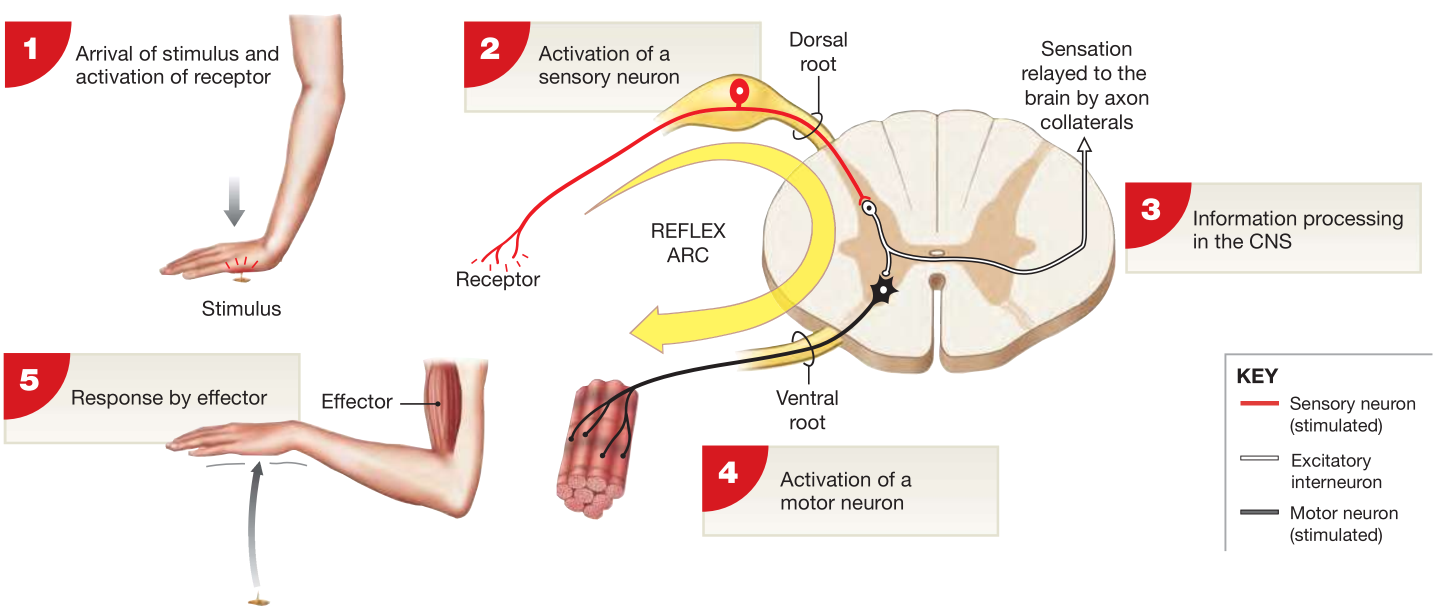
The "wiring" of a single reflex is called a **reflex arc.** A reflex arc begins at a receptor and ends at a peripheral effector, such as a muscle fiber or a gland cell. **Figure 13–15** diagrams the five steps in a simple neural reflex known as a *withdrawal reflex*:

1 ***The Arrival of a Stimulus and Activation of a Receptor.*** A *receptor* is either a specialized cell or the dendrites of a sensory neuron. Receptors are sensitive to physical or chemical changes in the body or to changes in the external environment. The general categories of sensory receptors were introduced in Chapter 12. p. 379 If you lean on a tack, for example, pain receptors in the palm of your hand are activated. These receptors, the dendrites of sensory neurons, respond to stimuli that cause or accompany tissue damage. (We discuss the link between receptor stimulation and sensory neuron activation further in Chapter 15.)

2 ***The Activation of a Sensory Neuron.*** When the dendrites are stretched, there is a graded depolarization that leads to the formation and propagation of action potentials along the axons of the sensory neurons. This information reaches the spinal cord by way of a dorsal root. In our example, 1 and 2 involve the same cell. However, the two steps may involve different cells. For example, reflexes triggered by loud sounds begin when receptor cells in the inner ear release neurotransmitters that stimulate sensory neurons.

3 ***Information Processing.*** In our example, information processing begins when excitatory neurotransmitter molecules, released by the synaptic terminal of a sensory neuron, arrive at the postsynaptic membrane of an interneuron. The neurotransmitter produces an excitatory postsynaptic potential (EPSP), which is integrated with other stimuli arriving at the postsynaptic cell at that moment. p. 408 The information processing is thus performed by the interneuron. In the simplest reflexes, such as the *stretch reflex*, considered in a later section, the sensory neuron innervates a motor neuron directly. In that case, it is the

Figure 13–15 Events in a Neural Reflex. A simple reflex arc, such as the withdrawal reflex, consists of a sensory neuron, an interneuron, and a motor neuron.



motor neuron that performs the information processing. By contrast, complex reflexes introduced later in the chapter involve several interneurons, some releasing excitatory neurotransmitters *(excitatory interneurons)* and others releasing inhibitory neurotransmitters *(inhibitory interneurons)*.

4 ***The Activation of a Motor Neuron.*** The axons of the stimulated motor neurons carry action potentials into the periphery—in this example, through the ventral root of a spinal nerve.

5 ***The Response of a Peripheral Effector.*** The release of neurotransmitters by the motor neurons at synaptic terminals then leads to a response by a peripheral effector—in this case, a skeletal muscle whose contraction pulls your hand away from the tack.

A reflex response generally removes or opposes the original stimulus; in this case, the contracting muscle pulls your hand away from a painful stimulus. This reflex arc is therefore an example of *negative feedback*. ⮌ p. 12 By opposing potentially harmful changes in the internal or external environment, reflexes play an important role in homeostatic maintenance. The immediate reflex response is typically not the only response to a stimulus. The other responses, which are directed by your brain, involve multiple synapses and take longer to organize and coordinate.

Classification of Reflexes

Reflexes are classified on the basis of (1) their development, (2) the nature of the resulting motor response, (3) the complexity of the neural circuit involved, or (4) the site of information processing. These categories are not mutually exclusive—they represent different ways of describing a single reflex (**Figure 13–16**).

