



Cross section through two fascicles (bundles) of nerve fibers in a nerve

CHAPTER

13

The Spinal Cord, Spinal Nerves, and Somatic Reflexes

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Brushing Up

To understand this chapter, it is important that you understand or brush up on the following concepts:

- Function of antagonistic muscles (p. 329)
- Parallel after-discharge circuits (p. 472)

We studied the nervous system at a cellular level in chapter 12. In these next two chapters, we move up the structural hierarchy to study the nervous system at the organ and system levels of organization. The *spinal cord* is an “information highway” between your brain and your trunk and limbs. It is about as thick as a finger, and extends through the vertebral canal as far as your first lumbar vertebra. At regular intervals, it gives off a pair of *spinal nerves* that receive sensory input from the skin, muscles, bones, joints, and viscera, and that issue motor commands back to muscle and gland cells. The spinal cord is a component of the central nervous system and the spinal nerves a component of the peripheral nervous system, but these central and peripheral components are so closely linked structurally and functionally that it is appropriate that we consider them together in this chapter. The brain and cranial nerves will be discussed in chapter 14.

The Spinal Cord

Objectives

When you have completed this section, you should be able to

- name the two types of tissue in the central nervous system and state their locations;
- describe the gross and microscopic anatomy of the spinal cord; and
- name the major conduction pathways of the spinal cord and state their functions.

Functions

The spinal cord serves three principal functions:

1. **Conduction.** The spinal cord contains bundles of nerve fibers that conduct information up and down the cord, connecting different levels of the trunk with each other and with the brain. This enables sensory information to reach the brain, motor commands to reach the effectors, and input received at one level of the cord to affect output from another level.
2. **Locomotion.** Walking involves repetitive, coordinated contractions of several muscle groups in the limbs. Motor neurons in the brain initiate walking and determine its speed, distance, and direction, but the simple repetitive muscle contractions that put one foot in front of another, over and over, are coordinated by groups of neurons called **central pattern generators** in the cord. These neuronal circuits produce the sequence of outputs to the extensor and flexor muscles that cause alternating movements of the legs.
3. **Reflexes.** Reflexes are involuntary stereotyped responses to stimuli. They involve the brain, spinal cord, and peripheral nerves.

Gross Anatomy

The **spinal cord** (fig. 13.1) is a cylinder of nervous tissue that begins at the foramen magnum and passes through the vertebral canal as far as the inferior margin of the first lumbar vertebra (L1). In adults, it averages about 1.8 cm thick and 45 cm long. Early in fetal development, the spinal cord extends for the full length of the vertebral column. However, the vertebral column grows faster than the spinal cord, so the cord extends only to L3 by the time of birth and to L1 in an adult. Thus, it occupies only the upper two-thirds of the vertebral canal; the lower one-third is described shortly. The cord gives rise to 31 pairs of spinal nerves that pass through the intervertebral foramina. Although the spinal cord is not visibly segmented, the part supplied by each pair of spinal nerves is called a *segment*. The cord exhibits longitudinal grooves on its ventral and dorsal sides—the *ventral median fissure* and *dorsal median sulcus*, respectively.

The spinal cord is divided into **cervical**, **thoracic**, **lumbar**, and **sacral regions**. It may seem odd that it has a sacral region when the cord itself ends well above the sacrum. These regions, however, are named for the level of the vertebral column from which the spinal nerves emerge, not for the vertebrae that contain the cord itself.

In the inferior cervical region, a **cervical enlargement** of the cord gives rise to nerves of the upper limbs. In the lumbosacral region, there is a similar **lumbar enlargement** where nerves to the pelvic region and lower limbs arise. Inferior to the lumbar enlargement, the cord tapers to a point called the **medullary cone**. The lumbar enlargement and medullary cone give rise to a bundle of nerve roots that occupy the canal of vertebrae L2 to S5. This bundle, named the **cauda equina**¹ (CAW-duh ee-KWY-nah) for its resemblance to a horse’s tail, innervates the pelvic organs and lower limbs.

Think About It

Spinal cord injuries commonly result from fractures of vertebrae C5 to C6, but never from fractures of L3 to L5. Explain both observations.

Meninges of the Spinal Cord

The spinal cord and brain are enclosed in three fibrous membranes called **meninges** (meh-NIN-jeez)—singular, *meninx*² (MEN-inks). These membranes separate the soft tissue of the central nervous system from the bones of the vertebrae and skull. From superficial to deep, they are the dura mater, arachnoid mater, and pia mater.

¹cauda = tail + equin = horse

²menin = membrane

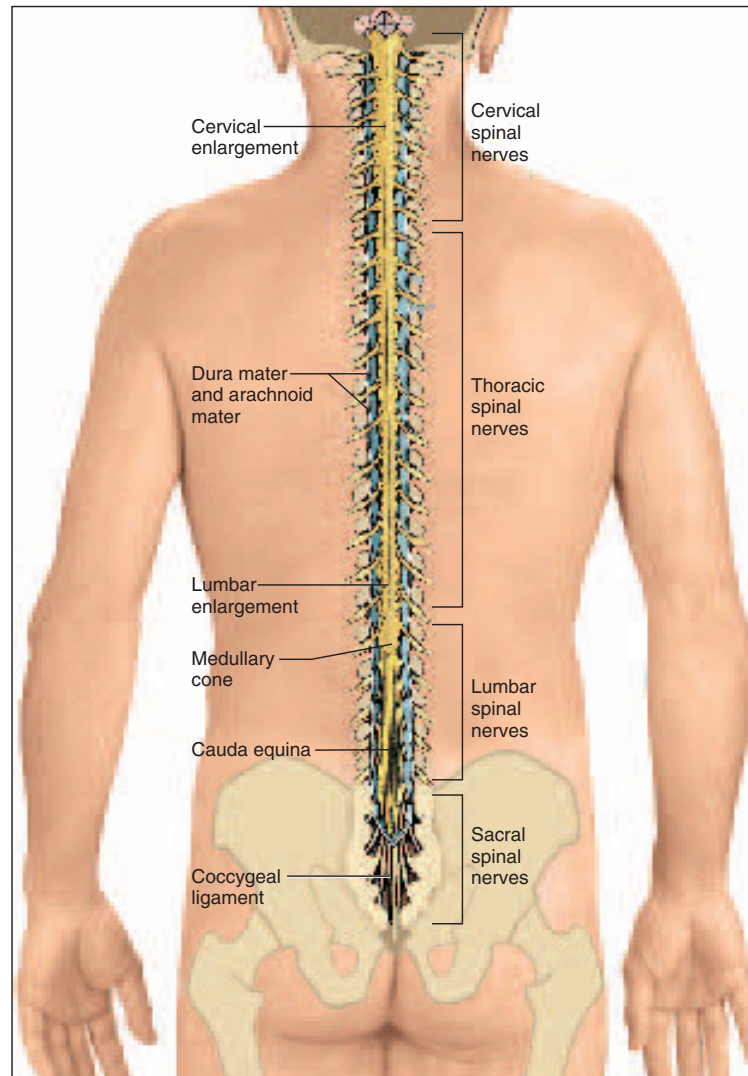


Figure 13.1 The Spinal Cord, Dorsal Aspect.

The **dura mater**³ (DOO-ruh MAH-tur) forms a loose-fitting sleeve called the **dural sheath** around the spinal cord. It is a tough collagenous membrane with a thickness and texture similar to a rubber kitchen glove. The space between the sheath and vertebral bone, called the **epidural space**, is occupied by blood vessels, adipose tissue, and loose connective tissue (fig. 13.2a). Anesthetics are sometimes introduced to this space to block pain signals during childbirth or surgery; this procedure is called *epidural anesthesia*.

The **arachnoid**⁴ (ah-RACK-noyd) **mater** adheres to the dural sheath. It consists of a simple squamous epithelium, the *arachnoid membrane*, adhering to the inside of the dura, and a loose mesh of collagenous and elastic fibers spanning the gap between the arachnoid membrane and the pia mater. This gap, called the **subarachnoid space**, is filled with cerebrospinal fluid (CSF), a clear liquid discussed in chapter 14.

The **pia**⁵ (PEE-uh) **mater** is a delicate, translucent membrane that closely follows the contours of the spinal cord. It continues beyond the medullary cone as a fibrous

³dura = tough + mater = mother, womb

⁴arachn = spider, spider web + oid = resembling

⁵pia = tender, soft

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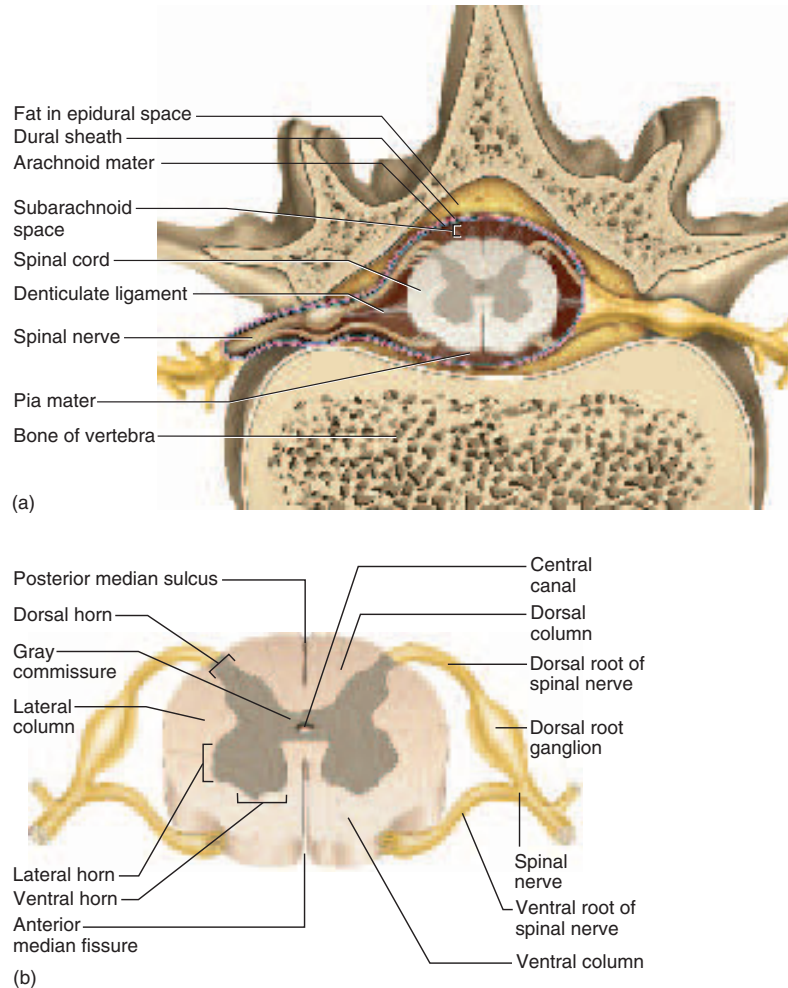


Figure 13.2 Cross Section of the Thoracic Spinal Cord. (a) Relationship to the vertebra, meninges, and spinal nerve. (b) Anatomy of the spinal cord itself.

strand, the *terminal filum*, forming part of the **coccygeal ligament** that anchors the cord to vertebra L2. At regular intervals along the cord, extensions of the pia called **denticulate ligaments** extend through the arachnoid to the dura, anchoring the cord and preventing side-to-side movements.

Insight 13.1 Clinical Application

Spina Bifida

About one baby in 1,000 is born with *spina bifida* (SPY-nuh BIF-ih-duh), a congenital defect resulting from the failure of one or more vertebrae to form a complete vertebral arch for enclosure of the spinal

cord. This is especially common in the lumbosacral region. One form, *spina bifida occulta*,⁶ involves only one to a few vertebrae and causes no functional problems. Its only external sign is a dimple or hairy pigmented spot. *Spina bifida cystica*⁷ is more serious. A sac protrudes from the spine and may contain meninges, cerebrospinal fluid, and parts of the spinal cord and nerve roots (fig. 13.3). In extreme cases, inferior spinal cord function is absent, causing lack of bowel control and paralysis of the lower limbs and urinary bladder. The last of these conditions can lead to chronic urinary infections and renal failure. Pregnant women can significantly reduce the risk of spina bifida by taking supplemental folic acid (a B vitamin) during early pregnancy. Good sources of folic acid include green leafy vegetables, black beans, lentils, and enriched bread and pasta.

⁶*bifid* = divided, forked + *occult* = hidden

⁷*cyst* = sac, bladder



Figure 13.3 Spina Bifida Cystica.

Cross-Sectional Anatomy

Figure 13.2*a* shows the relationship of the spinal cord to a vertebra and spinal nerve, and figure 13.2*b* shows the cord itself in more detail. The spinal cord, like the brain, consists of two kinds of nervous tissue called gray and white matter. **Gray matter** has a relatively dull color because it contains little myelin. It contains the somas, dendrites, and proximal parts of the axons of neurons. It is the site of synaptic contact between neurons, and therefore the site of all synaptic integration (information processing) in the central nervous system. **White matter** contains an abundance of myelinated axons, which give it a bright, pearly white appearance. It is composed of bundles of axons, called **tracts**, that carry signals from one part of the CNS to another. In fixed and silver-stained nervous tissue, gray matter tends to have a darker brown or golden color and white matter a lighter tan to yellow color.

Gray Matter

The spinal cord has a central core of gray matter that looks somewhat butterfly- or H-shaped in cross sections. The core consists mainly of two **dorsal (posterior) horns**, which extend toward the dorsolateral surfaces of the cord, and two thicker **ventral (anterior) horns**, which extend toward the ventrolateral surfaces. The right and left sides are connected by a **gray commissure**. In the middle of the commissure is the **central canal**, which is collapsed in most areas of the adult spinal cord, but in some places (and in young children) remains open, lined with ependymal cells, and filled with CSF.

As a spinal nerve approaches the cord, it branches into a **dorsal root** and **ventral root**. The dorsal root carries sensory nerve fibers, which enter the dorsal horn of the cord and sometimes synapse with an interneuron there. Such interneurons are especially numerous in the cervical and lumbar enlargements and are quite evident in histological sections at these levels. The ventral horns contain the large somas of the somatic motor neurons. Axons from these neurons exit by way of the ventral root of the spinal nerve and lead to the skeletal muscles. The spinal nerve roots are described more fully later in this chapter.

In the thoracic and lumbar regions, an additional **lateral horn** is visible on each side of the gray matter. It contains neurons of the sympathetic nervous system, which send their axons out of the cord by way of the ventral root along with the somatic efferent fibers.

White Matter

The white matter of the spinal cord surrounds the gray matter and consists of bundles of axons that course up and down the cord and provides avenues of communication between different levels of the CNS. These bundles are arranged in three pairs called **columns** or **funiculi**⁸ (few-NIC-you-lie)—a **dorsal (posterior)**, **lateral**, and **ventral (anterior) column** on each side. Each column consists of subdivisions called **tracts** or **fasciculi**⁹ (fah-SIC-you-lye).

⁸*funiculus* = little rope, cord

⁹*fasciculus* = little bundle

Spinal Tracts

Knowledge of the locations and functions of the spinal tracts is essential in diagnosing and managing spinal cord injuries. **Ascending tracts** carry sensory information up the cord and **descending tracts** conduct motor impulses down. All nerve fibers in a given tract have a similar origin, destination, and function.

Several of these tracts undergo **decussation**¹⁰ (DEE-cuh-SAY-shun) as they pass up or down the brainstem and spinal cord—meaning that they cross over from the left side of the body to the right, or vice versa. As a result, the left side of the brain receives sensory information from the right side of the body and sends its motor commands to that side, while the right side of the brain senses and controls the left side of the body. A stroke that damages motor centers of the right side of the brain can thus cause paralysis of the left limbs and vice versa. When the origin and destination of a tract are on opposite sides of the body, we say they are **contralateral**¹¹ to each other. When a tract does not decussate, so the origin and destination of its fibers are on the same side of the body, we say they are **ipsilateral**.¹²

The major spinal cord tracts are summarized in table 13.1 and figure 13.4. Bear in mind that each tract is repeated on the right and left sides of the spinal cord.

