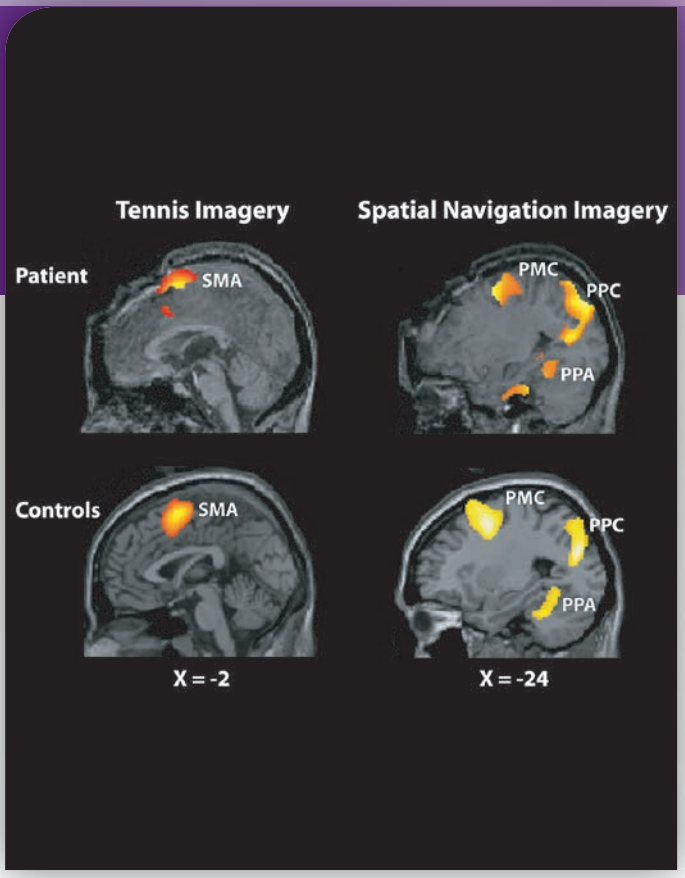
9

Nervous System



A woman who had suffered brain injury in a traffic accident and was in a persistent vegetative state was asked to imagine herself playing tennis and walking through the rooms of her home, while undergoing neuroimaging with functional MRI. Although she could not move or respond verbally, the patterns in which her brain lit up matched those of 12 healthy individuals as they completed the same tasks.

"Islands of awareness" in the vegetative brain. The twenty-three-year-old had been in a persistent vegetative state for five months after sustaining traumatic brain injury in a car accident. She was awake, but apparently not aware, and unable to communicate in any way. To an observer, she had no sense of her own existence and did not react to sight or sound. But the young woman was aware—she just could not communicate.

British researchers used functional MRI (fMRI), a form of neuroimaging that measures regional blood flow, to give the patient a way to communicate in response to a stimulus. In a preliminary experiment, fMRI tracked her response to speech. First she heard a sentence that made sense, and then a sentence that had the same cadence as the first but was all nonsense words. Her brain lit up in the speech-processing centers only when the sentence she heard had meaning. When she heard a sentence that included a homonym—a word that could have either of two meanings—an additional brain region lit up.

The researchers next asked the patient to imagine herself playing tennis and then walking through her house. Healthy individuals asked to do the same were controls. The young woman's brain and the control brains lit up in exactly the same areas. The researchers then devised a new set of experiments in which people in vegetative states who responded to "tennis" and "house" were told to use these imaginings as stand-ins for the words "yes" and "no." The test was to then ask the patients yes-no questions, and have them answer by imagining either being in a house or playing tennis; one image meant "yes" and one meant "no." The questions were highly specific about their pasts. When the patients imagined "tennis" or "house," the results were seen in the fMRI. They were correct every time, even after researchers switched the meanings from "tennis" signifying no and "house" yes to the opposite. This discovery of what the researchers call "islands of awareness" in the brain is changing the way that we view a persistent vegetative state. However, not all patients respond this way.

LEARNING OUTCOMES

After studying this chapter, you should be able to do the following:

9.1 Introduction
1. Distinguish between the two types of cells that compose nervous tissue. (p. 224)
2. Name the two major groups of nervous system organs. (p. 225)

9.2 General Functions of the Nervous System
3. Explain the general functions of the nervous system. (p. 225)

9.3 Neuroglia
4. State the functions of neuroglia in the central nervous system. (p. 226)
5. Distinguish among the types of neuroglia in the central nervous system. (p. 226)
6. Describe the Schwann cells of the peripheral nervous system. (p. 227)

9.4 Neurons
7. Describe the general structure of a neuron. (p. 228)
8. Explain how differences in structure and function are used to classify neurons. (pp. 228–231)

9.5 The Synapse
9. Explain how information passes from one neuron to another. (p. 232)

9.6 Cell Membrane Potential
10. Explain how a membrane becomes polarized. (p. 232)
11. Describe the events that lead to the generation of an action potential. (p. 236)