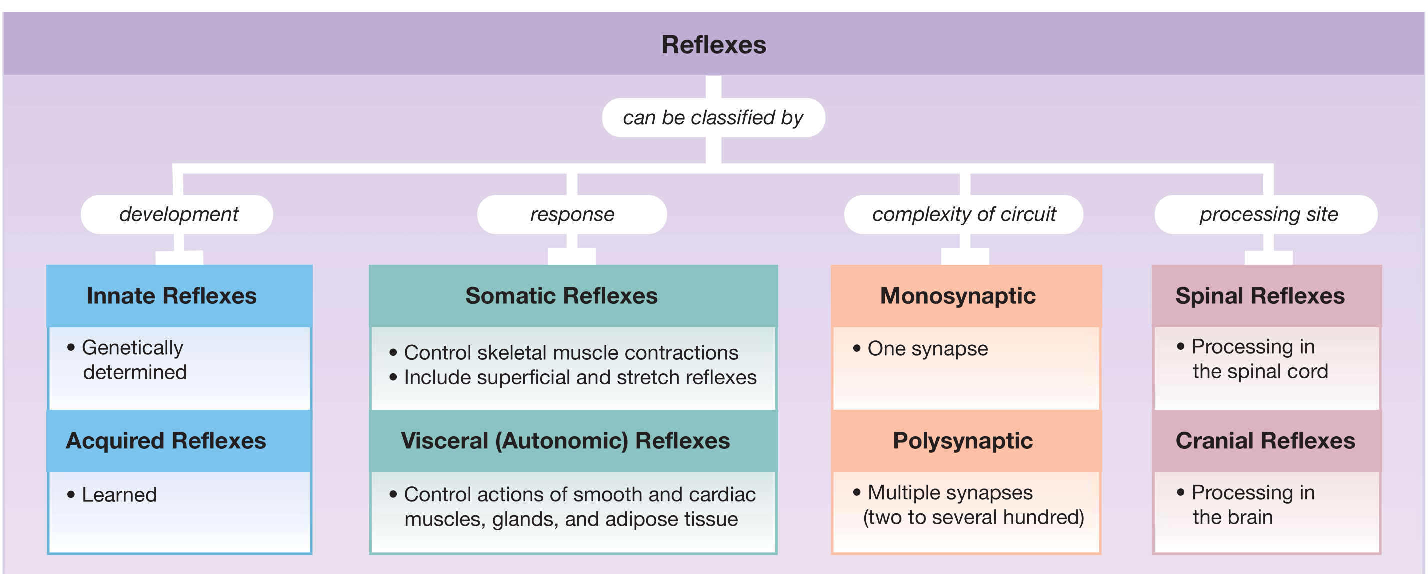
Development of Reflexes

Innate reflexes result from the connections that form between neurons during development. Such reflexes generally appear in a predictable sequence, from the simplest reflex responses (withdrawal from pain) to more complex motor patterns (chewing, suckling, or tracking objects with the eyes). The neural connections responsible for the basic motor patterns of an innate reflex are genetically programmed. Examples include the reflexive removal of your hand from a hot stovetop and blinking when your eyelashes are touched.

More complex, learned motor patterns are called **acquired reflexes.** An experienced driver steps on the brake when trouble appears ahead; a professional skier must make equally quick adjustments in body position while racing. These motor responses are rapid and automatic, but they were learned rather than preestablished. Such reflexes are enhanced by repetition. The distinction between innate and acquired reflexes is not absolute: Some people can learn motor patterns quicker than others, and the differences probably have a genetic basis.

Most reflexes, whether innate or acquired, can be modified over time or suppressed through conscious effort. For example, while walking a tightrope over the Grand Canyon, you might ignore a bee sting on your hand, although under other circumstances you would probably withdraw your hand immediately, while shouting and thrashing as well.

Figure 13–16 The Classification of Reflexes.



Nature of the Response

Somatic reflexes provide a mechanism for the involuntary control of the muscular system. *Superficial reflexes* are triggered by stimuli at the skin or mucous membranes. *Stretch reflexes* are triggered by the sudden elongation of a tendon, and thus of the muscle to which it attaches; a familiar example is the *patellar*, or *"knee-jerk," reflex* that is usually tested during physical exams. These reflexes are also known as *deep tendon reflexes*, or *myotatic reflexes*. **Visceral reflexes,** or *autonomic reflexes*, control the activities of other systems. We consider somatic reflexes in detail in this chapter and visceral reflexes in Chapter 16.

The movements directed by somatic reflexes are neither delicate nor precise. You might therefore wonder why they exist at all, because we have voluntary control over the same muscles. In fact, somatic reflexes are absolutely vital, primarily because they are *immediate*. Making decisions and coordinating voluntary responses take time, and in an emergency—when you slip while walking down a flight of stairs, or accidentally press your hand against a knife edge—any delay increases the likelihood of severe injury. Thus, somatic reflexes provide a rapid response that can be modified later, if necessary, by voluntary motor commands.

Complexity of the Circuit

In the simplest reflex arc, a sensory neuron synapses directly on a motor neuron, which serves as the processing center. Such a reflex is a **monosynaptic reflex.** Transmission across a chemical synapse always involves a synaptic delay, but with only one synapse, the delay between the stimulus and the response is minimized. Most reflexes, however, have at least one interneuron between the sensory neuron and the motor neuron, as diagrammed in **Figure 13–15**. Such **polysynaptic reflexes** have a longer delay between stimulus and response. The length of the delay is proportional to the number of synapses involved. Polysynaptic reflexes can produce far more complicated responses than monosynaptic reflexes, because the interneurons can control motor neurons that activate several muscle groups simultaneously.

Processing Sites

In **spinal reflexes,** the important interconnections and processing events occur in the spinal cord. We discuss these reflexes further in the next section. Reflexes processed in the brain, called **cranial reflexes,** are considered in Chapters 14, 16, and 17.

Checkpoint

15. **Define reflex.**
16. **What is the minimum number of neurons in a reflex arc?**
17. **One of the first somatic reflexes to develop is the suckling reflex. Which type of reflex is this?**

See the blue Answers tab at the back of the book.

13-7 Spinal reflexes vary in complexity

Spinal reflexes range in complexity from simple monosynaptic reflexes involving a single segment of the spinal cord to polysynaptic reflexes that involve many segments. In the most complicated spinal reflexes, called **intersegmental reflex arcs,** many segments interact to produce a coordinated, highly variable motor response.

Monosynaptic Reflexes

In monosynaptic reflexes, there is little delay between sensory input and motor output. These reflexes control the most rapid, *stereotyped* (preexisting, mechanically repetitive) *motor responses* of the nervous system to specific stimuli.

The Stretch Reflex

The best-known monosynaptic reflex is the **stretch reflex,** which provides automatic regulation of skeletal muscle length. The **patellar reflex** is an example. When a physician taps your patellar tendon with a reflex hammer, receptors in the quadriceps muscle are stretched (**Figure 13–17**). The distortion of the receptors in turn stimulates sensory neurons that extend into the spinal cord and synapse on motor neurons that control the motor units in the stretched muscle. This leads to a reflexive contraction of the stretched muscle that extends the knee in a brief kick. To summarize: The stimulus (increasing muscle length) activates a sensory neuron, which triggers an immediate motor response (contraction of the stretched muscle) that counteracts the stimulus. Because the action potentials traveling toward and away from the spinal cord are conducted along large, myelinated Type A fibers, the entire reflex is completed within 20–40 msec.

The receptors in stretch reflexes are called *muscle spindles*. (The sensory mechanism is described in the next section.) The stretching of muscle spindles produces a sudden burst of activity in the sensory neurons that monitor them. This in turn leads to stimulation of motor neurons that control the motor units in the stretched muscle. The result is rapid muscle shortening, and this returns the muscle spindles to their resting length. The rate of action potential generation in the sensory neurons then decreases, causing a drop in muscle tone to resting levels.