¹⁰*decuss* = to cross, form an X

¹¹*contra* = opposite

¹²*ipsi* = the same + *later* = side

Ascending Tracts

Ascending tracts carry sensory signals up the spinal cord. Sensory signals typically travel across three neurons from their origin in the receptors to their destination in the sensory areas of the brain: a **first-order neuron** that detects a stimulus and transmits a signal to the spinal cord or brainstem; a **second-order neuron** that continues as far as a “gateway” called the *thalamus* at the upper end of the brainstem; and a **third-order neuron** that carries the signal the rest of the way to the sensory region of the cerebral cortex. The axons of these neurons are called the first-through third-order nerve fibers. Deviations from the pathway described here will be noted for some of the sensory systems to follow.

The major ascending tracts are as follows. The names of most ascending tracts consist of the prefix *spino-* followed by a root denoting the destination of its fibers in the brain.

- The **gracile**¹³ **fasciculus** (GRAS-el fah-SIC-you-lus) carries signals from the midthoracic and lower parts of the body. Below vertebra T6, it composes the entire dorsal column. At T6, it is joined by the cuneate fasciculus, discussed next. It consists of first-order nerve fibers that travel up the ipsilateral side of the spinal cord and terminate at the *gracile nucleus* in the medulla oblongata of the brainstem. These fibers carry

¹³*gracil* = thin, slender

Table 13.1 Major Spinal Tracts

Tract	Column	Decussation	Functions
Ascending (sensory) Tracts			
Gracile fasciculus	Dorsal	In medulla	Limb and trunk position and movement, deep touch, visceral pain, vibration, below level T6
Cuneate fasciculus	Dorsal	In medulla	Same as gracile fasciculus, from level T6 up
Spinothalamic	Lateral and ventral	In spinal cord	Light touch, tickle, itch, temperature, pain, and pressure
Dorsal spinocerebellar	Lateral	None	Feedback from muscles (proprioception)
Ventral spinocerebellar	Lateral	In spinal cord	Same as dorsal spinocerebellar
Descending (motor) Tracts			
Lateral corticospinal	Lateral	In medulla	Fine control of limbs
Ventral corticospinal	Ventral	None	Fine control of limbs
Tectospinal	Lateral and ventral	In midbrain	Reflexive head-turning in response to visual and auditory stimuli
Lateral reticulospinal	Lateral	None	Balance and posture; regulation of awareness of pain
Medial reticulospinal	Ventral	None	Same as lateral reticulospinal
Vestibulospinal	Ventral	None	Balance and posture

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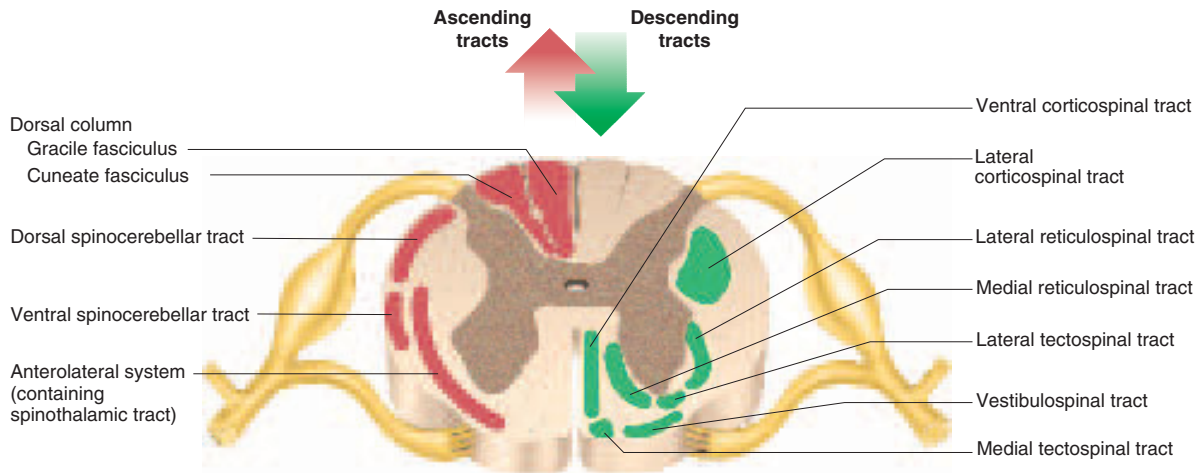


Figure 13.4 Tracts of the Spinal Cord. All of the illustrated tracts occur on both sides of the cord, but only the ascending sensory tracts are shown on the *left* (red), and only the descending motor tracts on the *right* (green).

If you were told that this cross section is either at level T4 or T10, how could you determine which is correct?

signals for vibration, visceral pain, deep and discriminative touch (touch whose location one can precisely identify), and especially *proprioception*¹⁴ from the lower limbs and lower trunk. (Proprioception is a nonvisual sense of the position and movements of the body.)

- The **cuneate**¹⁵ (CUE-nee-ate) **fasciculus** (fig. 13.5a) joins the gracile fasciculus at the T6 level. It occupies the lateral portion of the dorsal column and forces the gracile fasciculus medially. It carries the same type of sensory signals, originating from level T6 and up (from the upper limb and chest). Its fibers end in the *cuneate nucleus* on the ipsilateral side of the medulla oblongata. In the medulla, second-order fibers of the gracile and cuneate systems decussate and form the **medial lemniscus**¹⁶ (lem-NIS-cus), a tract of nerve fibers that leads the rest of the way up the brainstem to the thalamus. Third-order fibers go from the thalamus to the cerebral cortex. Because of decussation, the signals carried by the gracile and cuneate fasciculi ultimately go to the contralateral cerebral hemisphere.
- The **spinothalamic** (SPY-no-tha-LAM-ic) **tract** (fig. 13.5b) and some smaller tracts form the *anterolateral system*, which passes up the anterior

and lateral columns of the spinal cord. The spinothalamic tract carries signals for pain, temperature, pressure, tickle, itch, and light or crude touch. Light touch is the sensation produced by stroking hairless skin with a feather or cotton wisp, without indenting the skin; crude touch is touch whose location one can only vaguely identify. In this pathway, first-order neurons end in the dorsal horn of the spinal cord near the point of entry. Second-order neurons decussate to the opposite side of the spinal cord and there form the ascending spinothalamic tract. These fibers lead all the way to the thalamus. Third-order neurons continue from there to the cerebral cortex.

- The **dorsal** and **ventral spinocerebellar** (SPY-no-SERR-eh-BEL-ur) **tracts** travel through the lateral column and carry proprioceptive signals from the limbs and trunk to the cerebellum, a large motor control area at the rear of the brain. The first-order neurons of this system originate in the muscles and tendons and end in the dorsal horn of the spinal cord. Second-order neurons send their fibers up the spinocerebellar tracts and end in the cerebellum. Fibers of the dorsal tract travel up the ipsilateral side of the spinal cord. Those of the ventral tract cross over and travel up the contralateral side but then cross back in the brainstem to enter the ipsilateral cerebellum. Both tracts provide the cerebellum with feedback needed to coordinate muscle action, as discussed in chapter 14.

¹⁴*proprio* = one's own + *cept* = receive, sense

¹⁵*cune* = wedge

¹⁶*lemniscus* = ribbon

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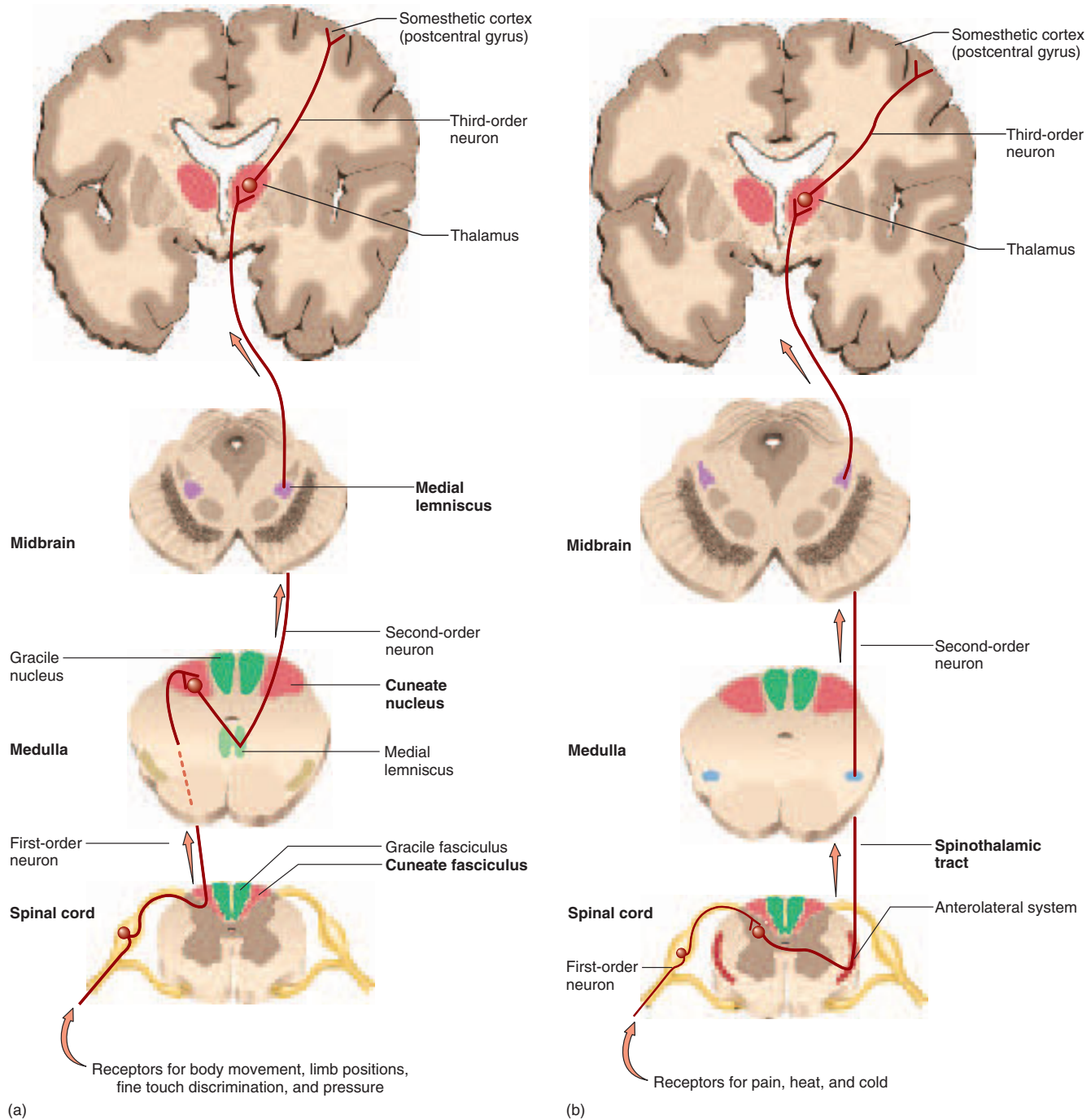


Figure 13.5 Some Ascending Pathways of the CNS. The spinal cord, medulla, and midbrain are shown in cross section and the cerebrum and thalamus (top) in frontal section. Nerve signals enter the spinal cord at the bottom of the figure and carry somatosensory information up to the cerebral cortex. (a) The cuneate fasciculus and medial lemniscus; (b) the spinothalamic tract.

Descending Tracts

Descending tracts carry motor signals down the brainstem and spinal cord. A descending motor pathway typically involves two neurons called the upper and lower motor neuron. The **upper motor neuron** begins with a soma in the cerebral cortex or brainstem and has an axon that terminates on a **lower motor neuron** in the brainstem or spinal cord. The axon of the lower motor neuron then leads the rest of the way to the muscle or other target organ. The names of most descending tracts consist of a word root denoting the point of origin in the brain, followed by the suffix *-spinal*. The major descending tracts are described here.

- The **corticospinal** (COR-tih-co-SPY-nul) **tracts** carry motor signals from the cerebral cortex for precise, finely coordinated limb movements. The fibers of this system form ridges called *pyramids* on the ventral surface of the medulla oblongata, so these tracts were once called *pyramidal tracts*. Most corticospinal fibers decussate in the lower medulla and form the **lateral corticospinal tract** on the contralateral side of the spinal cord. A few fibers remain uncrossed and form the **ventral corticospinal tract** on the ipsilateral side (fig. 13.6). Fibers of the ventral tract decussate lower in the spinal cord, however, so even they control contralateral muscles.
- The **tectospinal** (TEC-toe-SPY-nul) **tract** begins in a midbrain region called the *tectum* and crosses to the contralateral side of the brainstem. In the lower medulla, it branches into *lateral* and *medial tectospinal tracts* of the upper spinal cord. These are involved in reflex movements of the head, especially in response to visual and auditory stimuli.
- The **lateral and medial reticulospinal** (reh-TIC-you-lo-SPY-nul) **tracts** originate in the *reticular formation* of the brainstem. They control muscles of the upper and lower limbs, especially to maintain posture and balance. They also contain *descending analgesic pathways* that reduce the transmission of pain signals to the brain (see chapter 16).
- The **vestibulospinal** (vess-TIB-you-lo-SPY-nul) **tract** begins in a brainstem *vestibular nucleus* that receives impulses for balance from the inner ear. The tract passes down the ventral column of the spinal cord and controls limb muscles that maintain balance and posture.

Rubrospinal tracts are prominent in other mammals, where they aid in muscle coordination. Although often pictured in illustrations of human anatomy, they are almost nonexistent in humans and have little functional importance.

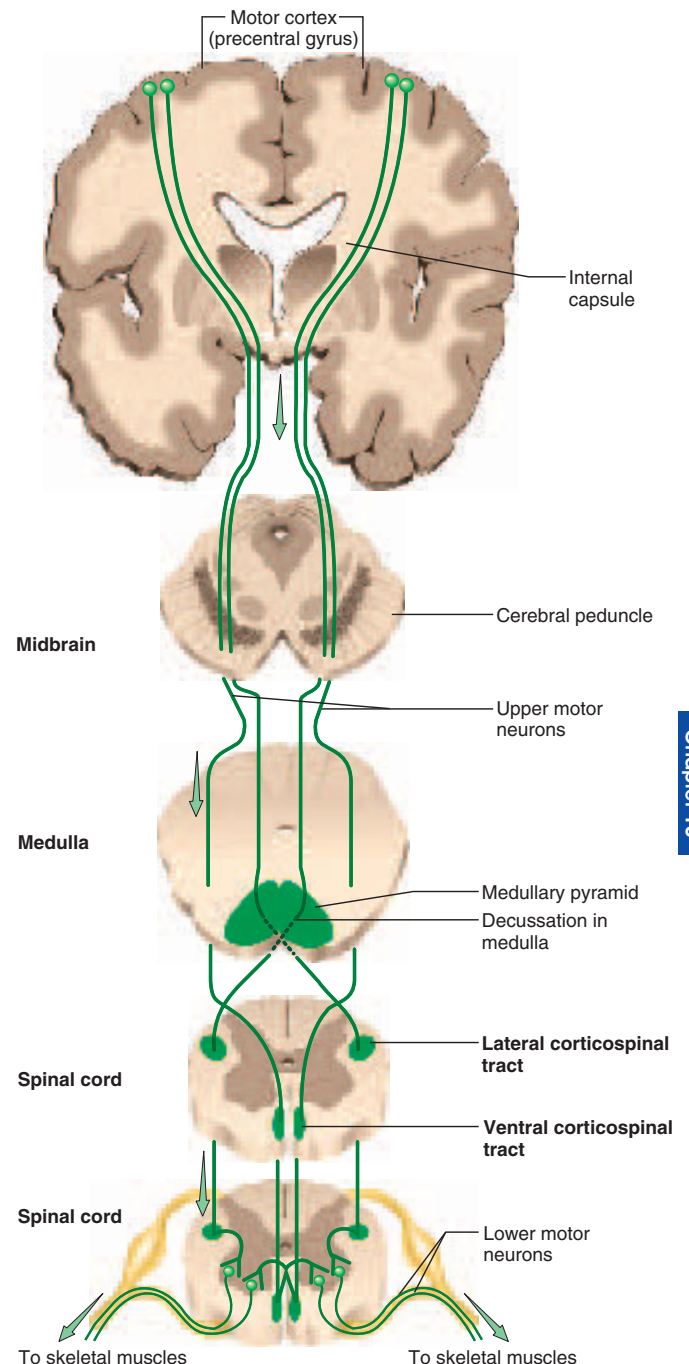


Figure 13.6 Two Descending Pathways of the CNS. The lateral and ventral corticospinal tracts, which carry signals for voluntary muscle contraction. Nerve signals originate in the cerebral cortex at the top of the figure and carry motor commands down the spinal cord.