9.7 Impulse Conduction

12. Compare impulse conduction in myelinated and unmyelinated neurons. (p. 236)

9.8 Synaptic Transmission

13. Identify the changes in membrane potential associated with excitatory and inhibitory neurotransmitters. (p. 239)

9.9 Impulse Processing

14. Describe the general ways in which the nervous system processes information. (p. 240)

9.10 Types of Nerves

15. Describe how nerves are classified. (p. 241)

9.11 Nerve Pathways

16. Describe the function of each part of a reflex arc, and name two reflex examples. (p. 242)

9.12 Meninges

17. Describe the coverings of the brain and spinal cord. (p. 243)

9.13 Spinal Cord

18. Describe the structure of the spinal cord and its major functions. (p. 245)

9.14 Brain

19. Name the major parts and functions of the brain. (pp. 247–257)

20. Distinguish among sensory, association, and motor areas of the cerebral cortex. (p. 250)

21. Describe the location, formation, and function of cerebrospinal fluid. (p. 252)

9.15 Peripheral Nervous System

22. List the major parts of the peripheral nervous system. (pp. 257–258)

23. Name the cranial nerves, and list their major functions. (pp. 258–260)

24. Describe the structure of a spinal nerve. (p. 261)

9.16 Autonomic Nervous System

25. Describe the functions of the autonomic nervous system. (p. 262)

26. Distinguish between the sympathetic and parasympathetic divisions of the autonomic nervous system. (p. 262)

27. Describe a sympathetic and a parasympathetic nerve pathway. (pp. 263–265)

AIDS TO UNDERSTANDING WORDS

(Appendix A on page 577 has a complete list of Aids to Understanding Words.)

ax- [axis] *ax*on: Cylindrical nerve fiber that carries impulses away from a neuron cell body.

dendr- [tree] *dendr*ite: Branched nerve cell process that serves as a receptor surface of a neuron.

funi- [small cord or fiber] *funi*culus: Major nerve tract or bundle of myelinated nerve cell axons in the spinal cord.

gangli- [a swelling] *gangli*on: Mass of neuron cell bodies.

-lemm [rind or peel] neuri*lemm*a: Sheath that surrounds the myelin of a nerve cell axon.

mening- [membrane] *mening*es: Membranous coverings of the brain and spinal cord.

moto- [moving] *moto*r neuron: Neuron that stimulates a muscle to contract or a gland to secrete.

peri- [around] *peri*pheral nervous system: Portion of the nervous system that consists of nerves branching from the brain and spinal cord.

plex- [interweaving] choroid *plex*us: Mass of specialized capillaries associated with spaces in the brain.

sens- [feeling] *sens*ory neuron: Neuron that conducts impulses into the brain or spinal cord.

syn- [together] *syn*apse: Junction between two neurons.

ventr- [belly or stomach] *ventr*icle: Fluid-filled space in the brain.

9.1 Introduction

Feeling, thinking, remembering, moving, and being aware of the world require activity from the nervous system. This vast collection of cells also helps coordinate all other body functions to maintain homeostasis and to enable the body to respond to changing conditions. Information from inside and outside the body is brought to the brain and spinal cord, which then stimulate responses from muscles and glands.

Recall from chapter 5 (p. 122) that nervous tissue consists of masses of nerve cells, or **neurons.** These cells are the main functional units of the nervous system and are specialized to react to physical and chemical changes in their surroundings (fig. 9.1). Neurons carry information in the form of electrochemical changes, called **impulses,** which allow them to communicate with other neurons and with cells outside the nervous system.

> The impulse conducted along an axon is often referred to as a nerve impulse. This may be misleading, because the term "nerve" in anatomy refers to a bundle of axons, not an individual cell. A similar situation arises when referring to a neuron as a nerve cell. We continue to use both of the terms "nerve impulse" "and nerve cell" in this book because they are familiar to teachers and students, but we feel it is important to point out this departure from strict anatomical terminology.

A typical neuron has a rounded area called the **cell body,** and two types of extensions: dendrites and axons. **Dendrites,** which may be numerous, receive input, and **axons** send information away from the cell in the form of impulses. Most neurons have only one axon. Figure 9.1 depicts these major parts of a neuron.

Nervous tissue also includes **neuroglia** that provide physical support, insulation, and nutrients for neurons.

During development before birth, neuroglia release and relay signals that guide the differentiation of neurons from progenitor cells (see chapter 3, p. 82).

An important part of the nervous system at the cellular level is not a cell at all, but the small space between a neuron and the cell(s) with which it communicates, called a **synapse** (sin′aps). Biological messenger molecules called **neurotransmitters** (nu″ro-trans-mit′erz) convey neural information across synapses.

The organs of the nervous system can be divided into two groups. One group, consisting of the brain and spinal cord, forms the **central nervous system (CNS).** The other, composed of the nerves (bundles of axons) that connect the central nervous system to other body parts, is called the **peripheral nervous system (PNS)** (fig. 9.2). Together, these systems provide three general functions: sensory, integrative, and motor.

PRACTICE

1. What are the two major types of cells that form nervous tissue?
2. What are the two major subdivisions of the nervous system?