Muscle Spindles

The sensory receptors involved in the stretch reflex are **muscle spindles.** Each consists of a bundle of small, specialized skeletal muscle fibers called **intrafusal muscle fibers** (**Figure 13–18**). The muscle spindle is surrounded by larger skeletal muscle fibers, called **extrafusal muscle fibers.** These fibers are responsible for the resting muscle tone and, at greater levels of stimulation, for the contraction of the entire muscle.

Figure 13–17 A Stretch Reflex. In the patellar reflex, a representative stretch reflex, the stimulus is a tap on the patellar tendon that stretches receptors within the quadriceps muscles. The response is a brief contraction of those muscles, which produces a noticeable kick.

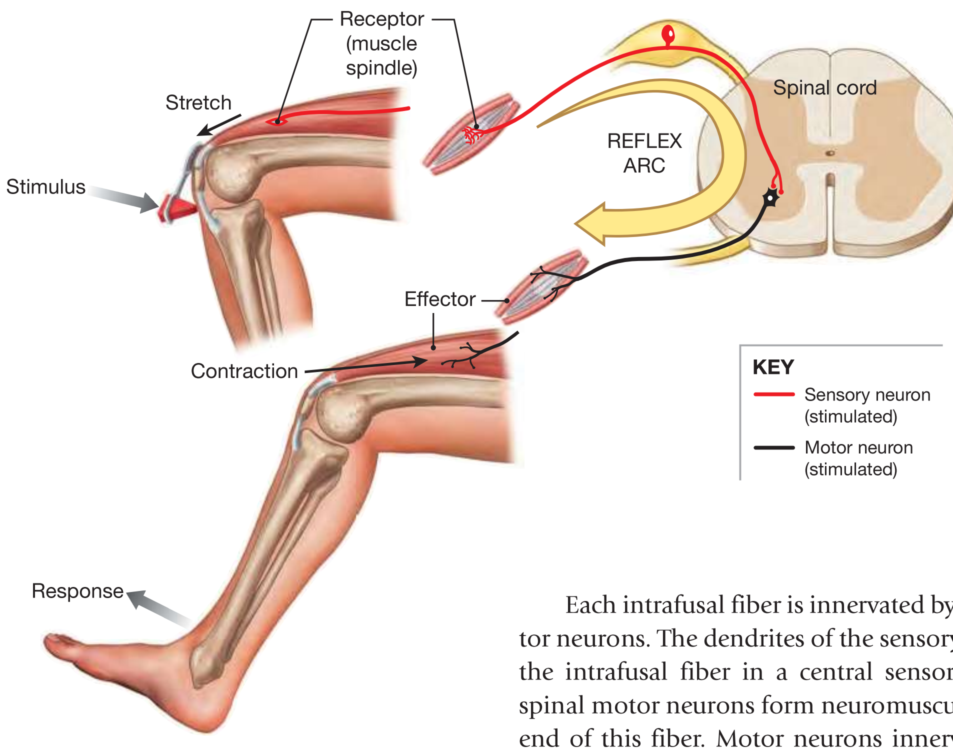
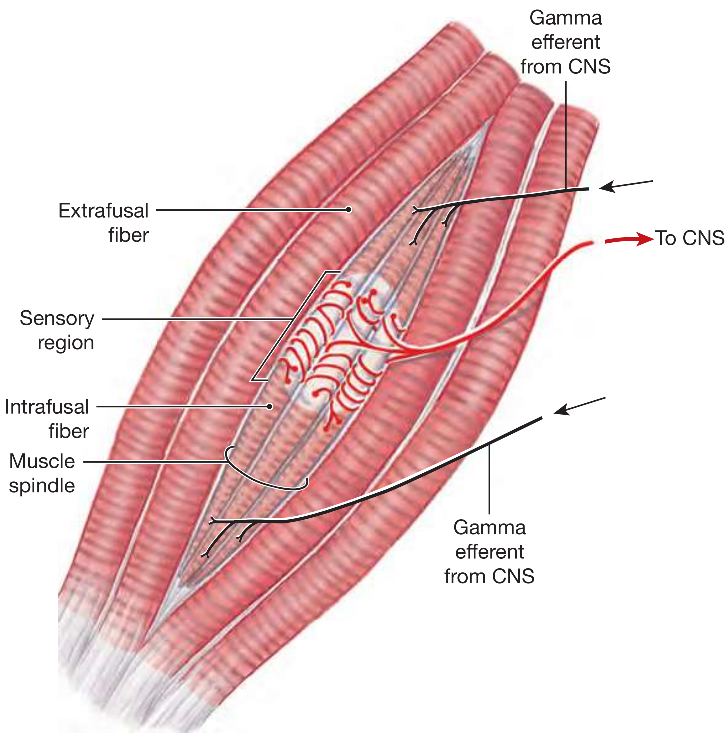


Figure 13–18 A Muscle Spindle. The location, structure, and innervation of a muscle spindle.



Each intrafusal fiber is innervated by both sensory and motor neurons. The dendrites of the sensory neuron spiral around the intrafusal fiber in a central sensory region. Axons from spinal motor neurons form neuromuscular junctions on either end of this fiber. Motor neurons innervating intrafusal fibers are called **gamma motor neurons;** their axons are called **gamma efferents.** An intrafusal fiber has one set of myofibrils at each end. Instead of extending the length of the muscle fiber, as in extrafusal fibers, these myofibrils run from the end of the intrafusal fiber only to the sarcolemma in the central region that is closely monitored by the sensory neuron. The gamma efferents enable the CNS to adjust the sensitivity of the muscle spindle. Before seeing how this is accomplished, let's consider the normal functioning of this sensory receptor and its effects on the surrounding extrafusal fibers.

The sensory neuron is always active, conducting impulses to the CNS. The axon enters the CNS in a dorsal root and synapses on motor neurons in the anterior gray horn of the spinal cord. Axon collaterals distribute the information to the brain, providing information about the muscle spindle. Stretching the central portion of the intrafusal fiber distorts the dendrites and stimulates the sensory neuron, increasing the frequency of action potential generation. Compressing the central portion inhibits the sensory neuron, decreasing the frequency of action potential generation.

The axon of the sensory neuron synapses on CNS motor neurons that control the extrafusal muscle fibers of the same muscle. An increase in sensory neuron stimulation, caused by stretching of the intrafusal fiber, will increase stimulation to the motor neuron controlling the surrounding extrafusal fibers, so muscle tone increases. This increase provides automatic resistance that reduces the chance of muscle damage due to overstretching. The

13

patellar reflex and similar reflexes serve this function. A decrease in the stimulation of the sensory neuron, due to compression of the intrafusal fiber, will lead to a decrease in the stimulation of the motor neuron controlling the surrounding extrafusal fibers, so muscle tone decreases. This decrease reduces resistance to the movement under way. For example, if your elbow is flexed and you let gravity extend it, the triceps brachii muscle, which is compressed by this movement, relaxes.