Think About It

You are blindfolded and either a tennis ball or an iron ball is placed in your right hand. What spinal tract(s) would carry the signals that enable you to discriminate between these two objects?

Insight 13.2 Clinical Application

Poliomyelitis and Amyotrophic Lateral Sclerosis

*Poliomyelitis*¹⁷ and *amyotrophic lateral sclerosis*¹⁸ (ALS) are two diseases that involve destruction of motor neurons. In both diseases, the skeletal muscles atrophy from lack of innervation.

Poliomyelitis is caused by the poliovirus, which destroys motor neurons in the brainstem and ventral horn of the spinal cord. Signs of polio include muscle pain, weakness, and loss of some reflexes, followed by paralysis, muscular atrophy, and sometimes respiratory arrest. The virus spreads by fecal contamination of water. Historically, polio afflicted mainly children, who sometimes contracted the virus in the summer by swimming in contaminated pools. The polio vaccine has nearly eliminated new cases.

ALS is also known as Lou Gehrig disease after the baseball player who contracted it. It is marked not only by the degeneration of motor neurons and atrophy of the muscles, but also sclerosis of the lateral regions of the spinal cord—hence its name. In most cases of ALS, neurons are destroyed by an inability of astrocytes to reabsorb glutamate from the tissue fluid, allowing this neurotransmitter to accumulate to a toxic level. The early signs of ALS include muscular weakness and difficulty in speaking, swallowing, and using the hands. Sensory and intellectual

functions remain unaffected, as evidenced by the accomplishments of astrophysicist and best-selling author Stephen Hawking, who was stricken with ALS while he was in college. Despite near-total paralysis, he remains highly productive and communicates with the aid of a speech synthesizer and computer. Tragically, many people are quick to assume that those who have lost most of their ability to communicate their ideas and feelings have no ideas and feelings to communicate. To a victim, this may be more unbearable than the loss of motor function itself.

¹⁷ *polio* = gray matter + *myel* = spinal cord + *itis* = inflammation
¹⁸ *a* = without + *myo* = muscle + *troph* = nourishment

Before You Go On

Answer the following questions to test your understanding of the preceding section:

1. Name the four major regions and two enlargements of the spinal cord.
2. Describe the distal (inferior) end of the spinal cord and the contents of the vertebral canal from level L2 to S5.
3. Sketch a cross section of the spinal cord showing the dorsal and ventral horns. Where are the gray and white matter? Where are the columns and tracts?
4. Give an anatomical explanation as to why a stroke in the right cerebral hemisphere can paralyze the limbs on the left side of the body.

The Spinal Nerves

Objectives

When you have completed this section, you should be able to

- describe the attachment of a spinal nerve to the spinal cord;
- trace the branches of a spinal nerve distal to its attachment;
- name the five plexuses of spinal nerves and describe their general anatomy;
- name some major nerves that arise from each plexus; and
- explain the relationship of dermatomes to the spinal nerves.

General Anatomy of Nerves and Ganglia

The spinal cord communicates with the rest of the body by way of the spinal nerves. Before we discuss those specific nerves, however, it is necessary to be familiar with the structure of nerves and ganglia in general.

A **nerve** is a cordlike organ composed of numerous nerve fibers (axons) bound together by connective tissue (fig. 13.8). If we compare a nerve fiber to a wire carrying an electrical current in one direction, a nerve would be comparable to an electrical cable composed of thousands of wires carrying currents in opposite directions. A nerve contains anywhere from a few nerve fibers to more than a million. Nerves usually have a pearly white color and resemble frayed string as they divide into smaller and smaller branches.



Figure 13.7 Stephen Hawking (1942–), Lucasian Professor of Mathematics at Cambridge University.

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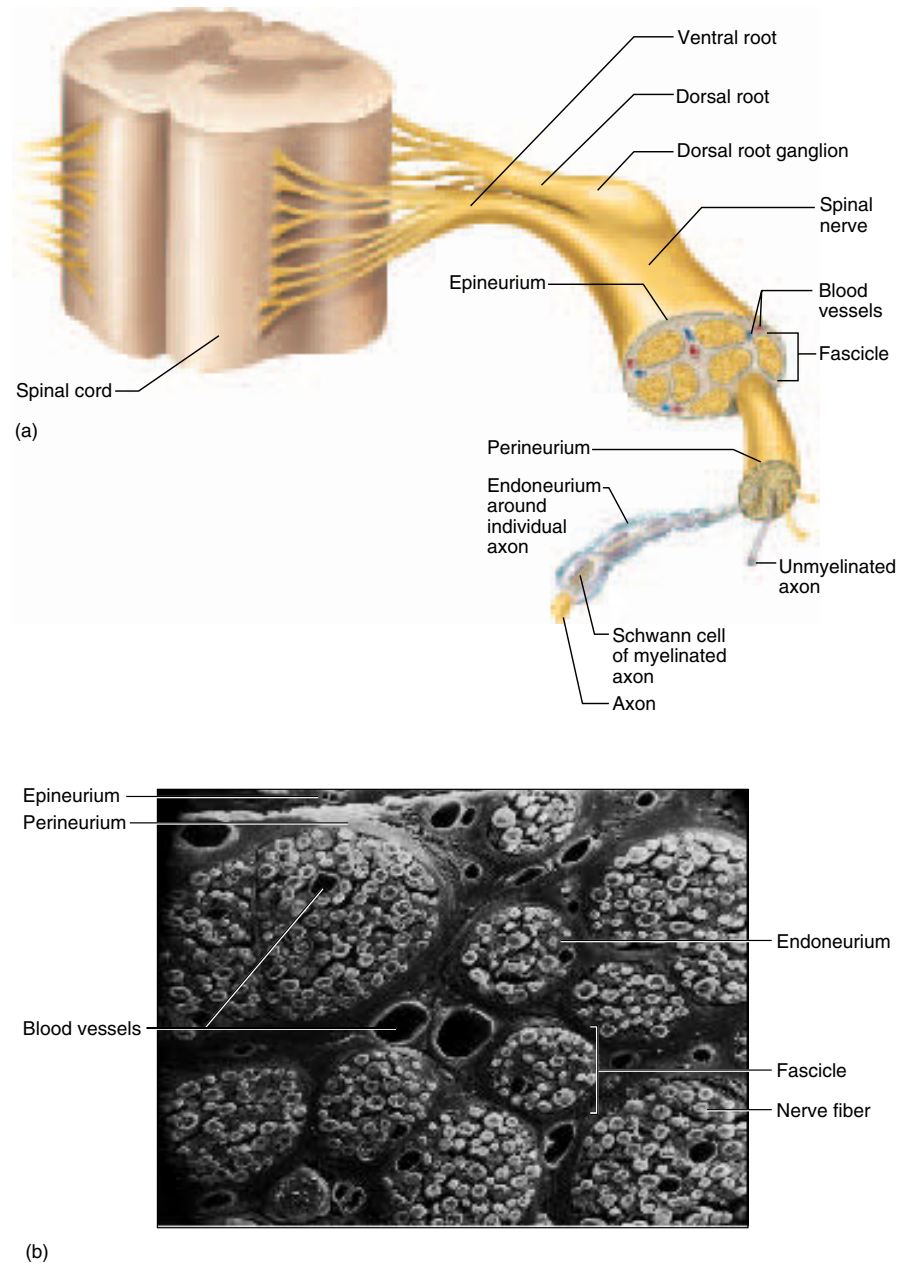


Figure 13.8 Anatomy of a Nerve. (a) A spinal nerve and its association with the spinal cord. (b) Cross section of a nerve (SEM). Myelinated nerve fibers appear as white rings and unmyelinated fibers as solid gray. Credit for b: Richard E. Kessel and Randy H. Kardon, *Tissues and Organs: A Text-Atlas of Scanning Electron Microscopy*, 1979, W. H. Freeman and Company.

Nerve fibers of the peripheral nervous system are ensheathed in Schwann cells, which form a neurilemma and often a myelin sheath around the axon (see chapter 12). External to the neurilemma, each fiber is surrounded by a basal lamina and then a thin sleeve of loose connective tissue

called the **endoneurium**. In most nerves, the nerve fibers are gathered in bundles called **fascicles**, each wrapped in a sheath called the **perineurium**. The perineurium is composed of one to six layers of overlapping, squamous, epithelium-like cells. Several fascicles are then

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bundled together and wrapped in an outer **epineurium** to compose the nerve as a whole. The epineurium is composed of dense irregular fibrous connective tissue and protects the nerve from stretching and injury. Nerves have a high metabolic rate and need a plentiful blood supply. Blood vessels penetrate as far as the perineurium, and oxygen and nutrients diffuse through the extracellular fluid from there to the nerve fibers.

Think About It

How does the structure of a nerve compare to that of a skeletal muscle? Which of the descriptive terms for nerves have similar counterparts in muscle histology?

Peripheral nerve fibers are of two kinds: *sensory (afferent) fibers* carry signals from sensory receptors to the CNS, and *motor (efferent) fibers* carry signals from the CNS to muscles and glands. Both sensory and motor fibers can also be described as *somatic* or *visceral* and as *general* or *special* depending on the organs they innervate (table 13.2).

A **mixed nerve** consists of both sensory and motor fibers and thus transmits signals in two directions, although any one nerve fiber within the nerve transmits signals one way only. Most nerves are mixed. Purely **sensory nerves**, composed entirely of sensory axons, are less common; they include the olfactory and optic nerves discussed in chapter 14. Nerves that carry only motor fibers are called **motor nerves**. Many nerves often described as motor are actually mixed because they carry sensory signals of proprioception from the muscle back to the CNS.

If a nerve resembles a thread, a **ganglion**¹⁹ resembles a knot in the thread. A ganglion is a cluster of cell

¹⁹*gangli* = knot

Table 13.2 The Classification of Nerve Fibers

Class	Description
Afferent fibers	Carry sensory signals from receptors to the CNS
Efferent fibers	Carry motor signals from the CNS to effectors
Somatic fibers	Innervate skin, skeletal muscles, bones, and joints
Visceral fibers	Innervate blood vessels, glands, and viscera
General fibers	Innervate widespread organs such as muscles, skin, glands, viscera, and blood vessels
Special fibers	Innervate more localized organs in the head, including the eyes, ears, olfactory and taste receptors, and muscles of chewing, swallowing, and facial expression

bodies (somas) outside the CNS. It is enveloped in an epineurium continuous with that of the nerve. Among the somas are bundles of nerve fibers leading into and out of the ganglion. Figure 13.9 shows a type of ganglion called the *dorsal root ganglion* associated with the spinal nerves.

Spinal Nerves

There are 31 pairs of **spinal nerves**: 8 cervical (C1–C8), 12 thoracic (T1–T12), 5 lumbar (L1–L5), 5 sacral (S1–S5), and 1 coccygeal (Co) (fig. 13.10). The first cervical nerve emerges between the skull and atlas, and the others emerge through intervertebral foramina, including the anterior and posterior foramina of the sacrum.

Proximal Branches

Each spinal nerve has two points of attachment to the spinal cord (fig. 13.11). Dorsally, a branch of the spinal nerve called the **dorsal root** divides into six to eight *nerve rootlets* that enter the spinal cord (fig. 13.12). A little distal to the rootlets is a swelling called the **dorsal root ganglion**, which contains the somas of afferent neurons. Ventrally, another row of six to eight rootlets leave the spinal cord and converge to form the **ventral root**.

The dorsal and ventral roots merge, penetrate the dural sac, enter the intervertebral foramen, and there form the spinal nerve proper.

Spinal nerves are mixed nerves, with a two-way traffic of afferent (sensory) and efferent (motor) signals. Afferent signals approach the cord by way of the dorsal root and enter the dorsal horn of the gray matter. Efferent signals begin at the somas of motor neurons in the ventral horn and leave the spinal cord via the ventral root. Some viruses invade the central nervous system by way of these roots (see insight 13.3).

The dorsal and ventral roots are shortest in the cervical region and become longer inferiorly. The roots that arise from segments L2 to Co of the cord form the cauda equina.

Distal Branches

Distal to the vertebrae, the branches of a spinal nerve are more complex (fig. 13.13). Immediately after emerging from the intervertebral foramen, the nerve divides into a **dorsal ramus**,²⁰ a **ventral ramus**, and a small **meningeal branch**. The meningeal branch (see fig. 13.11) reenters the vertebral canal and innervates the meninges, vertebrae, and spinal ligaments. The dorsal ramus innervates the muscles and joints in that region of the spine and the skin

²⁰*ramus* = branch

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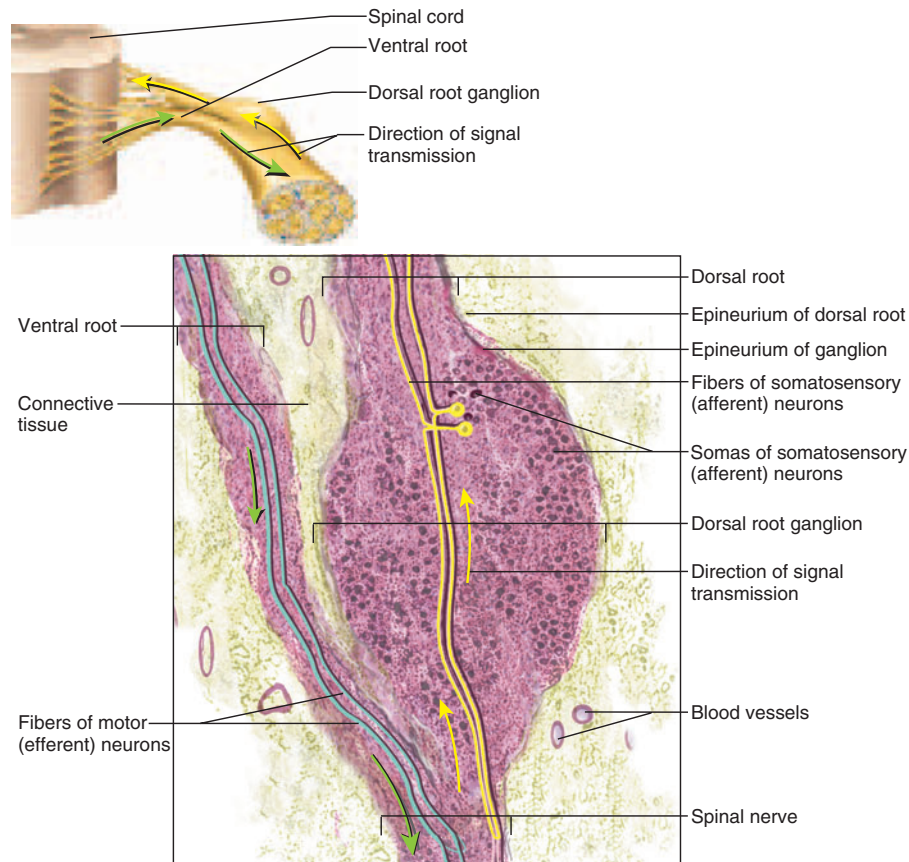


Figure 13.9 Anatomy of a Ganglion. The dorsal root ganglion contains the somas of unipolar sensory neurons conducting signals to the spinal cord. To the left of it is the ventral root of the spinal nerve, which conducts motor signals away from the spinal cord. (The ventral root is not part of the ganglion.)

Where are the somas of the motor neurons located?

of the back. The ventral ramus innervates the ventral and lateral skin and muscles of the trunk and gives rise to nerves of the limbs.

Think About It

Do you think the meningeal branch is sensory, motor, or mixed? Explain your reasoning.

The ventral ramus differs from one region of the trunk to another. In the thoracic region, it forms an **intercostal nerve** that travels along the inferior margin of a rib and innervates the skin and intercostal muscles (thus contributing to breathing), as well as the internal oblique, external oblique, and transversus abdominis muscles. All other ventral rami form the *nerve plexuses* described next.