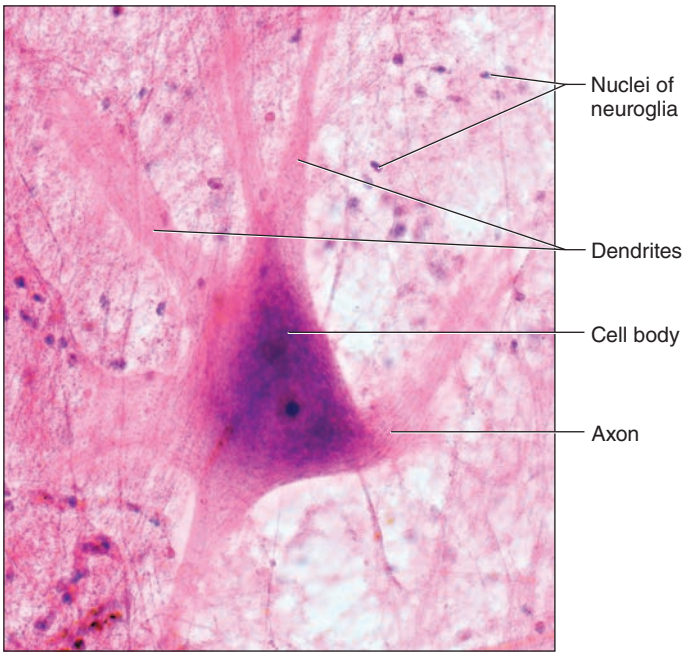


FIGURE 9.1 AP|R Neurons are the structural and functional units of the nervous system (600×). The dark spots in the area surrounding the neuron are the nuclei of neuroglia. Note the dendrites and the single axon of the neuron.

9.2 General Functions of the Nervous System

The *sensory function* of the nervous system derives from **sensory receptors** (sen′so-re re-sep′torz) at the ends of peripheral neurons (see chapter 10, p. 274). These receptors gather information by detecting changes inside and outside the body. Sensory receptors monitor external environmental factors, such as light and sound intensities, and conditions of the body's internal environment, such as temperature and oxygen level.

Sensory receptors convert environmental information into impulses, which are then conducted on peripheral nerves to the central nervous system. There, the signals are integrated; that is, they are brought together, creating sensations, adding to memory, or helping produce thoughts that translate sensations into perceptions. As a result of this *integrative function,* we make conscious or subconscious decisions, and then we use *motor functions* to act on them.

The motor functions of the nervous system employ peripheral neurons, which conduct impulses from the central nervous system to responsive structures called **effectors** (e-fek′torz). Effectors, which are outside the nervous system, include muscles and glands whose actions are either controlled or modified by neurons.

The motor functions of the peripheral nervous system can be divided into two categories. Those that are under voluntary (conscious) control compose the **somatic nervous system,** which controls skeletal muscle. In contrast, the **autonomic nervous system**

CAREER CORNER

Occupational Therapist

The man with amyotrophic lateral sclerosis (ALS, or Lou Gehrig's disease) had been growing frustrated with his increasing inability to carry out the activities of daily living. He couldn't use his hands, and his wrists were growing weaker. A visit from an occupational therapist greatly improved both his independence and his spirit.

The occupational therapist showed the man how to continue to use a bathroom sink by supporting his weight on his arms, and how to use mirrors to compensate for his neck stiffness. The therapist was comforting and practical as he demonstrated how to repurpose metal salad tongs to hold toilet paper to care for bathroom needs.

An occupational therapist helps a person maintain normal activities while struggling with a disease, injury, disability, or other limitation. The therapist evaluates the patient's situation and how it is likely to change, sets goals, researches and presents interventions and adaptive equipment that may help, and assesses results. The therapist may also instruct family members and caregivers on how to assist the patient.

Occupational therapists work in health-care facilities, schools, home health services, and nursing homes. They must have a master's degree in occupational therapy and state licensure.