Many stretch reflexes are **postural reflexes**—reflexes that help us maintain a normal upright posture. Standing, for example, involves a cooperative effort on the part of many muscle groups. Some of these muscles work in opposition to one another, exerting forces that keep the body's weight balanced over the feet. If the body leans forward, stretch receptors in the calf muscles are stimulated. Those muscles then respond by contracting, thereby returning the body to an upright position. If the muscles overcompensate and the body begins to lean back, the calf muscles relax. But then stretch receptors in muscles of the shins and thighs are stimulated, and the problem is corrected immediately.

Postural muscles generally maintain a firm muscle tone and have extremely sensitive stretch receptors. As a result, very fine adjustments are continually being made, and you are not aware of the cycles of contraction and relaxation that occur. Stretch reflexes are only one type of postural reflex; there are many complex polysynaptic postural reflexes.

Now that you understand the basic stretch reflex, we return to the role of the gamma efferents, which let the CNS adjust the sensitivity of muscle spindles. Gamma efferents play a vital role whenever voluntary contractions change the length of a muscle. Impulses arriving over gamma efferents cause the contraction of myofibrils in the intrafusal fibers as the biceps brachii muscle shortens. The myofibrils pull on the sarcolemma in the central portion of the intrafusal fiber—the region monitored by the sensory neuron—until that membrane is stretched to its normal resting length. As a result, the muscle spindles remain sensitive to any externally imposed changes in muscle length. Thus, if someone drops a ball into your palm when your elbow is partially flexed, the muscle spindles will automatically adjust the muscle tone to compensate for the increased load.

Polysynaptic Reflexes

Polysynaptic reflexes can produce far more complicated responses than can monosynaptic reflexes. One reason is that the interneurons involved can control several muscle groups. Moreover, these interneurons may produce either excitatory or inhibitory postsynaptic potentials (EPSPs or IPSPs) at CNS motor nuclei, so the response can involve the stimulation of some muscles and the inhibition of others.

The Tendon Reflex

The stretch reflex regulates the length of a skeletal muscle. The **tendon reflex** monitors the external tension produced during a muscular contraction and prevents tearing or breaking of the tendons. The sensory receptors for this reflex have not been identified, but they are distinct from both muscle spindles and proprioceptors in tendons. The receptors are stimulated when the collagen fibers are stretched to a dangerous degree. These receptors activate sensory neurons that stimulate inhibitory interneurons in the spinal cord. These interneurons in turn innervate the motor neurons controlling the skeletal muscle. The greater the tension in the tendon, the greater is the inhibitory effect on the motor neurons. As a result, a skeletal muscle generally cannot develop enough tension to break its tendons.

Withdrawal Reflexes

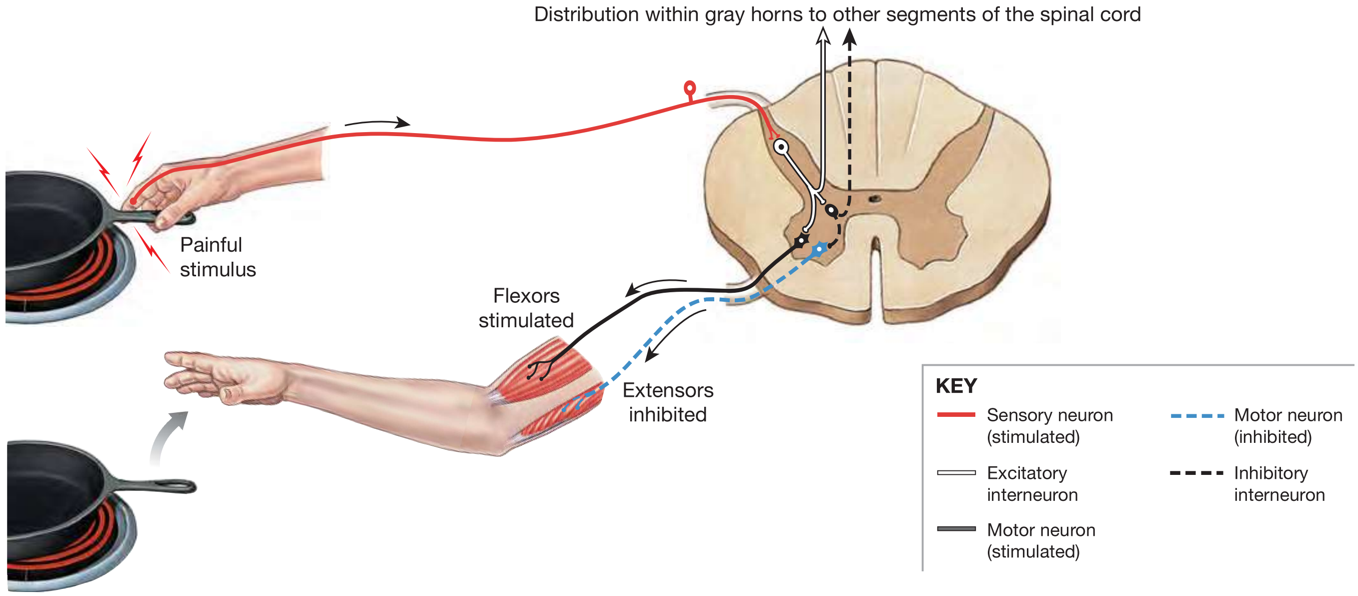
Withdrawal reflexes move affected parts of the body away from a stimulus. The strongest withdrawal reflexes are triggered by painful stimuli, but these reflexes are sometimes initiated by the stimulation of touch receptors or pressure receptors.

The **flexor reflex,** a representative withdrawal reflex, affects the muscles of a limb (**Figure 13–19**). Recall from Chapter 9 and Chapter 11 that flexion is a reduction in the angle between two articulating bones, and that the contractions of flexor muscles perform this movement. ⮌ pp. 259, 327 If you grab an unexpectedly hot pan on the stove, a dramatic flexor reflex will occur. When the pain receptors in your hand are stimulated, the sensory neurons activate interneurons in the spinal cord that stimulate motor neurons in the anterior gray horns. The result is a contraction of flexor muscles that yanks your hand away from the stove.

When a specific muscle contracts, opposing muscles must relax to permit the movement. For example, flexor muscles that bend the elbow (such as the biceps brachii muscle) are opposed by extensor muscles (such as the triceps brachii muscle) that straighten it out. A potential conflict exists: In theory, the contraction of a flexor muscle should trigger a stretch reflex in the extensors that would cause them to contract, opposing the movement. Interneurons in the spinal cord prevent such competition through **reciprocal inhibition.** When one set of motor neurons is stimulated, those neurons that control antagonistic muscles are inhibited. The term *reciprocal* refers to the fact that the system works both ways: When the flexors contract, the extensors relax; when the extensors contract, the flexors relax.