Insight 13.3 Clinical Application

Shingles

Chickenpox (*varicella*), a common disease of early childhood, is caused by the *varicella-zoster* virus. It produces an itchy rash that usually clears up without complications. The virus, however, remains for life in the dorsal root ganglia. The immune system normally keeps it in check. If the immune system is compromised, however, the virus can travel down the sensory nerves by fast axonal transport and cause *shingles* (*herpes zoster*). This is characterized by a painful trail of skin discoloration and fluid-filled vesicles along the path of the nerve. These signs usually appear in the chest and waist, often on just one side of the body. Shingles usually occurs after the age of 50. While it can be very painful and may last 6 months or longer, it eventually heals spontaneously and requires no special treatment other than aspirin and steroidal ointment to relieve pain and inflammation.

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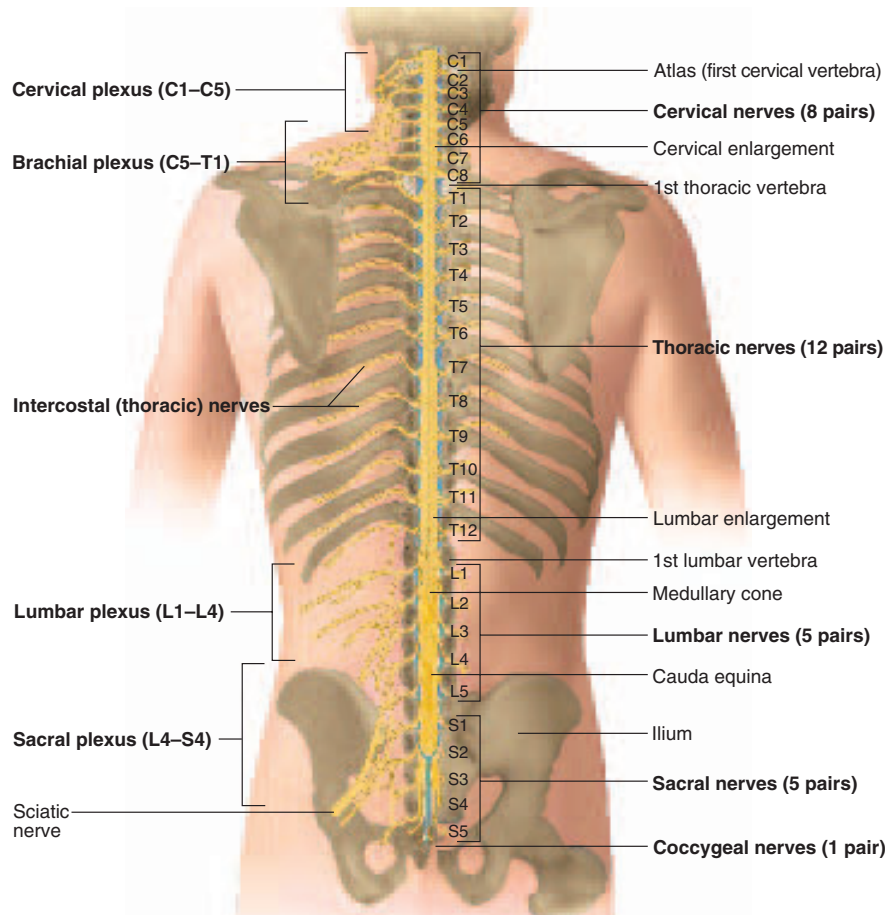


Figure 13.10 The Spinal Nerve Roots and Plexuses, Dorsal View.

Nerve Plexuses

Except in the thoracic region, the ventral rami branch and anastomose (merge) repeatedly to form five weblike nerve plexuses: the small **cervical plexus** deep in the neck, the **brachial plexus** near the shoulder, the **lumbar plexus** of the lower back, the **sacral plexus** immediately inferior to this, and finally the tiny **coccygeal plexus** adjacent to the lower sacrum and coccyx. A general view of these plexuses is shown in figure 13.10; they are illustrated and described in tables 13.3 through 13.6. The muscle actions controlled by these nerves are described in the muscle tables in chapter 10.

Insight 13.4 Clinical Application

Spinal Nerve Injuries

The radial and sciatic nerves are especially vulnerable to injury. The radial nerve, which passes through the axilla, may be compressed against the humerus by improperly adjusted crutches, causing *crutch paralysis*. A similar injury often resulted from the now-discredited practice of trying to correct a dislocated shoulder by putting a foot in a person's armpit and pulling on the arm. One consequence of radial nerve injury is *wrist drop*—the fingers, hand, and wrist are chronically flexed because the extensor muscles supplied by the radial nerve are paralyzed.

Because of its position and length, the sciatic nerve of the hip and thigh is the most vulnerable nerve in the body. Trauma to this nerve produces *sciatica*, a sharp pain that travels from the gluteal region along the posterior side of the thigh and leg as far as the ankle. Ninety percent of cases result from a herniated intervertebral disc or osteoarthritis of the lower spine, but sciatica can also be caused by pressure from a pregnant uterus, dislocation of the hip, injections in the wrong area of the buttock, or sitting for a long time on the edge of a hard chair. Men sometimes suffer sciatica from the habit of sitting on a wallet carried in the hip pocket.

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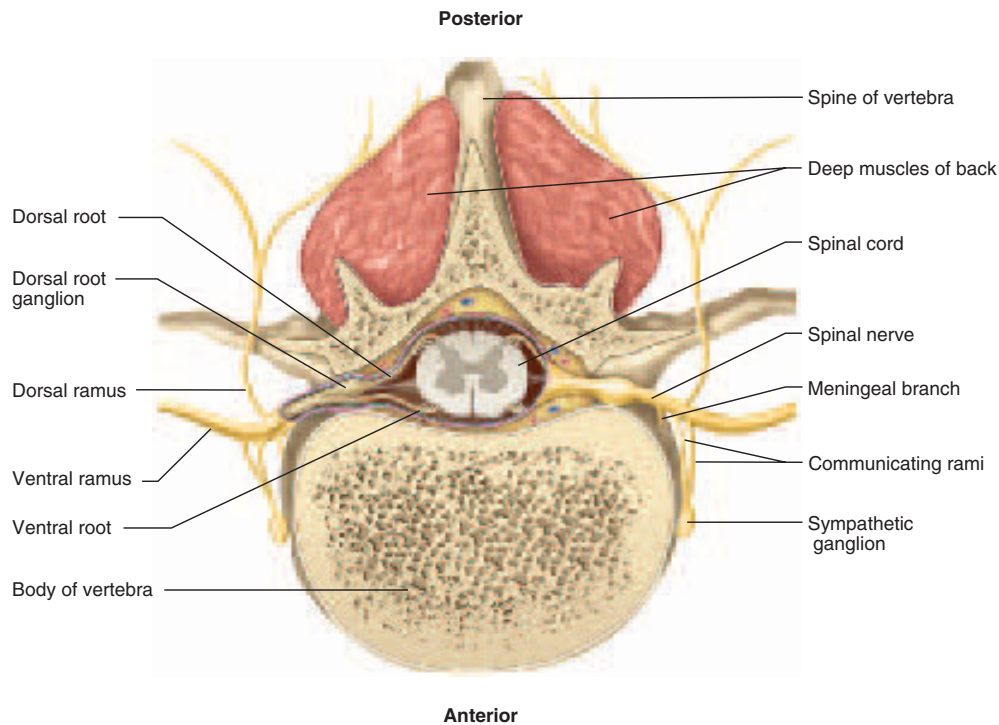


Figure 13.11 Branches of a Spinal Nerve in Relation to the Spinal Cord and Vertebra (cross section).



Figure 13.12 The Point of Entry of Two Spinal Nerves into the Spinal Cord. Dorsal view with vertebrae cut away. Note that each dorsal root divides into several rootlets that enter the spinal cord. A segment of the spinal cord is the portion receiving all the rootlets of one spinal nerve. In the labeled rootlets of spinal nerve C5, are the nerve fibers afferent or efferent? How do you know?

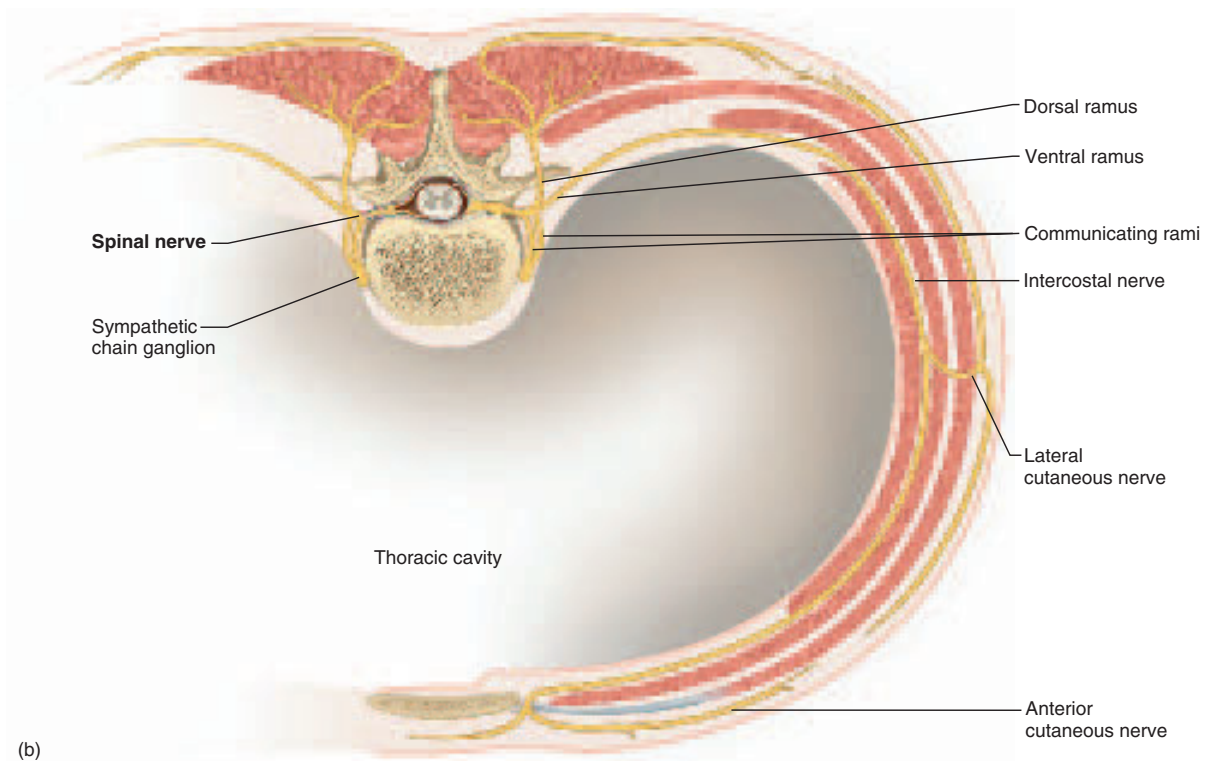
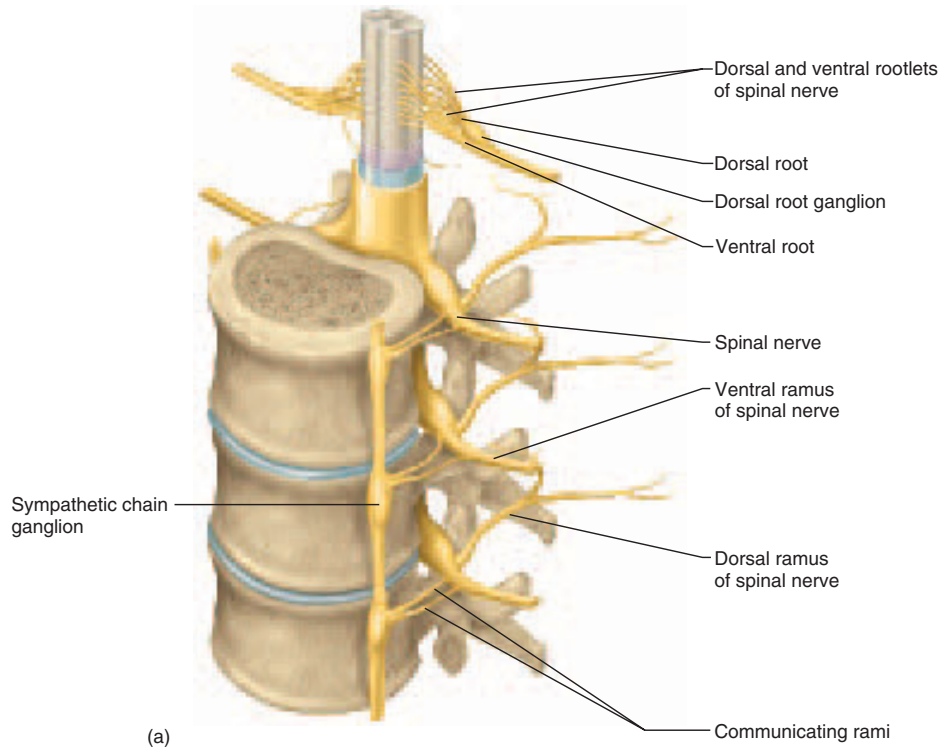


Figure 13.13 Rami of the Spinal Nerves. (a) Anterolateral view of the spinal nerves and their subdivisions in relation to the spinal cord and vertebrae. (b) Cross section of the thorax showing innervation of muscles of the chest and back.

Table 13.3 The Cervical Plexus

The cervical plexus (fig. 13.14) receives fibers from the ventral rami of nerves C1 to C5 and gives rise to the nerves listed, in order from superior to inferior. The most important of these are the *phrenic*²¹ nerves, which travel down each side of the mediastinum, innervate the diaphragm, and play an essential role in breathing. In addition to the major nerves listed here, there are several motor branches that innervate the geniohyoid, thyrohyoid, scalene, levator scapulae, trapezius, and sternocleidomastoid muscles.

Lesser Occipital Nerve

Composition: Somatosensory

Innervation: Skin of lateral scalp and dorsal part of external ear

Great Auricular Nerve

Composition: Somatosensory

Innervation: Skin of and around external ear

Transverse Cervical Nerve

Composition: Somatosensory

Innervation: Skin of ventral and lateral aspect of neck

Ansa Cervicalis

Composition: Motor

Innervation: Omohyoid, sternohyoid, and sternothyroid muscles

Supraclavicular Nerve

Composition: Somatosensory

Innervation: Skin of lower ventral and lateral neck, shoulder, and ventral chest

Phrenic (FREN-ic) Nerve

Composition: Motor

Innervation: Diaphragm

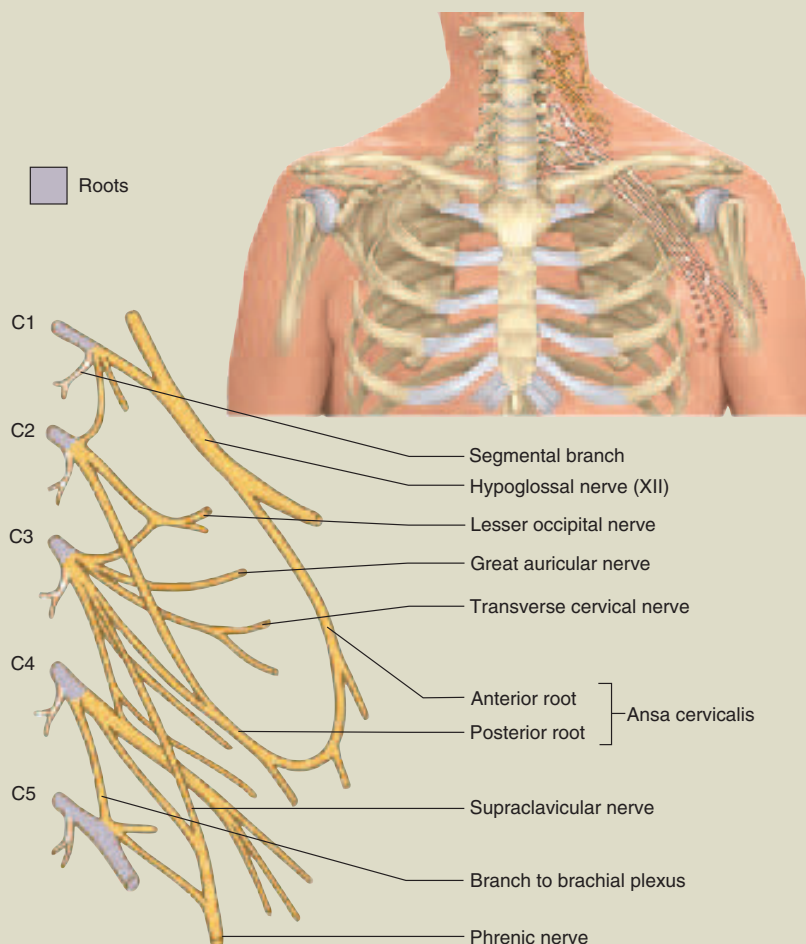


Figure 13.14 The Cervical Plexus.