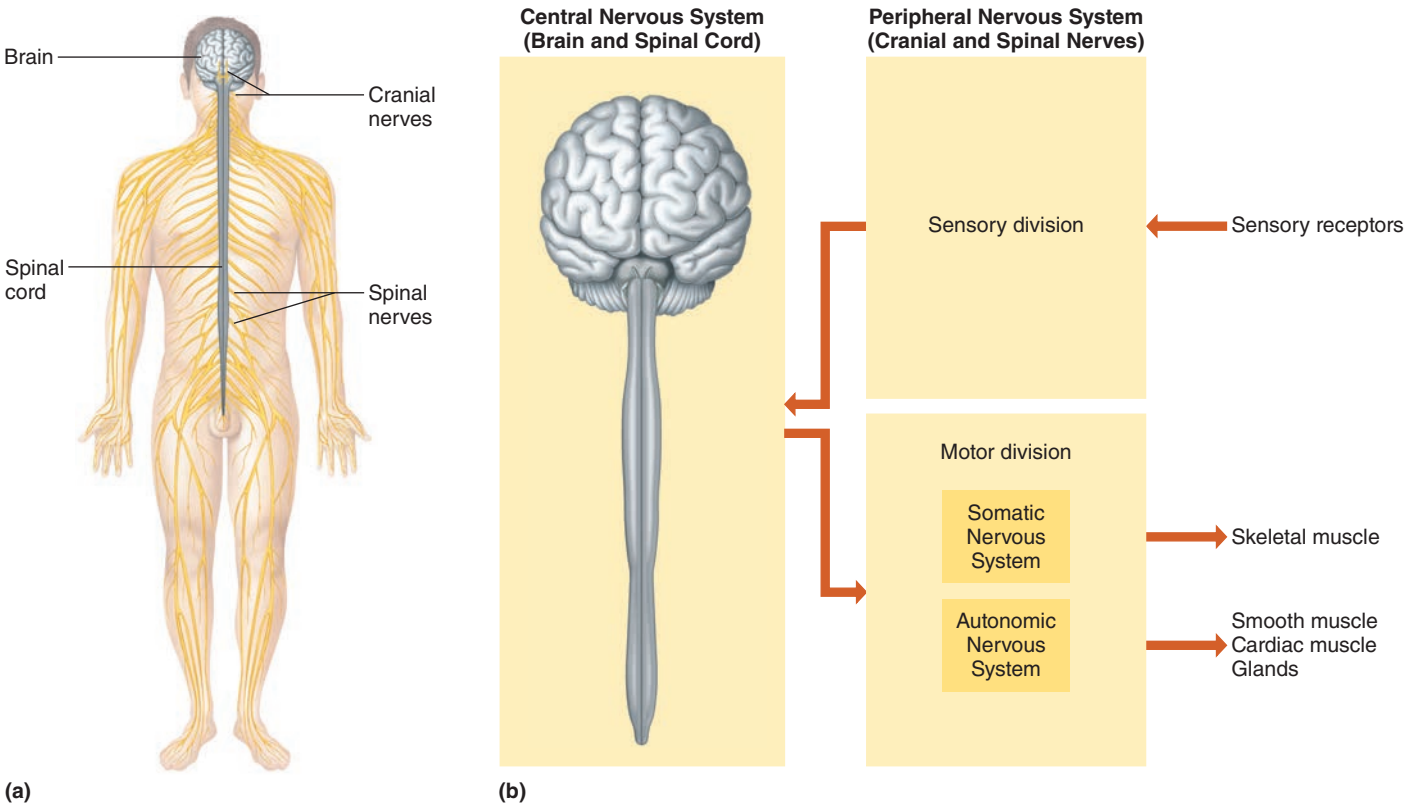


FIGURE 9.2 Nervous system. **(a)** The nervous system includes the central nervous system (brain and spinal cord) and the peripheral nervous system (cranial nerves and spinal nerves). **(b)** The nervous system receives information from sensory receptors and initiates responses through effector organs (muscles and glands).

controls effectors that are involuntary, such as cardiac muscle, smooth muscle, and various glands.

The nervous system can detect changes outside and inside the body, make decisions based on the information received, and stimulate muscles or glands to respond. Typically these responses counteract the effects of the changes detected, and in this way the nervous system helps maintain homeostasis.

PRACTICE

3. How do sensory receptors collect information?
4. How does the central nervous system integrate incoming information?
5. What are the two types of motor functions of the nervous system?

9.3 | Neuroglia

Neurons cannot exist without neuroglia, which fill spaces, provide structural frameworks, produce the components of the electrical insulator **myelin** (mi′ĕ-lin), and carry on phagocytosis. In the central nervous system, neuroglia greatly outnumber neurons, and can divide, whereas neurons do not normally divide. Neuroglia in the central nervous system are of the following types (fig. 9.3):

1. **Microglial cells** are scattered throughout the central nervous system. They support neurons and phagocytize bacterial cells and cellular debris, and form scars in areas of damage.
2. **Oligodendrocytes** align along axons (nerve fibers). They provide insulating layers of myelin, called a **myelin sheath** (mi′ĕ-lin shēth) around axons within the brain and spinal cord.
3. **Astrocytes,** commonly found between neurons and blood vessels, provide structural support, join parts by their abundant cellular processes, and help regulate the concentrations of nutrients and ions within the tissue. Astrocytes also form scar tissue that fills spaces following injury to the CNS.
4. **Ependymal cells** form an epithelial-like membrane that covers specialized brain parts (choroid plexuses) and form the inner linings that enclose spaces in the brain (ventricles) and spinal cord (central canal).