Withdrawal reflexes are much more complex than any monosynaptic reflex. They also show tremendous versatility, because the sensory neurons activate many pools of interneurons. If the stimuli are strong, interneurons will carry excitatory and inhibitory impulses up and down the spinal cord, affecting

Figure 13–19 **A Flexor Reflex.** The withdrawal reflex is an example of a flexor reflex. In this example, the stimulus is the pain experienced when grabbing a hot frying pan. The response, contraction of the flexor muscles of the arm, yanks the forearm and hand away from the pan; the movement is sudden and powerful enough that the pan is released. This response occurs while pain sensations are ascending to the brain within the lateral column, as indicated in **Figure 13–15**.



motor neurons in many segments. The end result is always the same: a coordinated movement away from the stimulus. But the distribution of the effects and the strength and character of the motor responses depend on the intensity and location of the stimulus. Mild discomfort might provoke a brief contraction in muscles of your hand and wrist. More powerful stimuli would produce coordinated muscular contractions affecting the positions of your hand, wrist, forearm, and arm. Severe pain would also stimulate contractions of your shoulder, trunk, and arm muscles. These contractions could last for several seconds, due to the activation of reverberating circuits. In contrast, monosynaptic reflexes are invariable and brief; the patellar reflex is completed in about 20 msec.

Crossed Extensor Reflexes

The stretch, tendon, and withdrawal reflexes involve *ipsilateral* (*ipsi*, same + *lateral*, side) *reflex arcs*: The sensory stimulus and the motor response occur on the same side of the body. The **crossed extensor reflex** (**Figure 13–20**) involves a *contralateral reflex arc* (*contra*, opposite), because the motor response occurs on the side opposite the stimulus.

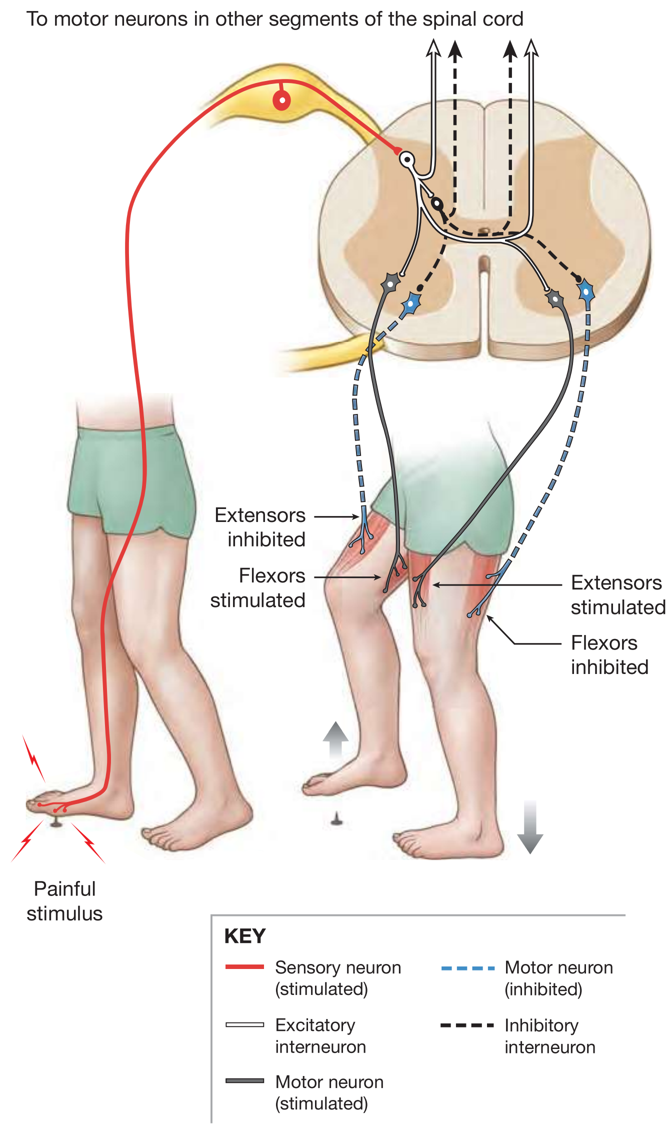
The crossed extensor reflex complements the flexor reflex, and the two occur simultaneously. When you step on a tack, while the flexor reflex pulls the affected foot away from the ground, the crossed extensor reflex straightens the other leg to support your body weight. In the crossed extensor reflex, the axons of interneurons responding to the pain cross to the other side of the spinal cord and stimulate motor neurons that control the extensor muscles of the uninjured leg. As a result, your opposite leg straightens to support the shifting weight. Reverberating circuits use positive feedback to ensure that the movement lasts long enough to be effective—all without motor commands from higher centers of the brain.

General Characteristics of Polysynaptic Reflexes

Polysynaptic reflexes range in complexity from a simple tendon reflex to the complex and variable reflexes associated with standing, walking, and running. Yet all polysynaptic reflexes share the following basic characteristics:

- *They Involve Pools of Interneurons.* Processing occurs in pools of interneurons before motor neurons are activated. The result may be excitation or inhibition; the tendon reflex produces inhibition of motor neurons, whereas the flexor and crossed extensor reflexes direct specific muscle contractions.
- *They Are Intersegmental in Distribution.* The interneuron pools extend across spinal segments and may activate muscle groups in many parts of the body.
- *They Involve Reciprocal Inhibition.* Reciprocal inhibition coordinates muscular contractions and reduces resistance to movement. In the flexor and crossed extensor reflexes, the contraction of one muscle group is associated with the inhibition of opposing muscles.

Figure 13–20 The Crossed Extensor Reflex. Pathways for sensations ascending to the brain are not shown.



- *They Have Reverberating Circuits, Which Prolong the Reflexive Motor Response.* Positive feedback between interneurons that innervate motor neurons and the processing pool maintains the stimulation even after the initial stimulus has faded.
- *Several Reflexes May Cooperate to Produce a Coordinated, Controlled Response.* As a reflex movement gets under way, antagonistic reflexes are inhibited. For example, during the stretch reflex, antagonistic muscles are inhibited; in the tendon reflex, antagonistic muscles are stimulated. In complex polysynaptic reflexes, commands may be distributed along the length of the spinal cord, producing a well-coordinated response.

Checkpoint

18. **Identify the basic characteristics of polysynaptic reflexes.**
19. **For the patellar (knee-jerk) reflex, how would the stimulation of the muscle spindle by gamma motor neurons affect the speed of the reflex?**
20. **A weight lifter is straining to lift a 200-kg barbell above his head. Shortly after he lifts it to chest height, his muscles appear to relax and he drops the barbell. Which reflex has occurred?**
21. **During a withdrawal reflex of the foot, what happens to the limb on the side opposite the stimulus? What is this response called?**

See the blue Answers tab at the back of the book.

13-8 The brain can affect spinal cord–based reflexes

Reflex motor behaviors occur automatically, without instructions from higher centers. However, higher centers can have a profound effect on the performance of a reflex. Processing centers in the brain can facilitate or inhibit reflex motor patterns based in the spinal cord. Descending tracts originating in the brain synapse on interneurons and motor neurons throughout the spinal cord. These synapses are continuously active, producing EPSPs or IPSPs at the postsynaptic membrane.