²¹phren = diaphragm

Table 13.4 The Brachial Plexus

The brachial plexus (figs. 13.15 and 13.16) is formed by the ventral rami of nerves C4 to T2. It passes over the first rib into the axilla and innervates the upper limb and some muscles of the neck and shoulder. It gives rise to nerves for cutaneous sensation, muscle contraction, and proprioception from the joints and muscles.

The subdivisions of this plexus are called *roots*, *trunks*, *divisions*, and *cords* (color-coded in figure 13.15). The five *roots* are the ventral rami of nerves C5 to T1, which provide most of the fibers to this plexus (C4 and T2 contribute partially). The five roots unite to form the *upper, middle, and lower trunks*. Each trunk divides into an *anterior* and *posterior division*, and finally the six divisions merge to form three large fiber bundles—the *posterior, medial, and lateral cords*.

Axillary Nerve

Composition: Motor and somatosensory

Origin: Posterior cord of brachial plexus

Sensory innervation: Skin of lateral shoulder and arm; shoulder joint

Motor innervation: Deltoid and teres minor

Radial Nerve

Composition: Motor and somatosensory

Origin: Posterior cord of brachial plexus

Sensory innervation: Skin of posterior aspect of arm, forearm, and wrist; joints of elbow, wrist, and hand

Motor innervation: Muscles of posterior arm and forearm: triceps brachii, supinator, anconeus, brachioradialis, extensor carpi radialis brevis, extensor carpi radialis longus, and extensor carpi ulnaris

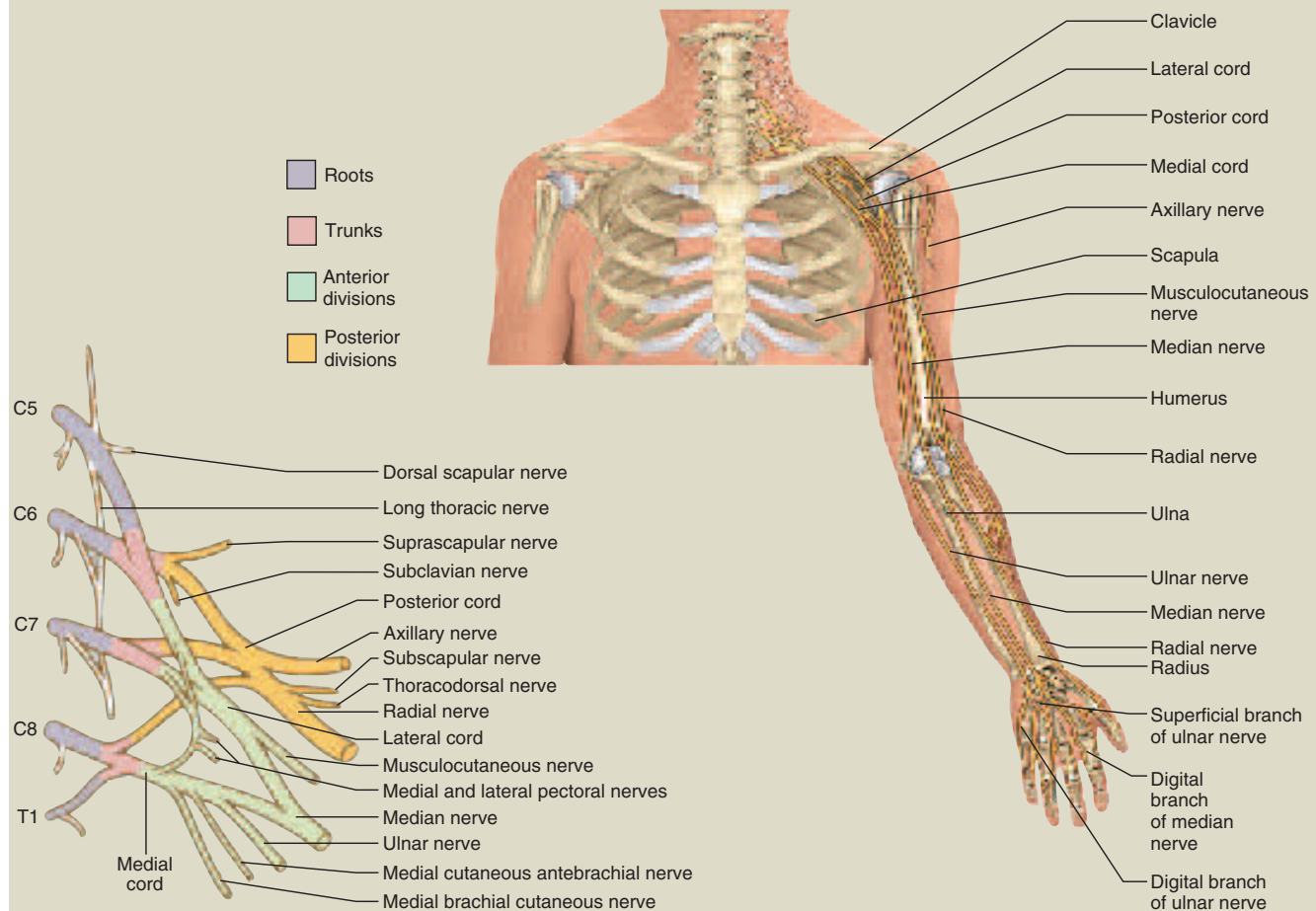


Figure 13.15 The Brachial Plexus.

(continued)

Table 13.4 The Brachial Plexus (continued)

Musculocutaneous Nerve

Composition: Motor and somatosensory
Origin: Lateral cord of brachial plexus
Sensory innervation: Skin of lateral aspect of forearm
Motor innervation: Muscles of anterior arm: coracobrachialis, biceps brachii, and brachialis

Median Nerve

Composition: Motor and somatosensory
Origin: Medial cord of brachial plexus
Sensory innervation: Skin of lateral two-thirds of hand, joints of hand
Motor innervation: Flexors of anterior forearm; thenar muscles; first and second lumbricals

Ulnar Nerve

Composition: Motor and somatosensory
Origin: Medial cord of brachial plexus
Sensory innervation: Skin of medial part of hand; joints of hand
Motor innervation: Flexor carpi ulnaris, flexor digitorum profundus, adductor pollicis, hypothenar muscles, interosseous muscles, and third and fourth lumbricals

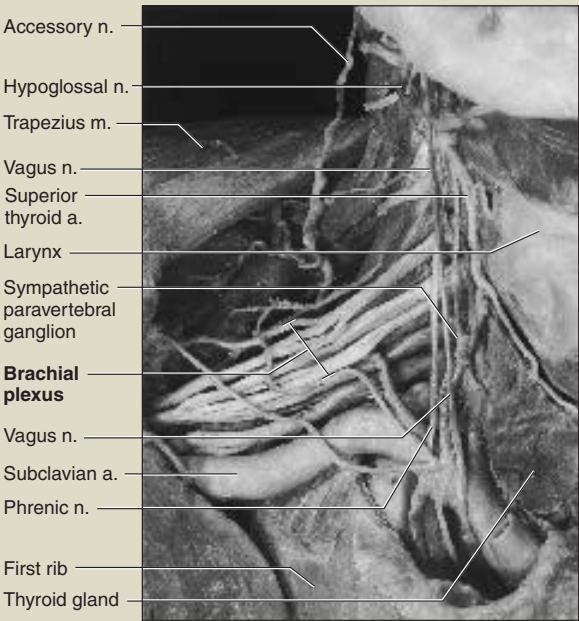


Figure 13.16 Photograph of the Brachial Plexus. Anterior view of the right shoulder, also showing three of the cranial nerves, the sympathetic trunk, and the phrenic nerve (a branch of the cervical plexus). Most of the other structures resembling nerves in this photograph are blood vessels. (a. = artery; m. = muscle; n. = nerve.)

Table 13.5 The Lumbar Plexus

The lumbar plexus (fig. 13.17) is formed from the ventral rami of nerves L1 to L4 and some fibers from T12. With only five roots and two divisions, it is less complex than the brachial plexus.

Iliohypogastric Nerve

Composition: Motor and somatosensory

Sensory innervation: Skin of anterior abdominal wall

Motor innervation: Internal and external obliques and transversus abdominis

Ilioinguinal Nerve

Composition: Motor and somatosensory

Sensory innervation: Skin of upper medial thigh; male scrotum and root of penis; female labia majora

Motor innervation: Joins iliohypogastric nerve and innervates the same muscles

Genitofemoral Nerve

Composition: Somatosensory

Sensory innervation: Skin of middle anterior thigh; male scrotum and cremaster muscle; female labia majora

Femoral Nerve

Composition: Motor and somatosensory

Sensory innervation: Skin of anterior and lateral thigh; medial leg and foot

Motor innervation: Anterior muscles of thigh and extensors of leg; iliacus, psoas major, pectineus, quadriceps femoris, and sartorius

Saphenous (sah-FEE-nus) Nerve

Composition: Somatosensory

Sensory innervation: Skin of medial aspect of leg and foot; knee joint

Obturator Nerve

Composition: Motor and somatosensory

Sensory innervation: Skin of superior medial thigh; hip and knee joints

Motor innervation: Adductor muscles of leg: external obturator, pectineus, adductor longus, adductor brevis, adductor magnus, and gracilis

Lateral Femoral Cutaneous Nerve

Composition: Somatosensory

Sensory innervation: Skin of lateral aspect of thigh

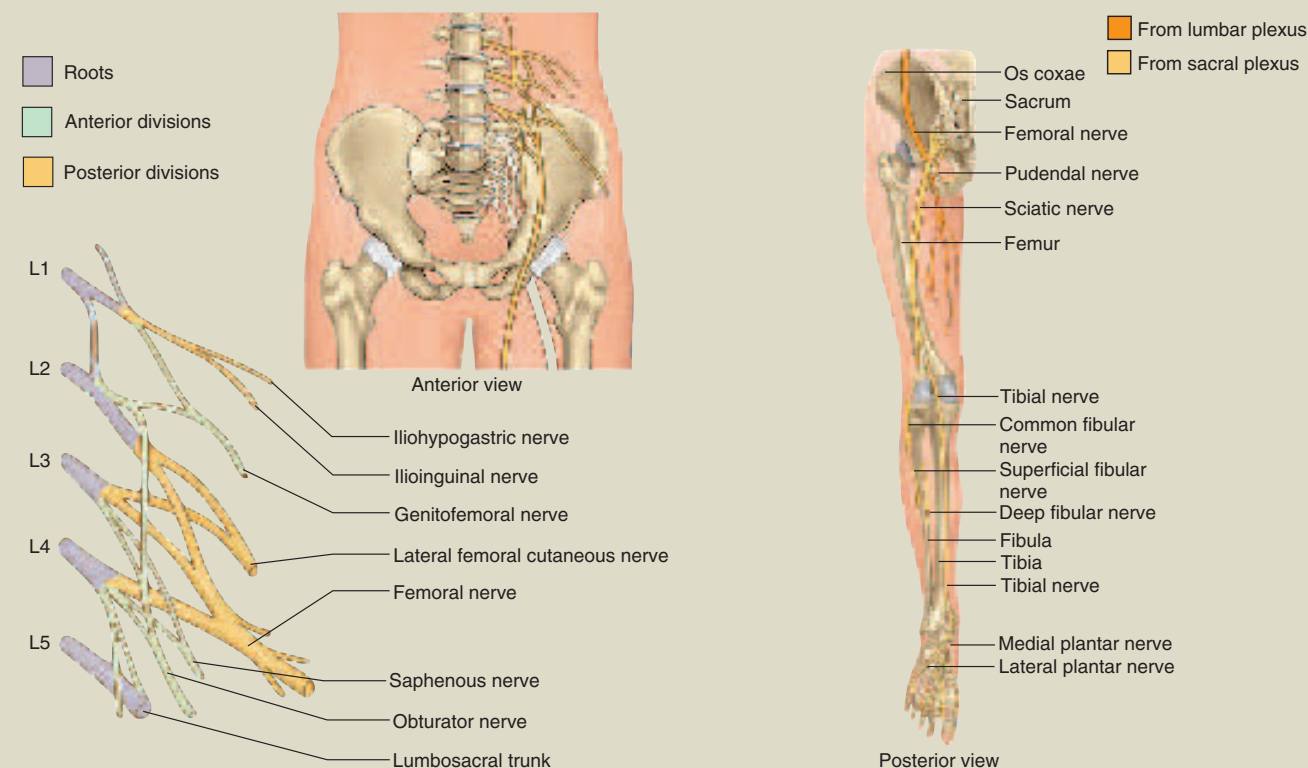


Figure 13.17 The Lumbar Plexus.

Table 13.6 The Sacral and Coccygeal Plexuses

The sacral plexus is formed from the ventral rami of nerves L4, L5, and S1 to S4. It has six roots and anterior and posterior divisions. Since it is connected to the lumbar plexus by fibers that run through the *lumbosacral trunk*, the two plexuses are sometimes referred to collectively as the *lumbosacral plexus*. The coccygeal plexus is a tiny plexus formed from the ventral rami of S4, S5, and Co (fig. 13.18).

The *tibial* and *common fibular nerves* listed in this table travel together through a connective tissue sheath; they are referred to collectively as the **sciatic** (sy-AT-ic) **nerve**. The sciatic nerve passes through the greater sciatic notch of the pelvis, extends for the length of the thigh, and ends at the popliteal fossa. Here, the tibial and common fibular nerves diverge and follow their separate paths into the leg. The sciatic nerve is a common focus of injury and pain.

Superior Gluteal Nerve

Composition: Motor

Motor innervation: Gluteus minimus, gluteus medius, and tensor fasciae latae

Inferior Gluteal Nerve

Composition: Motor

Motor innervation: Gluteus maximus

Nerve to Piriformis

Composition: Motor

Motor innervation: Piriformis

Nerve to Quadratus Femoris

Composition: Motor and somatosensory

Sensory innervation: Hip joint

Motor innervation: Quadratus femoris and gemellus inferior

Nerve to Internal Obturator

Composition: Motor

Motor innervation: Internal obturator and gemellus superior

Perforating Cutaneous Nerve

Composition: Somatosensory

Sensory innervation: Skin of posterior aspect of buttock

Posterior Cutaneous Nerve

Composition: Somatosensory

Sensory innervation: Skin of lower lateral buttock, anal region, upper posterior thigh, upper calf, scrotum, and labia majora

Tibial Nerve

Composition: Motor and somatosensory

Sensory innervation: Skin of posterior leg and sole of foot; knee and foot joints

Motor innervation: Semitendinosus, semimembranosus, long head of biceps femoris, gastrocnemius, soleus, flexor digitorum longus, flexor hallucis longus, tibialis posterior, popliteus, and intrinsic muscles of foot

(continued)

Table 13.6 The Sacral and Coccygeal Plexuses (continued)

Common Fibular (peroneal) Nerve

Composition: Motor and somatosensory

Sensory innervation: Skin of anterior distal one-third of leg, dorsum of foot, and toes I and II; knee joint

Motor innervation: Short head of biceps femoris, fibularis tertius, fibularis brevis, fibularis longus, tibialis anterior, extensor hallucis longus, extensor digitorum longus, and extensor digitorum brevis

Pudendal Nerve

Composition: Motor and somatosensory

Sensory innervation: Skin of penis and scrotum of male; clitoris, labia majora and minora, and lower vagina of female

Motor innervation: Muscles of perineum

Coccygeal Nerve

Composition: Motor and somatosensory

Sensory innervation: Skin over coccyx

Motor innervation: Muscles of pelvic floor

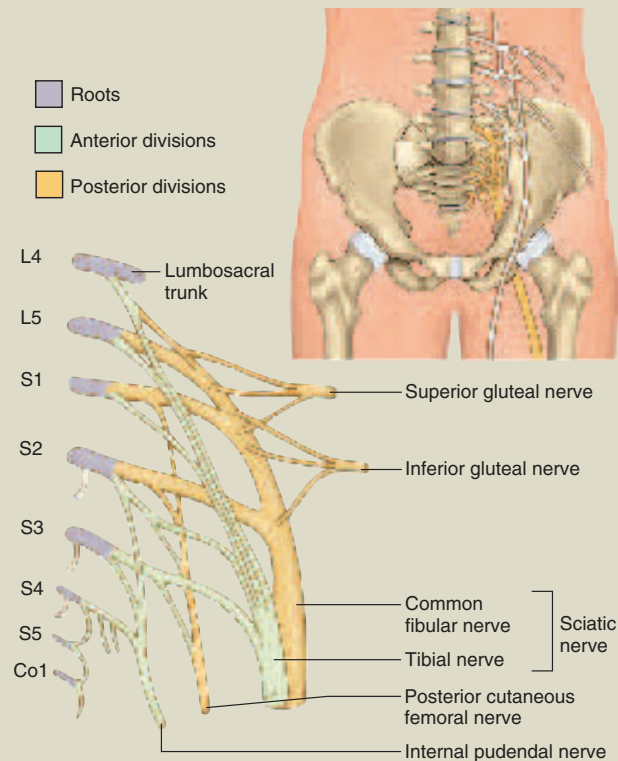


Figure 13.18 The Sacral and Coccygeal Plexuses.