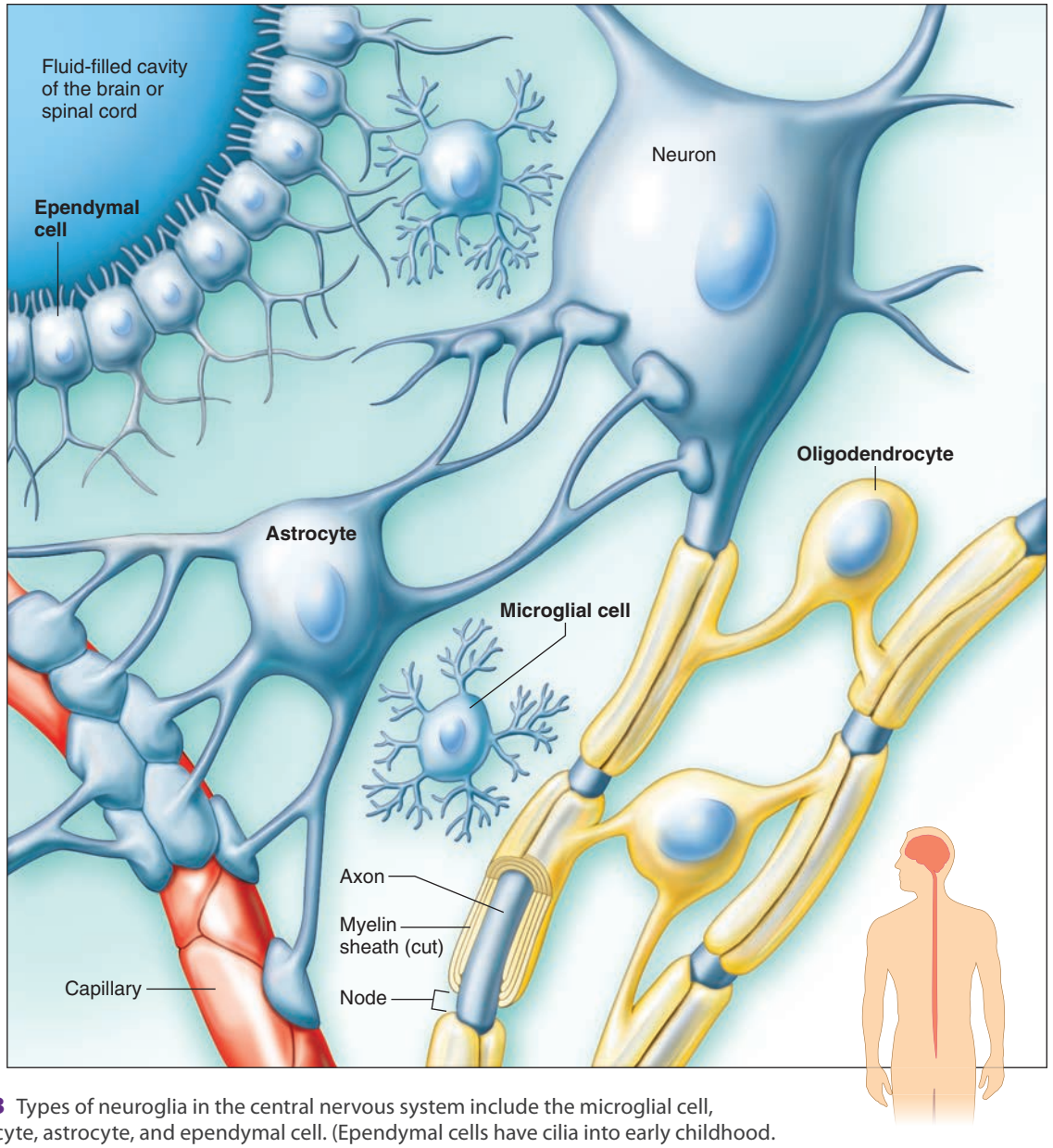


FIGURE 9.3 Types of neuroglia in the central nervous system include the microglial cell, oligodendrocyte, astrocyte, and ependymal cell. (Ependymal cells have cilia into early childhood. In adults, cilia remain only on ependymal cells in the ventricles of the brain.)

Neuroglia assemble in a special, protective way in the brain. Most capillaries (the smallest blood vessels) are "leaky," allowing small molecules to enter or leave the bloodstream. The cells that form capillaries in the brain, in contrast, are much more tightly connected, thanks partly to astrocytes. This specialized architecture creates a "blood–brain barrier" that shields delicate brain tissue from chemical fluctuations, blocking entry to many substances. Drug developers must consider the barrier when formulating drugs that act in the brain, including ingredients that let the drug through.

The peripheral nervous system includes neuroglia called **Schwann cells.** They produce the myelin sheath around axons of myelinated neurons.

Too few and too many neuroglia can harm health. Fast-growing gliomas are brain tumors consisting of rapidly dividing neuroglia (neurons do not normally divide). Immediately after a spinal cord injury, destruction of neuroglia strips axons of myelin. Subsequent overgrowth of neuroglia forms scars, which impede recovery of function.

PRACTICE

6. List the functions of the cells that support neurons.
7. Distinguish among the types of neuroglia in the central nervous system.
8. What is the function of Schwann cells in the peripheral nervous system?

9.4 | Neurons

Neuron Structure

Neurons vary considerably in size and shape, but they all have common features. These include a cell body; the tubular, cytoplasm-filled dendrites, which conduct impulses to the neuron cell body; and an axon, which conducts impulses away from the neuron cell body.

The neuron cell body consists of granular cytoplasm, a cell membrane, and organelles such as mitochondria, lysosomes, a Golgi apparatus, and a network of fine threads called **neurofibrils** (nu″ro-fi′brilz), which extends into the axon. Scattered throughout the cytoplasm are many membranous sacs called **chromatophilic substance** (Nissl bodies). These are similar to rough endoplasmic reticulum in other cells (fig. 9.4). Ribosomes attached to chromatophilic substance function in protein synthesis, as they do elsewhere. Near the center of the cell body is a large, spherical nucleus with a conspicuous nucleolus.

Dendrites are usually short and highly branched. These processes, together with the membrane of the cell body, are the neuron's main receptive surfaces with which axons from other neurons communicate.

In most neurons the axon arises from the cell body as a cone-shaped thickening called the *axon hillock.* Many mitochondria, microtubules, and neurofibrils are in the axon cytoplasm. An axon originates as a single structure but may give off side branches (collaterals). Its end may branch into many fine extensions that contact the receptive surfaces of other cells.

Larger axons of peripheral neurons are enclosed in *myelin sheaths* produced by Schwann cells (figs. 9.4 and 9.5). These cells wind tightly around axons, somewhat like a bandage wrapped around a finger, coating them with many layers of cell membrane that have little or no cytoplasm between them. The parts of the Schwann cells that contain most of the cytoplasm and the nuclei remain outside the myelin sheath and compose a **neurilemma** (nu″rĭ-lem′ah), or neurilemmal sheath, which surrounds the myelin sheath. Narrow gaps between Schwann cells are called **nodes of Ranvier** (nō-dz uv ron′vee-ay) (fig. 9.5).

Axons with myelin sheaths are called *myelinated,* and those that lack sheaths are *unmyelinated.* Myelin is also in the CNS, where groups of myelinated axons appear white, and masses of such axons form the *white matter.* Unmyelinated axons and neuron cell bodies form *gray matter* in the CNS.