Voluntary Movements and Reflex Motor Patterns

Spinal reflexes produce consistent, stereotyped motor patterns that are triggered by specific external stimuli. However, the same motor patterns can also be activated as needed by centers in the brain. By making use of these preexisting patterns, relatively few descending fibers can control complex motor functions. For example, neuronal pools in the spinal cord direct the motor patterns for walking, running, and jumping. The descending pathways from the brain provide appropriate facilitation, inhibition, or "fine-tuning" of the established patterns. This is a very efficient system that is similar to an order given in a military drill: A single command triggers a complex, predetermined sequence of events.

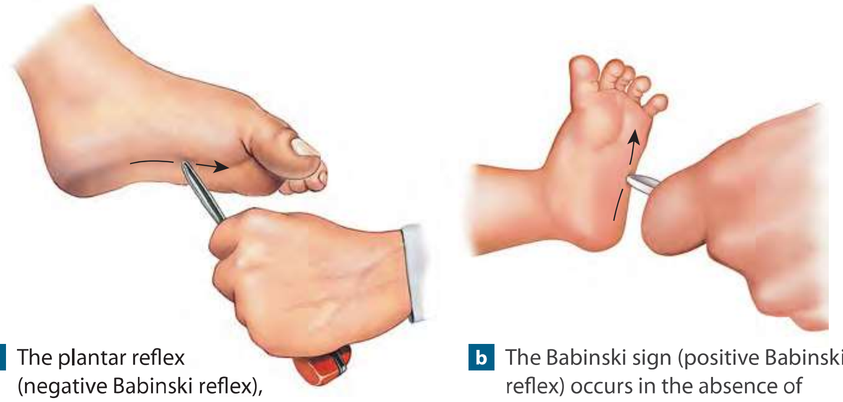
Motor control therefore involves a series of interacting levels. At the lowest level are monosynaptic reflexes that are rapid, but stereotyped and relatively inflexible. At the highest level are centers in the brain that can modulate or build on reflexive motor patterns.

Reinforcement and Inhibition

A single EPSP may not depolarize the postsynaptic neuron sufficiently to generate an action potential, but it does make that neuron more sensitive to other excitatory stimuli. This process of *facilitation* was introduced in Chapter 12. Alternatively, an IPSP will make the neuron less responsive to excitatory stimulation, through the process of *inhibition*. ↩ p. 409 By stimulating excitatory or inhibitory interneurons within the brain stem or spinal cord, higher centers can adjust the sensitivity of reflexes by creating EPSPs or IPSPs at the motor neurons involved in reflex responses.

When many of the excitatory synapses are chronically active, the postsynaptic neuron can enter a state of generalized facilitation. This facilitation of reflexes can result in **reinforcement,** an enhancement of spinal reflexes. For example, a voluntary effort to pull apart clasped hands elevates the general state of facilitation along the spinal cord, reinforcing all spinal reflexes. If a stimulus fails to elicit a particular reflex response during a clinical exam, there can be many reasons for the failure: The person may be consciously suppressing the response, the nerves involved may be damaged, or there may be underlying problems inside the CNS. The clinician may then ask the patient to perform an action designed to provide reinforcement. Reinforced reflexes are usually too strong to suppress consciously; if the reflex still fails to appear, the likelihood of nerve or CNS damage is increased, and more sophisticated tests, such as nerve conduction studies or scans, may be ordered.

Figure 13–21 The Babinski Reflexes.



a The plantar reflex (negative Babinski reflex), a curling of the toes, is seen in healthy adults.

b The Babinski sign (positive Babinski reflex) occurs in the absence of descending inhibition. It is normal in infants, but pathological in adults.

Other descending fibers have an inhibitory effect on spinal reflexes. In adults, stroking the lateral sole of the foot produces a curling of the toes, called a **plantar reflex,** or *negative Babinski reflex*, after about a 1-second delay (**Figure 13–21a**). Stroking an infant's foot on the lateral sole produces a fanning of the toes known as the **Babinski sign,** or *positive Babinski reflex* (**Figure 13–21b**). This response disappears as descending motor pathways develop. If either the higher centers or the descending tracts are damaged, the Babinski sign will reappear in an adult. As a result, this reflex is often tested if CNS injury is suspected.

Tips & Tricks

Facilitation and inhibition are similar to what happens when a symphony conductor raises or lowers one hand to control the music's volume while keeping the rhythm going with the baton hand: The basic pattern of beats doesn't change, but the loudness does.

Checkpoint

22. **Define reinforcement as it pertains to spinal reflexes.**
23. **After injuring her back, Tina exhibits a positive Babinski reflex. What does this imply about Tina's injury?**

See the blue Answers tab at the back of the book.

Related Clinical Terms

areflexia: Absence of reflexes.

Brown-Sequard syndrome: Loss of sensation and motor function that results from unilateral spinal cord lesions. Proprioception loss and weakness occur ipsilateral to the lesion while pain and temperature loss occur contralateral.

equinovarus: The foot is plantar flexed, inverted, and adducted; also called talipes equinovalgus.

Erb's palsy (Erb-Duchenne palsy): Obstetric condition characterized by paralysis or weakness of a newborn's upper arm muscles caused by a stretch injury to the brachial plexus.

hemiparesis: Slight paralysis or weakness affecting one side of the body.

Kernig's sign: Symptom of meningitis where patient cannot extend the leg at the knee due to stiffness in the hamstring muscles.

myelography: A diagnostic procedure in which a radiopaque dye is introduced into the cerebrospinal fluid to obtain an x-ray image of the spinal cord and cauda equina.

nerve conduction study: Test often performed along with electromyography (EMG); the test stimulates certain nerves and records their ability to send an impulse to the muscle; it can indicate where any blockage of the nerve pathway exists.

nerve growth factor: A peptide that promotes the growth and maintenance of neurons. Other factors that are important to neuron growth and repair include BDNF, NT-3, NT-4, and GAP-43.

paraplegia: Paralysis involving a loss of motor control of the lower, but not the upper, limbs.

quadriplegia: Paralysis involving the loss of sensation and motor control of the upper and lower limbs.

spinal shock: Term applied to all phenomena surrounding physiologic or anatomic transection of the spinal cord that results in temporary loss or depression of all or most spinal reflex activity inferior to the level of the injury.

tabes dorsalis: Slow progressive degeneration of the myelin layer of the sensory neurons of the spinal cord that occurs in the tertiary (third) phase of syphilis. Common signs and symptoms are pain, weakness, diminished reflexes, unsteady gait, and loss of coordination.