Cutaneous Innervation and Dermatomes

Each spinal nerve except C1 receives sensory input from a specific area of skin called a **dermatome**.²² A *dermatome map* (fig. 13.19) is a diagram of the cutaneous regions innervated by each spinal nerve. Such a map is oversimplified, however, because the dermatomes overlap at their edges by as much as 50%. Therefore, severance of one sensory nerve root does not entirely deaden sensation from a dermatome. It is necessary to sever or anesthetize three successive spinal nerves to produce a total loss of sensation from one dermatome. Spinal nerve damage is assessed by testing the dermatomes with pinpricks and noting areas in which the patient has no sensation.

²²derma = skin + tome = segment, part

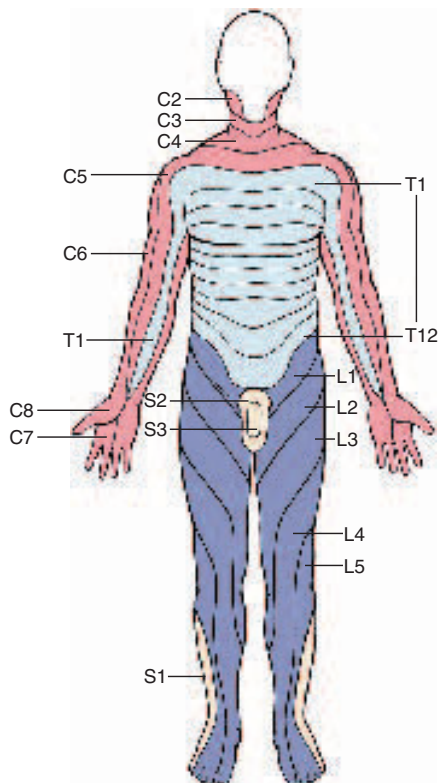


Figure 13.19 A Dermatome Map of the Anterior Aspect of the Body. Each zone of the skin is innervated by sensory branches of the spinal nerves indicated by the labels. Nerve C1 does not innervate the skin.

Before You Go On

Answer the following questions to test your understanding of the preceding section:

- What is meant by the dorsal and ventral roots of a spinal nerve? Which of these is sensory and which is motor?
- Where are the somas of the dorsal root located? Where are the somas of the ventral root?
- List the five plexuses of spinal nerves and state where each one is located.
- State which plexus gives rise to each of the following nerves: axillary, ilioinguinal, obturator, phrenic, pudendal, radial, and sciatic.

Somatic Reflexes

Objectives

When you have completed this section, you should be able to

- define *reflex* and explain how reflexes differ from other motor actions;
- describe the general components of a typical reflex arc; and
- explain how the basic types of somatic reflexes function.

Most of us have had our reflexes tested with a little rubber hammer; a tap near the knee produces an uncontrollable jerk of the leg, for example. In this section, we discuss what reflexes are and how they are produced by an assembly of receptors, neurons, and effectors. We also survey the different types of neuromuscular reflexes and how they are important to motor coordination.

The Nature of Reflexes

Reflexes are quick, involuntary, stereotyped reactions of glands or muscles to stimulation. This definition sums up four important properties of a reflex:

- Reflexes *require stimulation*—they are not spontaneous actions but responses to sensory input.
- Reflexes are *quick*—they generally involve few if any interneurons and minimum synaptic delay.
- Reflexes are *involuntary*—they occur without intent, often without our awareness, and they are difficult to suppress. Given an adequate stimulus, the response is essentially automatic. You may become conscious of the stimulus that evoked a reflex, and this awareness may enable you to correct or avoid a potentially dangerous situation, but awareness is not a part of the reflex itself. It may come after the reflex action has been completed, and somatic reflexes can occur even if the spinal cord has been severed so that no stimuli reach the brain.
- Reflexes are *stereotyped*—they occur in essentially the same way every time; the response is very predictable.

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Reflexes include glandular secretion and contractions of all three types of muscle. They also include some learned responses, such as the salivation of dogs in response to a sound they have come to associate with feeding time, first studied by Ivan Pavlov and named *conditioned reflexes*. In this section, however, we are concerned with unlearned skeletal muscle reflexes that are mediated by the brainstem and spinal cord. They result in the involuntary contraction of a muscle—for example, the quick withdrawal of your hand from a hot stove or the lifting of your foot when you step on something sharp. These are **somatic reflexes**, since they involve the somatic nervous system. Chapter 15 concerns *visceral reflexes*. The somatic reflexes have traditionally been called *spinal reflexes*, although some visceral reflexes also involve the spinal cord, and some somatic reflexes are mediated more by the brain than by the spinal cord.

A somatic reflex employs a **reflex arc**, in which signals travel along the following pathway:

1. *somatic receptors* in the skin, a muscle, or a tendon;
2. *afferent nerve fibers*, which carry information from these receptors into the dorsal horn of the spinal cord;
3. *interneurons*, which integrate information; these are lacking from some reflex arcs;
4. *efferent nerve fibers*, which carry motor impulses to the skeletal muscles; and
5. *skeletal muscles*, the somatic effectors that carry out the response.

The Muscle Spindle

Many somatic reflexes involve stretch receptors in the muscles called **muscle spindles**. These are among the body's **proprioceptors**—sense organs that monitor the position and movements of body parts. Muscle spindles are especially abundant in muscles that require fine control. The hand and foot have 100 or more spindles per gram of muscle, whereas there are relatively few in large muscles with coarse movements and none at all in the middle-ear muscles. Muscle spindles provide the cerebellum with the feedback it needs to regulate the tension in the skeletal muscles.

Muscle spindles are about 4 to 10 mm long, tapered at the ends, and scattered throughout the fleshy part of a muscle (fig. 13.20). A spindle contains 3 to 12 modified muscle fibers and a few nerve fibers, all wrapped in a fibrous capsule. The muscle fibers within a spindle are called **intrafusal**²³ **fibers**, while those of the rest of the muscle are called **extrafusal fibers**. Only the two ends of an intrafusal fiber have sarcomeres and are able to contract. The middle

portion acts as the stretch receptor. There are two classes of intrafusal fibers: *nuclear chain fibers*, which have a single file of nuclei in the noncontractile region, and *nuclear bag fibers*, which are about twice as long and have nuclei clustered in a thick midregion.

Muscle spindles have three types of nerve fibers:

1. **Primary afferent fibers**, which end in *annulospiral endings* that coil around the middle of nuclear chain and nuclear bag fibers. These respond mainly to the onset of muscle stretch.
2. **Secondary afferent fibers**, which have *flower-spray endings*, somewhat resembling the dried head of a wildflower, wrapped primarily around the ends of the nuclear chain fibers. These respond mainly to prolonged stretch.
3. **Gamma (γ) motor neurons**, which originate in the ventral horn of the spinal cord and lead to the contractile ends of the intrafusal fibers. The name distinguishes them from the **alpha (α) motor neurons**, which innervate the extrafusal fibers. Gamma motor neurons adjust the tension in a muscle spindle to variations in the length of the muscle. When a muscle shortens, the γ motor neurons stimulate the ends of the intrafusal fibers to contract slightly. This keeps the intrafusal fibers taut and responsive at all times. Without this feedback, the spindles would become flabby when a skeletal muscle shortened. This feedback is clearly very important, because γ motor neurons constitute about one-third of all the motor fibers in a spinal nerve.

The Stretch Reflex

When a muscle is stretched, it “fights back”—it contracts, maintains increased tonus, and feels stiffer than an unstretched muscle. This response, called the **stretch (myotatic)**²⁴ **reflex**, helps to maintain equilibrium and posture. For example, if your head starts to tip forward, it stretches muscles such as the semispinalis and splenius capitis of the nuchal region (back of your neck). This stimulates their muscle spindles, which send afferent signals to the cerebellum by way of the brainstem. The cerebellum integrates this information and relays it to the cerebral cortex, and the cortex sends signals back to the nuchal muscles. The muscles contract and raise your head.

Stretch reflexes often feed back not to a single muscle but to a set of synergists and antagonists. Since the contraction of a muscle on one side of a joint stretches the antagonistic muscle on the other side, the flexion of a joint triggers a stretch reflex in the extensors, and extension

²³*intra* = within + *fus* = spindle

²⁴*myo* = muscle + *tat* (from *tasis*) = stretch

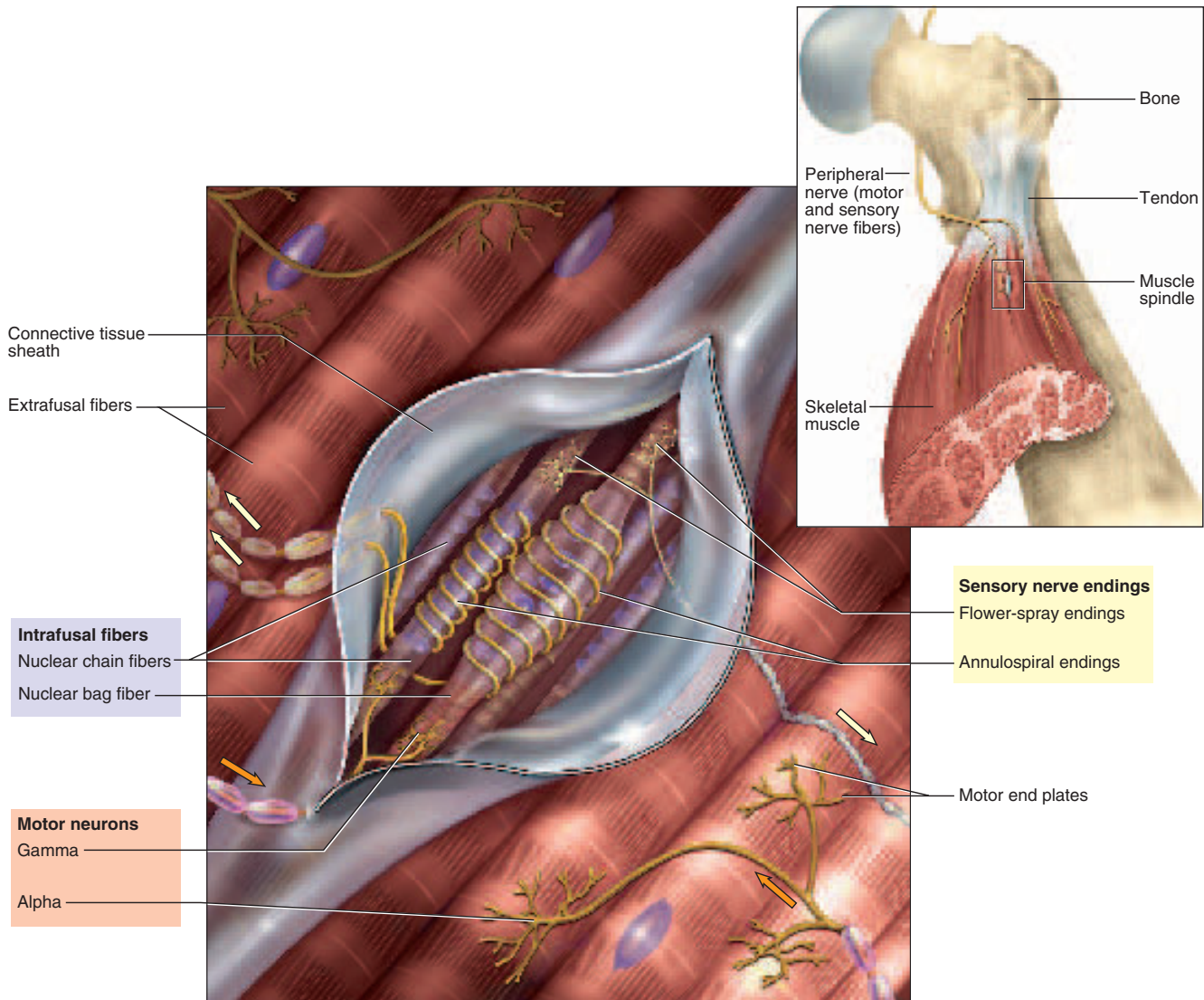


Figure 13.20 A Muscle Spindle and Its Innervation.

stimulates a stretch reflex in the flexors. Consequently, stretch reflexes are valuable in stabilizing joints by balancing the tension of the extensors and flexors. They also dampen (smooth) muscle action. Without stretch reflexes, a person's movements tend to be jerky. Stretch reflexes are especially important in coordinating vigorous and precise movements such as dance.

A stretch reflex is mediated primarily by the brain and is not, therefore, strictly a spinal reflex, but a weak component of it is spinal and occurs even if the spinal cord is severed from the brain. The spinal component can be more pronounced if a muscle is stretched very suddenly. This occurs

in a **tendon reflex**—the reflexive contraction of a muscle when its tendon is tapped, as in the familiar knee-jerk (patellar) reflex. Tapping the patellar ligament with a reflex hammer suddenly stretches the quadriceps femoris muscle of the thigh (fig. 13.21). This stimulates numerous muscle spindles in the quadriceps and sends an intense volley of signals to the spinal cord, mainly by way of primary afferent fibers.

In the spinal cord, the primary afferent fibers synapse directly with the α motor neurons that return to the muscle, thus forming **monosynaptic reflex arcs**. That is, there is only one synapse between the afferent and efferent neuron, therefore little synaptic delay and a very

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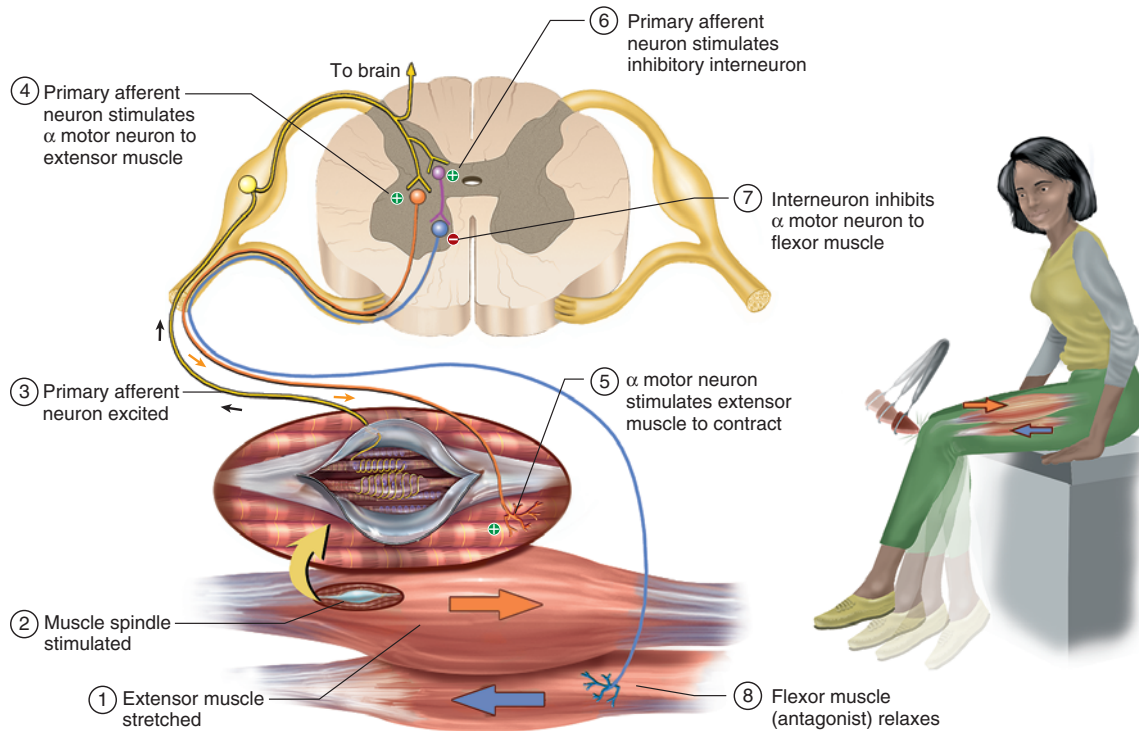


Figure 13.21 The Patellar Tendon Reflex Arc and Reciprocal Inhibition of the Antagonistic Muscle. Plus signs indicate excitation of a postsynaptic cell (EPSPs) and minus signs indicate inhibition (IPSPs). The tendon reflex is occurring in the quadriceps femoris muscle (red arrow), while the hamstring muscles are exhibiting reciprocal inhibition (blue arrow) so they do not contract and oppose the quadriceps.