Myelin begins to form on axons during the fourteenth week of prenatal development. Yet many of the axons in newborns are not completely myelinated. As a result, an infant's nervous system cannot function as effectively as that of an older child or adult. Infants' responses to stimuli are coarse and undifferentiated, and may involve the whole body. All myelinated axons begin to develop sheaths by the time a child starts to walk, and myelination continues into adolescence. Deficiencies of essential nutrients during the developmental years may limit myelin formation, which may impair nervous system function later in life.

When peripheral nerves are damaged, their axons can regenerate. The neurilemma plays an important role in this process. In contrast, CNS axons are myelinated by oligodendrocytes, which do not provide a neurilemma. Consequently, damaged CNS neurons usually do not regenerate.

The brain harbors small collections of neural stem cells that can divide to give rise to new neurons or neuroglia, depending upon their chemical surroundings. Neural stem cells are found in the hippocampus and near the brain's ventricles.

FACTS OF LIFE To picture the relative sizes of a typical neuron's parts, imagine that the cell body is the size of a tennis ball. The axon would then be a mile long and half an inch thick. The dendrites would fill a large bedroom.

Classification of Neurons

Neurons differ in the structure, size, and shape of their cell bodies. They also vary in the length and size of their axons and dendrites and in the number of connections they make with other neurons.

On the basis of structural differences, neurons are classified into three major groups (fig. 9.6). Each type of neuron is specialized to send an impulse in one direction.

1. **Multipolar neurons** have many processes arising from their cell bodies. Only one process of each neuron is an axon; the rest are dendrites. Most neurons whose cell bodies lie within the brain or spinal cord are multipolar.
2. **Bipolar neurons** have only two processes, one arising from each end of the cell body. These processes are structurally similar, but one is an axon and the other a dendrite. Neurons in specialized parts of the eyes, nose, and ears are bipolar.

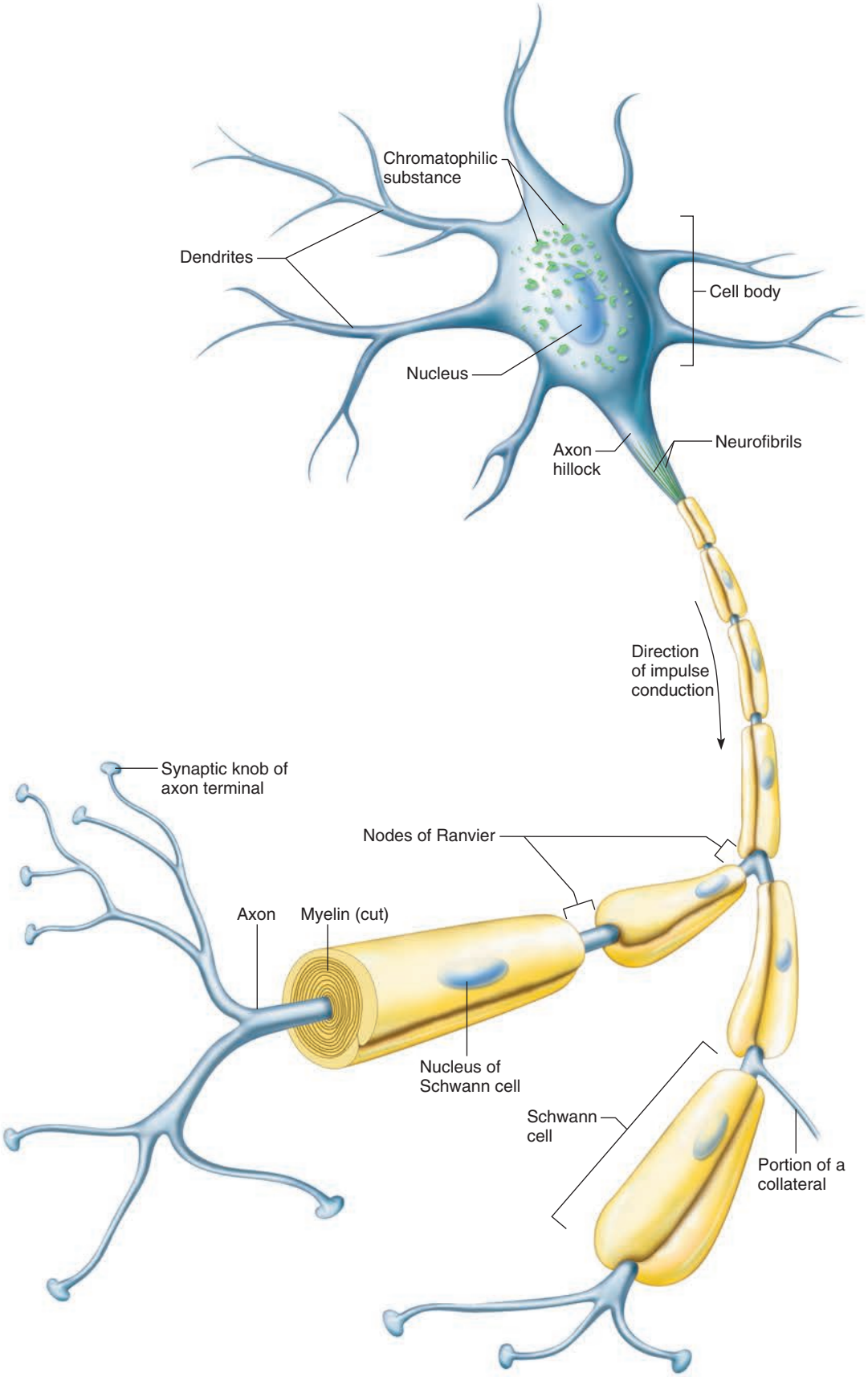


FIGURE 9.4 A common neuron.