Chapter Review

Study Outline

13

13-1 ◗ The brain and spinal cord make up the central nervous system, and the cranial nerves and spinal nerves constitute the peripheral nervous system p. 417

1. The CNS consists of the brain and spinal cord; the remainder of the nervous tissue forms the PNS. *(Figure 13–1)*

13-2 ◗ The spinal cord is surrounded by three meninges and conveys sensory and motor information p. 418

2. The adult spinal cord includes two localized **enlargements,** which provide innervation to the limbs. The spinal cord has 31 segments, each associated with a pair of **dorsal roots** and a pair of **ventral roots.** *(Figure 13–2)*
3. The **filum terminale** (a strand of fibrous tissue), which originates at the **conus medullaris,** ultimately becomes part of the **coccygeal ligament.** *(Figure 13–2)*
4. **Spinal nerves** are **mixed nerves:** They contain both afferent (sensory) and efferent (motor) fibers.
5. The **spinal meninges** provide physical stability and shock absorption for neural tissues of the spinal cord; the **cranial meninges** surround the brain. *(Figure 13–3)*
6. The **dura mater** covers the spinal cord; inferiorly, it tapers into the **coccygeal ligament.** The **epidural space** separates the dura mater from the walls of the vertebral canal. *(Figures 13–3, 13–4)*
7. Interior to the inner surface of the dura mater are the **subdural space,** the **arachnoid mater** (the second meningeal layer), and the **subarachnoid space.** The subarachnoid space contains **cerebrospinal fluid (CSF),** which acts as a shock absorber and a diffusion medium for dissolved gases, nutrients, chemical messengers, and waste products. *(Figures 13–3, 13–4)*
8. The **pia mater,** a meshwork of elastic and collagen fibers, is the innermost meningeal layer. **Denticulate ligaments** extend from the pia mater to the dura mater. *(Figures 13–3, 13–4)*

13-3 ◗ Gray matter is the region of integration and command initiation, and white matter carries information from place to place p. 422

9. The white matter of the spinal cord contains myelinated and unmyelinated axons, whereas the gray matter contains cell bodies of neurons and neuroglia and unmyelinated axons. The projections of gray matter toward the outer surface of the cord are called **horns.** *(Figure 13–5)*
10. The **posterior gray horns** contain somatic and visceral sensory nuclei; nuclei in the **anterior gray horns** function in somatic motor control. The **lateral gray horns** contain visceral motor neurons. The **gray commissures** contain axons that cross from one side of the spinal cord to the other. *(Figure 13–5)*
11. The white matter can be divided into six **columns** *(funiculi)*, each of which contains **tracts** *(fasciculi)*. **Ascending tracts** relay information from the spinal cord to the brain, and **descending tracts** carry information from the brain to the spinal cord. *(Figure 13–5)*

13-4 ◗ Spinal nerves form plexuses that are named according to their level of emergence from the vertebral canal p. 424

12. There are 31 pairs of spinal nerves. Each has an **epineurium** (outermost layer), a **perineurium,** and an **endoneurium** (innermost layer). *(Figure 13–6)*
13. A typical spinal nerve has a **white ramus** (containing myelinated axons), a **gray ramus** (containing unmyelinated fibers that innervate glands and smooth muscles in the body wall or limbs), a **dorsal ramus** (providing sensory and motor innervation to the skin and muscles of the back), and a **ventral ramus** (supplying the ventrolateral body surface, structures in the body wall, and the limbs). Each pair of nerves monitors a region of the body surface called a **dermatome.** *(Spotlight Figure 13–7; Figures 13–8, 13–9)*
14. A complex, interwoven network of nerves is a **nerve plexus.** The four large plexuses are the **cervical plexus,** the **brachial plexus,** the **lumbar plexus,** and the **sacral plexus.** *(Figures 13–10 to 13–13; Tables 13–1 to 13–3)*

13-5 ◗ Neuronal pools are functional groups of interconnected neurons p. 434

15. The body has sensory neurons, which deliver information to the CNS; motor neurons, which distribute commands to peripheral effectors; and interneurons, which interpret information and coordinate responses.
16. A functional group of interconnected neurons is a **neuronal pool.**
17. The neural circuit patterns are **divergence, convergence, serial processing, parallel processing,** and **reverberation.** *(Figure 13–14)*

13-6 ◗ Reflexes are rapid, automatic responses to stimuli p. 436

18. A *neural reflex* involves sensory fibers delivering information to the CNS, and motor fibers carrying commands to the effectors via the PNS.
19. A **reflex arc** is the neural "wiring" of a single reflex. *(Figure 13–15)*
20. The five steps involved in a neural reflex are (1) the arrival of a stimulus and activation of a receptor, (2) the activation of a sensory neuron, (3) information processing in the CNS, (4) the activation of a motor neuron, and (5) a response by an effector. *(Figure 13–15)*
21. Reflexes are classified according to (1) their development, (2) the nature of the resulting motor response, (3) the complexity of the neural circuit involved, and (4) the site of information processing. *(Figure 13–16)*
22. **Innate reflexes** result from the genetically determined connections that form between neurons during development. **Acquired reflexes** are learned and typically are more complex.
23. **Somatic reflexes** control skeletal muscles; **visceral reflexes** *(autonomic reflexes)* control the activities of other systems.
24. In a **monosynaptic reflex**—the simplest reflex arc—a sensory neuron synapses directly on a motor neuron, which acts as the processing center. In a **polysynaptic reflex,** which has at least one interneuron between the sensory afferent and the motor efferent, there is a longer delay between stimulus and response.
25. Reflexes processed in the brain are **cranial reflexes.** In a **spinal reflex,** the important interconnections and processing events occur in the spinal cord.

13-7 ◗ Spinal reflexes vary in complexity p. 438

26. Spinal reflexes range from simple monosynaptic reflexes to more complex polysynaptic and **intersegmental reflexes,** in which many segments interact to produce a coordinated motor response.
27. The **stretch reflex** (such as the **patellar,** or **knee-jerk, reflex**) is a monosynaptic reflex that automatically regulates skeletal muscle length and muscle tone. The sensory receptors involved are **muscle spindles.** *(Figures 13–17, 13–18)*
28. A **postural reflex** maintains one's normal upright posture.
29. Polysynaptic reflexes can produce more complicated responses than can monosynaptic reflexes. Examples include the **tendon reflex** (which monitors the tension produced during muscular contractions and prevents damage to tendons) and **withdrawal reflexes** (which move affected portions of the body away from a source of stimulation). The **flexor reflex** is a withdrawal reflex affecting the muscles of a limb. The **crossed extensor reflex** complements withdrawal reflexes. *(Figures 13–19, 13–20)*
30. All polysynaptic reflexes (1) involve pools of interneurons, (2) are intersegmental in distribution, (3) involve reciprocal inhibition, and (4) have reverberating circuits, which prolong the reflexive motor response. Several reflexes may cooperate to produce a coordinated response.

13-8 ◗ The brain can affect spinal cord–based reflexes p. 442

31. The brain can facilitate or inhibit reflex motor patterns based in the spinal cord.
32. Motor control involves a series of interacting levels. Monosynaptic reflexes form the lowest level; at the highest level are the centers in the brain that can modulate or build on reflexive motor patterns.
33. Facilitation can produce an enhancement of spinal reflexes known as **reinforcement.** Spinal reflexes may also be inhibited, as when the **plantar reflex** in adults replaces the **Babinski sign** in infants. *(Figure 13–21)*

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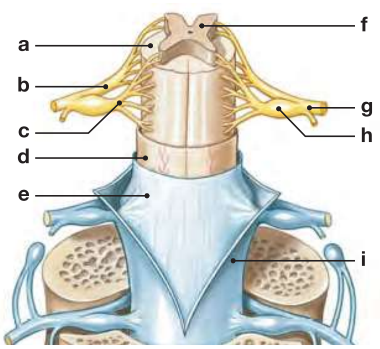
Review Questions

See the blue Answers tab at the back of the book.