Why is no IPSP shown at point 8 if the contraction of this muscle is being inhibited?

prompt response. The α motor neurons excite the quadriceps muscle, making it contract and creating the knee jerk.

There are many other tendon reflexes. A tap on the calcaneal tendon causes plantar flexion of the foot, a tap on the triceps brachii tendon causes extension of the elbow, and a tap on the cheek causes clenching of the jaw. Testing somatic reflexes is valuable in diagnosing many diseases that cause exaggeration, inhibition, or absence of reflexes, such as neurosyphilis, diabetes mellitus, multiple sclerosis, alcoholism, electrolyte imbalances, and lesions of the nervous system.

Stretch reflexes and other muscle contractions often depend on **reciprocal inhibition**, a reflex phenomenon that prevents muscles from working against each other by inhibiting antagonists. In the knee jerk, for example, the quadriceps femoris would not produce much joint movement if its antagonists, the hamstring muscles, contracted at the same time. But reciprocal inhibition prevents that from happening. Some branches of the sensory fibers from the muscle spindles in the quadriceps stimulate spinal cord interneurons which, in turn, inhibit the α motor neurons of the hamstring muscles (fig. 13.21). The hamstring muscles therefore remain relaxed and allow the quadriceps to extend the knee.

The Flexor (Withdrawal) Reflex

A **flexor reflex** is the quick contraction of flexor muscles resulting in the withdrawal of a limb from an injurious stimulus. For example, suppose you are wading in a lake and step on a broken bottle with your right foot (fig. 13.22). Even before you are consciously aware of the pain, you quickly pull your foot away before the glass penetrates any deeper. This action involves contraction of the flexors and relaxation of the extensors in that limb; the latter is another case of reciprocal inhibition.

The protective function of this reflex requires more than a quick jerk like a tendon reflex, so it involves more complex neural pathways. Sustained contraction of the flexors is produced by a parallel after-discharge circuit in the spinal cord (see fig. 12.27, p. 473). This circuit is part of a **polysynaptic reflex arc**—a pathway in which signals travel over many synapses on their way back to the muscle. Some signals follow routes with only a few synapses and return to the flexor muscles quickly. Others follow routes with more synapses, and therefore more delay, so they reach the flexor muscles a little later. Consequently, the flexor muscles receive prolonged output from the spinal cord and not just one sudden stimu-

lus as in a stretch reflex. By the time these efferent signals begin to die out, you will probably be consciously aware of the pain and begin taking voluntary action to prevent further harm.

The Crossed Extensor Reflex

In the preceding situation, if *all* you did was to quickly lift the injured leg from the lake bottom, you would fall over. To prevent this and maintain your balance, other reflexes shift your center of gravity over the leg that is still on the ground. The **crossed extensor reflex** is the contraction of extensor muscles in the limb opposite from the one that is withdrawn (fig. 13.22). It extends that limb and enables

you to keep your balance. To produce this reflex, branches of the afferent nerve fibers cross from the stimulated side of the body to the contralateral side of the spinal cord. There, they synapse with interneurons, which, in turn, excite or inhibit α motor neurons to the muscles of the contralateral limb.

In the ipsilateral leg (the side that was hurt), you would contract your flexors and relax your extensors to lift the leg from the ground. On the contralateral side, you would relax your flexors and contract the extensors to stiffen that leg, since it must suddenly support your entire body. At the same time, signals travel up the spinal cord and cause contraction of contralateral muscles of the hip and abdomen to shift your center of gravity over the

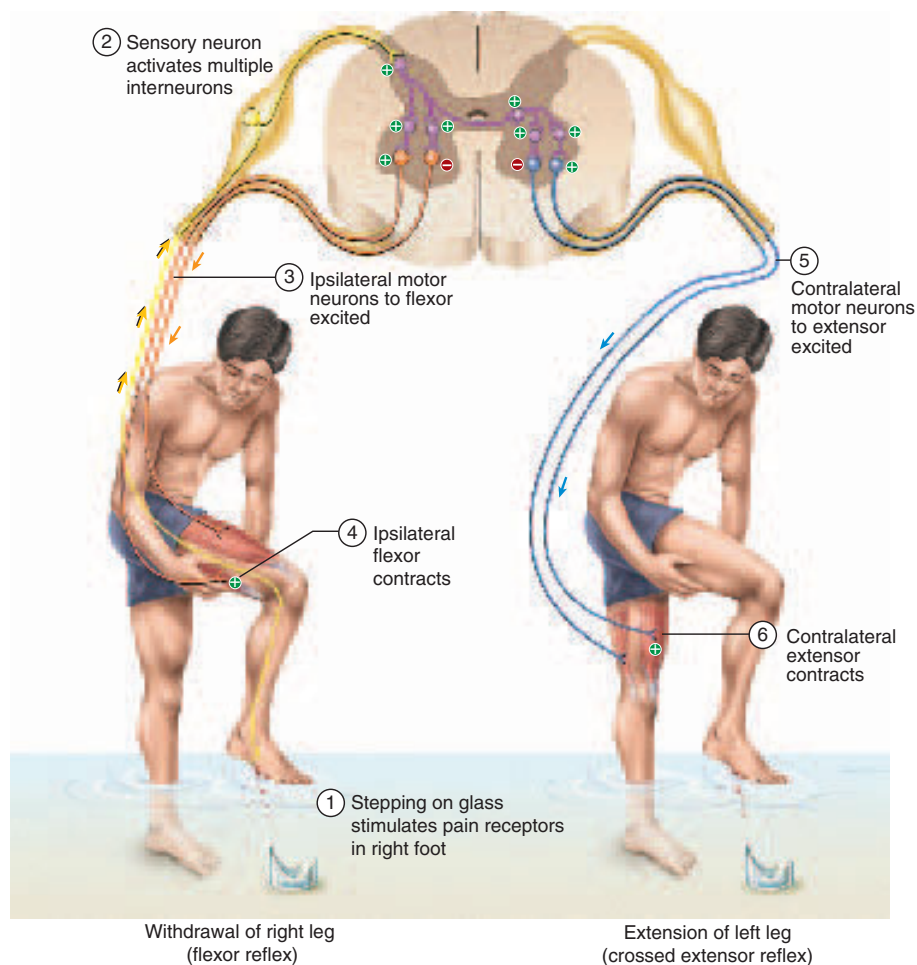


Figure 13.22 The Flexor and Crossed Extensor Reflexes. The pain stimulus triggers a withdrawal reflex, which results in contraction of flexor muscles of the injured limb. At the same time, a crossed extensor reflex results in contraction of extensor muscles of the opposite limb. The latter reflex aids in balance when the injured limb is raised. Note that for each limb, while the agonist contracts, the α motor neuron to its antagonist is inhibited, as indicated by the red minus signs in the spinal cord.

Would you expect this reflex arc to show more synaptic delay, or less, than the ones in figure 13.15? Why?

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extended leg. To a large extent, the coordination of all these muscles and maintenance of equilibrium is mediated by the cerebellum and cerebral cortex.

The flexor reflex employs an **ipsilateral reflex arc**—one in which the sensory input and motor output are on the same sides of the spinal cord. The crossed extensor reflex employs a **contralateral reflex arc**, in which the input and output are on opposite sides. An **intersegmental reflex arc** is one in which the input and output occur at different levels (segments) of the spinal cord—for example, when pain to the foot causes contractions of abdominal and hip muscles higher up the body. Note that all of these reflex arcs can function simultaneously to produce a coordinated protective response to pain.

The Golgi Tendon Reflex

Golgi tendon organs are proprioceptors located in a tendon near its junction with a muscle (fig. 13.23). A tendon organ is about 1 mm long and consists of an encapsulated tangle of knobby nerve endings entwined in the collagen fibers of the tendon. As long as the tendon is slack, its collagen fibers are slightly spread and they put little pressure on the nerve endings woven among them. When muscle contraction pulls on the tendon, the collagen fibers come together like the two sides of a stretched rubber band and squeeze the nerve endings between them. The nerve fiber sends signals to the spinal cord that provide the CNS with feedback on the degree of muscle tension at the joint.

The **Golgi tendon reflex** is a response to excessive tension on the tendon. It inhibits α motor neurons to the muscle so the muscle does not contract as strongly. This serves to moderate muscle contraction before it tears a tendon or pulls it loose from the muscle or bone. Nevertheless, strong muscles and quick movements sometimes damage a tendon before the reflex can occur, causing such athletic injuries as a ruptured calcaneal tendon.

The Golgi tendon reflex also functions when some parts of a muscle contract more than others. It inhibits the fibers connected with overstimulated tendon organs so that their contraction is more comparable to the contraction of the rest of the muscle. This reflex spreads the workload more evenly over the entire muscle, which is beneficial in such actions as maintaining a steady grip on a tool.

Table 13.7 and insight 13.5 describe some injuries and other disorders of the spinal cord and spinal nerves.

Insight 13.5 Clinical Application

Spinal Cord Trauma

Each year in the United States, 10,000 to 12,000 people become paralyzed by spinal cord trauma, usually as a result of vertebral fractures. The group at greatest risk is males from 16 to 30 years old, because of

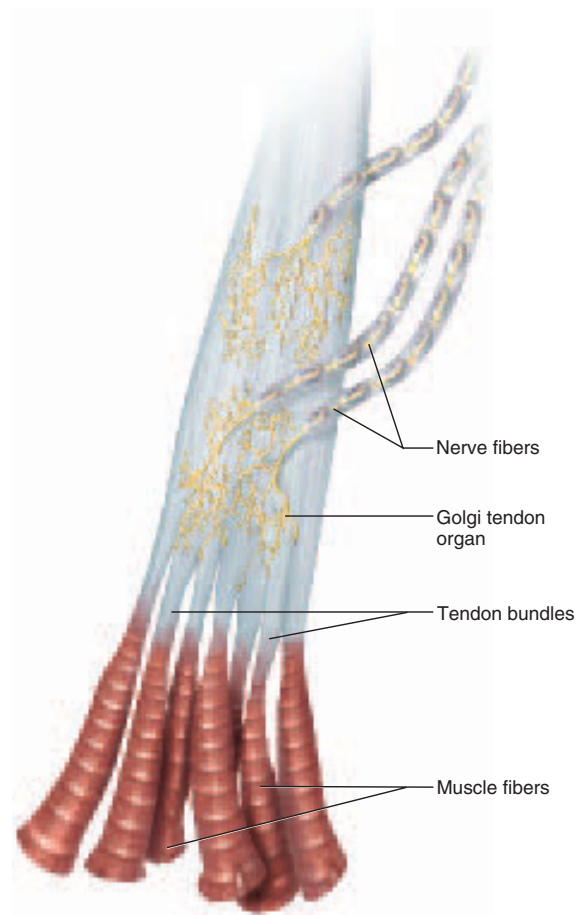


Figure 13.23 A Golgi Tendon Organ.

their high-risk behaviors. Fifty-five percent of their injuries are from automobile and motorcycle accidents, 18% from sports, and 15% from gunshot and stab wounds. Elderly people are also at above-average risk because of falls, and in times of war, battlefield injuries account for many cases.

Effects of Injury

Complete *transection* (severance) of the spinal cord causes immediate loss of motor control at and below the level of the injury. Transection superior to segment C4 presents a threat of respiratory failure. Victims also lose all sensation from the level of injury and below, although some patients temporarily feel burning pain within one or two dermatomes of the level of the lesion.

In the early stage, victims exhibit a syndrome (a suite of signs and symptoms) called *spinal shock*. The muscles below the level of injury exhibit flaccid paralysis and an absence of reflexes because of the lack of stimulation from higher levels of the CNS. For 8 days to 8 weeks after the accident, the patient typically lacks bladder and bowel reflexes and thus retains urine and feces. Lacking sympathetic stimulation to the blood vessels, a patient may exhibit *neurogenic shock* in which the vessels dilate and blood pressure drops dangerously low. Fever may occur because the hypothalamus cannot induce sweating to

Table 13.7 Some Disorders of the Spinal Cord and Spinal Nerves

Guillain-Barré syndrome	An acute demyelinating nerve disorder often triggered by viral infection, resulting in muscle weakness, elevated heart rate, unstable blood pressure, shortness of breath, and sometimes death from respiratory paralysis	
Neuralgia	General term for nerve pain, often caused by pressure on spinal nerves from herniated intervertebral discs or other causes	
Paresthesia	Abnormal sensations of prickling, burning, numbness, or tingling; a symptom of nerve trauma or other peripheral nerve disorders	
Peripheral neuropathy	Any loss of sensory or motor function due to nerve injury; also called <i>nerve palsy</i>	
Rabies (hydrophobia)	A disease usually contracted from animal bites, involving viral infection that spreads via somatic motor nerve fibers to the CNS and then autonomic nerve fibers, leading to seizures, coma, and death; invariably fatal if not treated before CNS symptoms appear	
Spinal meningitis	Inflammation of the spinal meninges due to viral, bacterial, or other infection	
<i>Disorders described elsewhere</i>		
Amyotrophic lateral sclerosis p. 490	Leprosy p. 589	Sciatica p. 494
Carpal tunnel syndrome p. 365	Multiple sclerosis p. 453	Shingles p. 493
Crutch paralysis p. 494	Poliomyelitis p. 490	Spina bifida p. 484
Diabetic neuropathy p. 670	Paraplegia p. 509	Spinal cord trauma p. 508
Hemiplegia p. 509	Quadriplegia p. 509	

cool the body. Spinal shock can last from a few days to 3 months, but typically lasts 7 to 20 days.

As spinal shock subsides, somatic reflexes begin to reappear, at first in the toes and progressing to the feet and legs. Autonomic reflexes also reappear. Contrary to the earlier urinary and fecal retention, a patient now has the opposite problem, incontinence, as the rectum and bladder empty reflexively in response to stretch. Both the somatic and autonomic nervous systems typically exhibit exaggerated reflexes, a state called *hyperreflexia* or the *mass reflex reaction*. Stimuli such as a full bladder or cutaneous touch can trigger an extreme cardiovascular reaction. The systolic blood pressure, normally about 120 mmHg, jumps to as high as 300 mmHg. This causes intense headaches and sometimes a stroke. Pressure receptors in the major arteries sense this rise in blood pressure and activate a reflex that slows the heart, sometimes to a rate as low as 30 or 40 beats/minute (*bradycardia*), compared to a normal rate of 70 to 80. The patient may also experience profuse sweating and blurred vision. Men at first lose the capacity for erection and ejaculation. They may recover these functions later and become capable of climaxing and fathering children, but without sexual sensation. In females, menstruation may become irregular or cease.

The most serious permanent effect of spinal cord trauma is paralysis. The flaccid paralysis of spinal shock later changes to spastic paralysis as spinal reflexes are regained, but lack inhibitory control from the brain. Spastic paralysis typically starts with chronic flexion of the hips and knees (flexor spasms) and progresses to a state in which the limbs become straight and rigid (extensor spasms). Three forms of muscle paralysis are *paraplegia*, a paralysis of both lower limbs resulting from spinal cord lesions at levels T1 to L1; *quadriplegia*, the paralysis of all four limbs resulting from lesions above level C5; and *hemiplegia*, paralysis of one side of the body, resulting not from spinal cord injuries but usually from a stroke or other brain lesion. Spinal cord lesions from C5 to C7 can produce a state of partial quadriplegia—total paralysis of the lower limbs and partial paralysis (*paresis*, or weakness) of the upper limbs.