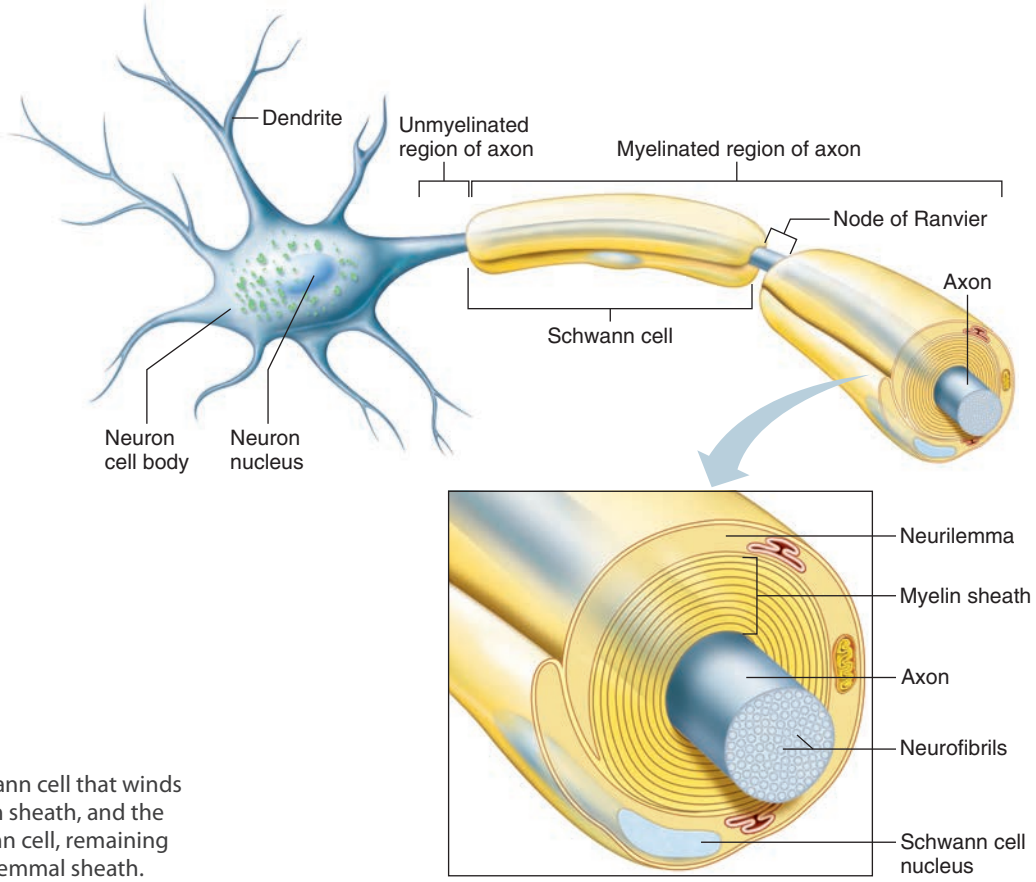


FIGURE 9.5 The portion of a Schwann cell that winds tightly around an axon forms a myelin sheath, and the cytoplasm and nucleus of the Schwann cell, remaining outside, form a neurilemma, or neurilemmal sheath.

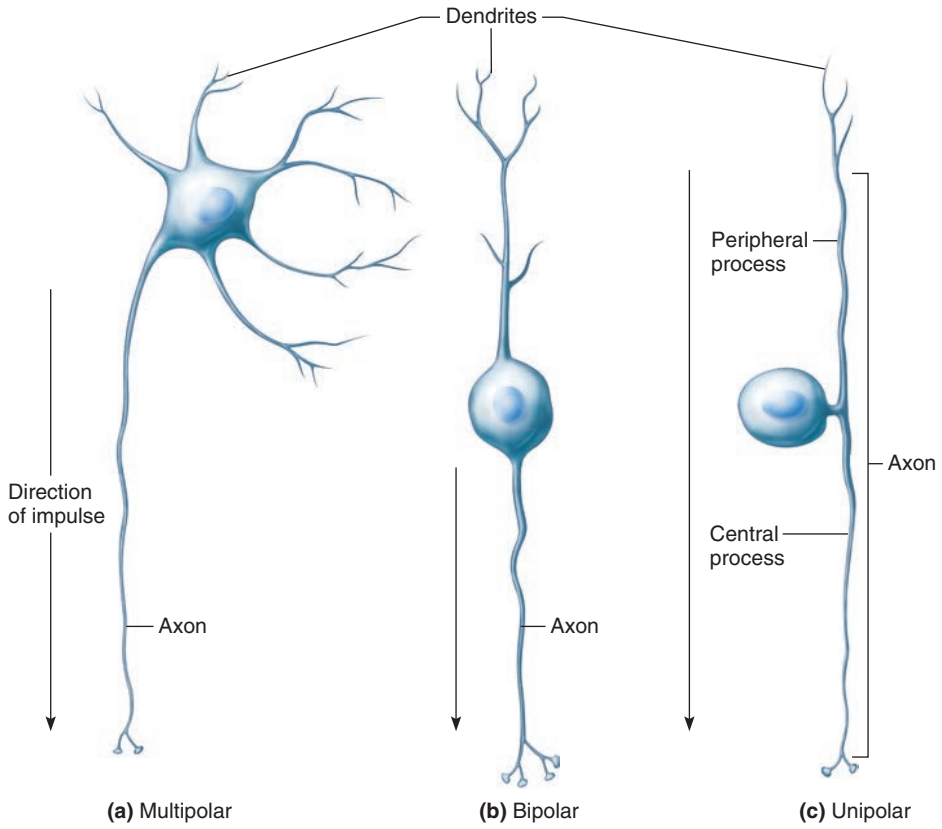


FIGURE 9.6 Structural types of neurons include **(a)** the multipolar neuron, **(b)** the bipolar neuron, and **(c)** the unipolar neuron.