LEVEL 1 Reviewing Facts and Terms

1. Label the anatomical structures of the spinal cord in the following figure.



(a) ______________________
(b) ______________________
(c) ______________________
(d) ______________________
(e) ______________________
(f) ______________________
(g) ______________________
(h) ______________________
(i) ______________________

2. The ventral roots of each spinal segment
   (a) bring sensory information into the spinal cord.
   (b) control peripheral effectors.
   (c) contain the axons of somatic motor and visceral motor neurons.
   (d) do both b and c.
3. Spinal nerves are called mixed nerves because they
   (a) contain sensory and motor fibers.
   (b) exit at intervertebral foramina.
   (c) are associated with a pair of dorsal root ganglia.
   (d) are associated with dorsal and ventral roots.
4. The adult spinal cord extends only to
   (a) the coccyx.
   (b) the sacrum.
   (c) the third or fourth lumbar vertebra.
   (d) the first or second lumbar vertebra.
   (e) the last thoracic vertebra.
5. Which of the following statements is *false* concerning the gray matter of the spinal cord?
   (a) It is located in the interior of the spinal cord around the central canal.
   (b) It functions in processing neural information.
   (c) It is primarily involved in relaying information to the brain.
   (d) It contains motor neurons.
   (e) It is divided into regions called horns.

6. The following are the steps involved in a reflex arc.
   (1) activation of a sensory neuron
   (2) activation of a motor neuron
   (3) response by an effector
   (4) arrival of a stimulus and activation of a receptor
   (5) information processing

The proper sequence of these steps is
   (a) 1, 3, 4, 5, 2.
   (b) 4, 5, 3, 1, 2.
   (c) 4, 1, 5, 2, 3.
   (d) 4, 3, 1, 5, 2.
   (e) 3, 1, 4, 5, 2.
7. A sensory region monitored by the dorsal rami of a single spinal segment is
   (a) a ganglion.
   (b) a fascicle.
   (c) a dermatome.
   (d) a ramus.
8. The major nerve of the cervical plexus that innervates the diaphragm is the
   (a) median nerve.
   (b) axillary nerve.
   (c) phrenic nerve.
   (d) fibular nerve.
9. The genitofemoral, femoral, and lateral femoral cutaneous nerves are major nerves of the
   (a) lumbar plexus.
   (b) sacral plexus.
   (c) brachial plexus.
   (d) cervical plexus.
10. The synapsing of several neurons on the same postsynaptic neuron is called
   (a) serial processing.
   (b) reverberation.
   (c) divergence.
   (d) convergence.
11. The reflexes that control the most rapid, stereotyped motor responses to stimuli are
   (a) monosynaptic reflexes.
   (b) polysynaptic reflexes.
   (c) tendon reflexes.
   (d) extensor reflexes.
12. An example of a stretch reflex triggered by passive muscle movement is the
   (a) tendon reflex.
   (b) patellar reflex.
   (c) flexor reflex.
   (d) ipsilateral reflex.
13. The contraction of flexor muscles and the relaxation of extensor muscles illustrate the principle of
   (a) reverberating circuitry.
   (b) generalized facilitation.
   (c) reciprocal inhibition.
   (d) reinforcement.
14. Reflex arcs in which the sensory stimulus and the motor response occur on the same side of the body are
   (a) contralateral.
   (b) paraesthetic.
   (c) ipsilateral.
   (d) monosynaptic.
15. Proceeding deep from the most superficial layer, number the following in the correct sequence:
   (a) ___________ walls of vertebral canal
   (b) ___________ pia mater
   (c) ___________ dura mater
   (d) ___________ arachnoid membrane
   (e) ___________ subdural space
   (f) ___________ subarachnoid space
   (g) ___________ epidural space
   (h) ___________ spinal cord

LEVEL 2 Reviewing Concepts

16. Explain the anatomical significance of the fact that spinal cord growth ceases at age 4.
17. List, in sequence, the five steps involved in a neural reflex.
18. Polysynaptic reflexes can produce far more complicated responses than can monosynaptic reflexes because
   (a) the response time is quicker.
   (b) the response is initiated by highly sensitive receptors.
   (c) motor neurons carry impulses at a faster rate than do sensory neurons.
   (d) the interneurons involved can control several muscle groups.
19. Why do cervical nerves outnumber cervical vertebrae?
20. If the anterior gray horns of the spinal cord were damaged, what type of control would be affected?
21. List all of the CNS sites where cerebrospinal fluid (CSF) is located. What are the functions of CSF?
22. What five characteristics are common to all polysynaptic reflexes?
23. Predict the effects on the body of a spinal cord transection at C_7. How would these effects differ from those of a spinal cord transection at T_{10}?
24. The subarachnoid space contains
   (a) cerebrospinal fluid.
   (b) lymph.
   (c) air.
   (d) connective tissue and blood vessels.
   (e) denticulate ligaments.

25. Side-to-side movements of the spinal cord are prevented by the
    - **(a)** filum terminale.
    - **(b)** denticulate ligaments.
    - **(c)** dura mater.
    - **(d)** pia mater.
    - **(e)** arachnoid mater.
26. Ascending tracts
    - **(a)** carry sensory information to the brain.
    - **(b)** carry motor information to the brain.
    - **(c)** carry sensory information from the brain.
    - **(d)** carry motor information from the brain.
    - **(e)** connect perceptive areas with the brain.
27. What effect does the stimulation of a sensory neuron that innervates an intrafusal muscle fiber have on muscle tone?

LEVEL 3 Critical Thinking and Clinical Applications

28. Mary complains that when she wakes up in the morning, her thumb and forefinger are always "asleep." She mentions this condition to her physician, who asks Mary whether she sleeps with her wrists flexed. She replies that she does. The physician tells Mary that sleeping in that position may compress a portion of one of her peripheral nerves, producing her symptoms. Which nerve is involved?
29. The improper use of crutches can produce a condition known as "crutch paralysis," characterized by a lack of response by the extensor muscles of the arm, and a condition known as "wrist drop," consisting of an inability to extend the fingers and wrist. Which nerve is involved?
30. Bowel and urinary bladder control involve spinal reflex arcs that are located in the sacral region of the spinal cord. In both instances, two sphincter muscles—an inner sphincter of smooth muscle and an outer sphincter of skeletal muscle—control the passage of wastes (feces and urine) out of the body. How would a transection of the spinal cord at the L_1 level affect an individual's bowel and bladder control?
31. Karen falls down a flight of stairs and suffers lumbar and sacral spinal cord damage due to hyperextension of her back. The injury resulted in edema around the central canal that compressed the anterior horn of the lumbar region. What signs would you expect to observe as a result of this injury?