Pathogenesis

Spinal cord trauma produces two stages of tissue destruction. The first is instantaneous—the destruction of cells by the traumatic event itself. The second wave of destruction, involving tissue death by necrosis and apoptosis, begins in minutes and lasts for days. It is far more destructive than the initial injury, typically converting a lesion in one spinal cord segment to a lesion that spans four or five segments, two above and two below the original site.

Microscopic hemorrhages appear in the gray matter and pia mater within minutes and grow larger over the next 2 hours. The white matter becomes edematous (swollen). This hemorrhaging and edema spread to adjacent segments of the cord, and can fatally affect respiration or brainstem function when it occurs in the cervical region. *Ischemia* (iss-KEE-me-uh), the lack of blood, quickly leads to tissue necrosis. The white matter regains circulation in about 24 hours, but the gray matter remains ischemic. Inflammatory cells (leukocytes and macrophages) infiltrate the lesion as the circulation recovers, and while they clean up necrotic tissue, they also contribute to the damage by releasing destructive free radicals and other toxic chemicals. The necrosis worsens, and is accompanied by another form of cell death, apoptosis (see chapter 5). Apoptosis of the spinal oligodendrocytes, the myelinating glial cells of the CNS, results in demyelination of spinal nerve fibers, followed by death of the neurons.

In as little as 4 hours, this second wave of destruction, called *post-traumatic infarction*, consumes about 40% of the cross-sectional area of the spinal cord; within 24 hours, it destroys 70%. As many as five segments of the cord become transformed into a fluid-filled cavity, which is replaced with collagenous scar tissue over the next 3 to 4 weeks. This scar is one of the obstacles to the regeneration of lost nerve fibers.

Treatment

The first priority in treating a spinal injury patient is to immobilize the spine to prevent further injury to the cord. Respiratory or other life support may also be required. Methylprednisolone, a steroid, dramatically

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improves recovery. Given within 3 hours of the trauma, it reduces injury to cell membranes and inhibits inflammation and apoptosis.

After these immediate requirements are met, reduction (repair) of the fracture is important. If a CT or MRI scan indicates spinal cord compression by the vertebral canal, a *decompression laminectomy* may be performed, in which the vertebral arch is removed from the affected region. CT and MRI have helped a great deal in recent decades for assessing vertebral and spinal cord damage, guiding surgical treatment, and improving recovery. Physical therapy is important for maintaining muscle and joint function as well as promoting the patient's psychological recovery.

Treatment of spinal cord injuries is a lively area of medical research today. Some current interests are the use of antioxidants to reduce free radical damage, and the implantation of embryonic stem cells, which has produced significant (but not perfect) recovery from spinal cord lesions in rats.

Before You Go On

Answer the following questions to test your understanding of the preceding section:

- Name five structural components of a typical somatic reflex arc. Which of these is absent from a monosynaptic arc?
- State the function of each of the following in a muscle spindle: intrafusal fiber, annulospiral ending, and γ motor neuron.
- Explain how nerve fibers in a tendon sense the degree of tension in a muscle.
- Why must the withdrawal reflex, but not the stretch reflex, involve a polysynaptic reflex arc?
- Explain why the crossed extensor reflex must accompany a withdrawal reflex of the leg.

Chapter Review

Review of Key Concepts

The Spinal Cord (p. 482)

- The spinal cord conducts signals up and down the body, contains *central pattern generators* that control locomotion, and mediates many reflexes.
- The spinal cord occupies the vertebral canal from vertebrae C1 to L1. A bundle of nerve roots called the *cauda equina* occupies the vertebral canal from C2 to S5.
- The cord is divided into cervical, thoracic, lumbar, and sacral regions, named for the levels of the vertebral column through which the spinal nerves emerge. The portion served by each spinal nerve is called a *segment* of the cord.
- Cervical and lumbar enlargements* are wide points in the cord marking the emergence of nerves that control the limbs.
- The spinal cord is enclosed in three fibrous *meninges*. From superficial to deep, these are the dura mater, arachnoid mater, and pia mater. An *epidural space* exists between the dura mater and vertebral bone, and a *subarachnoid space* between the arachnoid and pia mater.
- The pia mater issues periodic *denticulate ligaments* that anchor it

to the dura, and continues inferiorly as a *coccygeal ligament* that anchors the cord to vertebra L2.

- In cross section, the spinal cord exhibits a central H-shaped core of *gray matter* surrounded by *white matter*. The gray matter contains the somas, dendrites, and synapses while the white matter consists of nerve fibers (axons).
- The *dorsal horn* of the gray matter receives afferent (sensory) nerve fibers from the dorsal root of the spinal nerve. The *ventral horn* contains the somas that give rise to the efferent (motor) nerve fibers of the ventral root of the nerve. A *lateral horn* in the thoracic and lumbar regions contains somas of the sympathetic neurons.
- The white matter is divided into *dorsal*, *lateral*, and *ventral columns* on each side of the cord. Each column consists of one of more *tracts*, or bundles of nerve fibers. The nerve fibers in a given tract are similar in origin, destination, and function.
- Ascending tracts* carry sensory information up the cord to the brain. Their names and functions are listed in table 13.1.
- From receptor to cerebral cortex, sensory signals typically travel through

three neurons (first- through third-order) and cross over (*decussate*) from one side of the body to the other in the spinal cord or brainstem. Thus, the right cerebral cortex receives sensory input from the left side of the body (from the neck down) and vice versa.

- Descending tracts* carry motor commands from the brain downward. Their names and functions are also listed in table 13.1.
- Motor signals typically begin in an *upper motor neuron* in the cerebral cortex and travel to a *lower motor neuron* in the brainstem or spinal cord. The latter neuron's axon leaves the CNS in a cranial or spinal nerve leading to a muscle.

The Spinal Nerves (p. 490)

- A nerve is a cordlike organ composed of nerve fibers (axons) and connective tissue.
- Each nerve fiber is enclosed in its own fibrous sleeve called an *endoneurium*. Nerve fibers are bundled in groups called *fascicles* separated from each other by a *perineurium*. A fibrous *epineurium* covers the entire nerve.
- Nerve fibers are classified as *afferent* or *efferent* depending on the direction

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of signal conduction, *somatic* or *visceral* depending on the types of organs they innervate, and *special* or *general* depending on the locations of the organs they innervate (table 13.2).

4. A *sensory nerve* is composed of afferent fibers only, a *motor nerve* of efferent fibers only, and a *mixed nerve* is composed of both. Most nerves are mixed.
5. A *ganglion* is a swelling along the course of a nerve containing the cell bodies of the peripheral neurons.
6. There are 31 pairs of *spinal nerves*, which enter and leave the spinal cord and emerge mainly through the intervertebral foramina. Within the vertebral canal, each branches into a *dorsal root* which carries sensory signals to the dorsal horn of the spinal cord, and a *ventral root* which receives motor signals from the ventral horn. The dorsal root has a swelling, the *dorsal root ganglion*, containing unipolar neurons of somatic sensory neurons.
7. Distal to the intervertebral foramen, each spinal nerve branches into a *dorsal ramus*, *ventral ramus*, and *meningeal branch*.
8. The ventral ramus gives rise to *intercostal nerves* in the thoracic region and *nerve plexuses* in all other regions.

The nerve plexuses are weblike networks adjacent to the vertebral column: the *cervical*, *brachial*, *lumbar*, *sacral*, and *coccygeal plexus*. The nerves arising from each are described in tables 13.3 through 13.6.

Somatic Reflexes (p. 503)

1. A reflex is a quick, involuntary, stereotyped reaction of a gland or muscle to a stimulus.
2. *Somatic (spinal) reflexes* are responses of skeletal muscles. The nerve signals in a somatic reflex travel by way of a *reflex arc* from a receptor, via an afferent neuron to the spinal cord or brainstem, sometimes through interneurons in the CNS, then via an efferent neuron to a skeletal muscle.
3. Many somatic reflexes are initiated by *proprioceptors*, organs that monitor the position and movements of body parts.
4. *Muscle spindles* are proprioceptors embedded in the skeletal muscles that respond to stretching of the muscle. They are composed of modified *intrafusal muscle fibers*, *primary* and *secondary afferent nerve fibers*, and γ *motor neurons*, all enclosed in a fibrous sheath.
5. The *stretch reflex* is the tendency of a muscle to contract when it is

stretched, as in the patellar tendon (knee-jerk) reflex. Stretch reflexes smooth joint actions and maintain equilibrium and posture. Many stretch reflexes travel via *monosynaptic* pathways so there is minimal synaptic delay and a very quick response.

6. A stretch reflex is often accompanied by *reciprocal inhibition*, a reflex that prevents an antagonistic muscle from contracting and interfering with the reflex action.
7. The *flexor reflex* is the withdrawal of a limb from an injurious stimulus, as in pulling back from a hot stove. It employs a polysynaptic reflex arc that produces a sustained response in the muscle.
8. The *crossed extensor reflex* is contraction of the extensors on one side of the body when the flexors are contracted on the other side. It shifts the body weight so that one does not fall over.
9. The *Golgi tendon reflex* is the inhibition of a muscle contraction that occurs when its tendon is excessively stretched. Stretching stimulates a receptor in the tendon called a *Golgi tendon organ*. The reflex prevents tendon injuries and helps to distribute workload across a muscle.

Selected Vocabulary

spinal cord 482
meninges 482
dura mater 483
arachnoid mater 483
pia mater 483
gray matter 485
white matter 485

tract 485
dorsal horn 485
ventral horn 485
lateral horn 485
column 485
fasciculus 485

decussation 486
contralateral 486
ipsilateral 486
first- through third-order
neurons 486
upper motor neuron 489

lower motor neuron 489
nerve 490
dorsal root ganglion 492
somatic reflex 504
muscle spindle 504
proprioceptor 504

Testing Your Recall

1. Below L2, the vertebral canal is occupied by a bundle of spinal nerve roots called
 - a. the terminal filum.
 - b. the descending tracts.
 - c. the gracile fasciculus.
 - d. the medullary cone.
 - e. the cauda equina.
2. The brachial plexus gives rise to all of the following nerves *except*
 - a. the axillary nerve.
 - b. the radial nerve.
 - c. the saphenous nerve.
 - d. the median nerve.
 - e. the ulnar nerve.
3. Nerve fibers that adjust the tension in a muscle spindle are called
 - a. intrafusal fibers.
 - b. extrafusal fibers.
 - c. α motor neurons.
 - d. γ motor neurons.
 - e. annulospiral fibers.

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4. A stretch reflex requires the action of _____ to prevent an antagonistic muscle from interfering with the agonist.
 - a. γ motor neurons
 - b. a withdrawal reflex
 - c. a crossed extensor reflex
 - d. reciprocal inhibition
 - e. a contralateral reflex
5. A patient has a gunshot wound that caused a bone fragment to nick the spinal cord. The patient now feels no pain or temperature sensations from that level of the body down. Most likely, the _____ was damaged.
 - a. gracile fasciculus
 - b. medial lemniscus
 - c. tectospinal tract
 - d. lateral corticospinal tract
 - e. spinothalamic tract
6. Which of these is *not* a region of the spinal cord?
 - a. cervical
 - b. thoracic
 - c. pelvic
 - d. lumbar
 - e. sacral
7. In the spinal cord, the somas of the lower motor neurons are found in
 - a. the cauda equina.
 - b. the dorsal horns.
 - c. the ventral horns.
 - d. the dorsal root ganglia.
 - e. the fasciculi.
8. The outermost connective tissue wrapping of a nerve is called the
 - a. epineurium.
 - b. perineurium.
 - c. endoneurium.
 - d. arachnoid membrane.
 - e. dura mater.
9. The intercostal nerves between the ribs arise from which spinal nerve plexus?
 - a. cervical
 - b. brachial
 - c. lumbar
 - d. sacral
 - e. none of them
10. All somatic reflexes share all of the following properties except
 - a. they are quick.
 - b. they are monosynaptic.
 - c. they require stimulation.
 - d. they are involuntary.
 - e. they are stereotyped.
11. Outside the CNS, the somas of neurons are clustered in swellings called _____.
 - a. the dorsal root ganglia.
 - b. the fasciculi.
 - c. the dorsal root ganglia.
 - d. the dorsal root ganglia.
 - e. the fasciculi.
12. Distal to the intervertebral foramen, a spinal nerve branches into a dorsal and ventral _____.
 - a. the dorsal root ganglia.
 - b. the fasciculi.
 - c. the dorsal root ganglia.
 - d. the dorsal root ganglia.
 - e. the fasciculi.
13. The cerebellum receives feedback from the muscles and joints by way of the _____ tracts of the spinal cord.
14. In the _____ reflex, contraction of flexor muscles in one limb is accompanied by the contraction of extensor muscles in the contralateral limb.
15. Modified muscle fibers serving primarily to detect stretch are called _____.
16. The _____ nerves arise from the cervical plexus and innervate the diaphragm.
17. The crossing of a nerve fiber or tract from the right side of the CNS to the left, or vice versa, is called _____.
18. The nonvisual awareness of the body's position and movements is called _____.
19. The _____ ganglion contains the somas of neurons that carry sensory signals to the spinal cord.
20. The sciatic nerve is a composite of two nerves, the _____ and _____.

Answers in Appendix B

True or False

Determine which five of the following statements are false, and briefly explain why.

1. The gracile fasciculus is a descending spinal tract.
2. At the inferior end, the adult spinal cord ends before the vertebral column does.
3. Each spinal cord segment has only one pair of spinal nerves.
4. Some spinal nerves are sensory and others are motor.
5. The dura mater adheres tightly to the bone of the vertebral canal.
6. The dorsal and ventral horns of the spinal cord are composed of gray matter.
7. The corticospinal tracts carry motor signals down the spinal cord.
8. The dermatomes are nonoverlapping regions of skin innervated by different spinal nerves.
9. Somatic reflexes are those that do not involve the brain.
10. The Golgi tendon reflex acts to inhibit muscle contraction.

Answers in Appendix B

Testing Your Comprehension

- Jillian is thrown from a horse. She strikes the ground with her chin, causing severe hyperextension of the neck. Emergency medical technicians properly immobilize her neck and transport her to a hospital, but she dies 5 minutes after arrival. An autopsy shows multiple fractures of vertebrae C1, C6, and C7 and extensive damage to the spinal cord. Explain why she died rather than being left quadriplegic.
- Wallace is the victim of a hunting accident. A bullet grazed his vertebral column and bone fragments severed the left half of his spinal cord at segments T8 through T10. Since the accident, Wallace has had a condition called *dissociated sensory loss*, in which he feels no sensations of deep touch or limb position on the *left* side of his body below the injury and no sensations of pain or heat from the *right* side. Explain what spinal tract(s) the injury has affected and why these sensory losses are on opposite sides of the body.
- Anthony gets into a fight between rival gangs. As an attacker comes at him with a knife, he turns to flee, but stumbles. The attacker stabs him on the medial side of the right gluteal fold and Anthony collapses. He loses all use of his right limb, being unable to extend his hip, flex his knee, or move his foot. He never fully recovers these lost functions. Explain what nerve injury Anthony has most likely suffered.
- Stand with your right shoulder, hip, and foot firmly against a wall. Raise your left foot from the floor without losing contact with the wall at any point. What happens? Why? What principle of this chapter does this demonstrate?
- When a patient needs a tendon graft, surgeons sometimes use the tendon of the palmaris longus, a relatively dispensable muscle of the forearm. The median nerve lies nearby and looks very similar to this tendon. There have been cases where a surgeon mistakenly removed a section of this nerve instead of the tendon. What effects do you think such a mistake would have on the patient?

Answers at the Online Learning Center

Answers to Figure Legend Questions

- If it were T10, there would be no cuneate fasciculus; that exists only from T6 up.
- They are in the ventral horn of the spinal cord.
- They are afferent, because they arise from the dorsal root of the spinal nerve.
- Motor neurons are capable only of exciting skeletal muscle (end-plate potentials are always excitatory). To inhibit muscle contraction, it is necessary to inhibit the motor neuron at the CNS level (point 7).
- They would show more synaptic delay, because there are more synapses in the pathway.

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