3. **Unipolar neurons** have a single process extending from the cell body. A short distance from the cell body, this process divides into two branches, which really function as a single axon. One branch (the peripheral process) is associated with dendrites near a peripheral body part. The other branch (the central process) enters the brain or spinal cord. The cell bodies of unipolar neurons are found in some of the specialized masses of nervous tissue called **ganglia** (gang′gle-ah) (singular, *ganglion*), which are located outside the brain and spinal cord.

Neurons also vary in function. Different neurons may conduct impulses into the brain or spinal cord, conduct impulses from one area of the brain or spinal cord to another, or conduct impulses out of the brain or spinal cord. On the basis of functional differences, neurons are grouped as follows (fig. 9.7):

1. **Sensory neurons** (afferent neurons) conduct impulses from peripheral body parts into the brain or spinal cord. Sensory neurons either have specialized *receptor ends* at the tips of their dendrites, or they have dendrites that are closely associated with *receptor cells* in the skin or in sensory organs.

   Changes that occur inside or outside the body stimulate receptor ends or receptor cells, triggering sensory impulses. The impulses travel along the sensory neuron axons, which lead to the brain or spinal cord, where other neurons can process the impulses. Most sensory neurons are unipolar; some are bipolar.
2. **Interneurons** (also called *association* or *internuncial neurons*) lie entirely within the brain or spinal cord. They are multipolar and link other neurons. Interneurons conduct impulses from one part of the brain or spinal cord to another. That is, they may direct incoming sensory impulses to appropriate parts of the CNS for processing and interpreting. Other impulses are transferred to motor neurons. The cell bodies of some interneurons aggregate in specialized masses of nervous tissue called **nuclei** (singular, *nucleus*). Nuclei are similar to ganglia, but are within the central nervous system.
3. **Motor neurons** (efferent neurons) are multipolar and conduct impulses out of the brain or spinal cord to effectors. Motor impulses control muscle contraction and the secretions of glands.

Neurons deprived of oxygen change shape as their nuclei shrink, and they eventually disintegrate. Oxygen deficiency can result from lack of blood flow (ischemia) through nervous tissue, an abnormally low blood oxygen concentration (hypoxemia), or toxins that prevent neurons from using oxygen by blocking aerobic respiration.

PRACTICE

9. Distinguish between a dendrite and an axon.
10. Describe the components of a neuron.
11. Describe how a myelin sheath forms.
12. Explain why axons of peripheral nerves can regenerate, but axons of central nervous system nerves cannot.
13. Name three groups of neurons based on structure and three groups based on function.

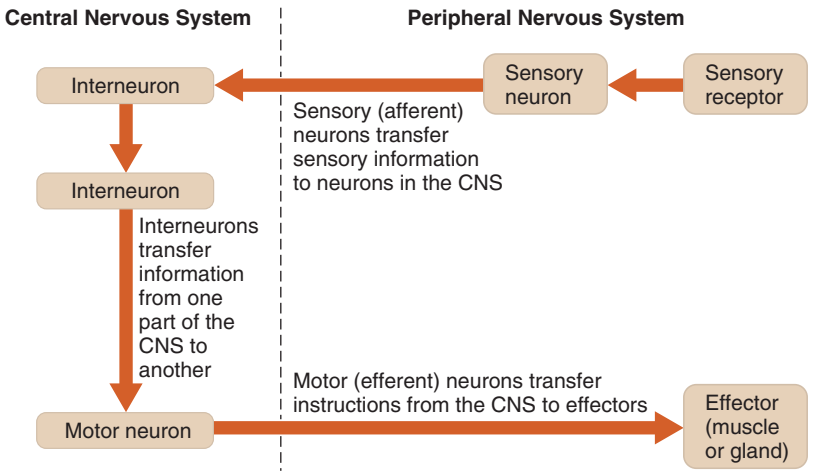


FIGURE 9.7 Neurons are classified by function as well as structure. Sensory (afferent) neurons carry information into the central nervous system (CNS), interneurons are completely within the CNS, and motor (efferent) neurons carry instructions to the effectors.

9.5 | The Synapse

As in the case of a motor neuron and a skeletal muscle fiber, the functional connection between two neurons is called a **synapse**. The neurons at a synapse are not in direct physical contact, but are separated by a gap called a *synaptic cleft.* Communication along a nerve pathway must cross these gaps (fig. 9.8).

When you receive a text message, the person texting is the sender and you are the receiver. Similarly, the neuron conducting the impulse to the synapse is the sender, or *presynaptic neuron.* The neuron that receives input at the synapse is the receiver, or *postsynaptic neuron.* The process whereby this message crosses the synaptic cleft is called *synaptic transmission.* Clinical Application 9.1 discusses some factors that affect synaptic transmission.

Synaptic transmission is a one-way process carried out by biochemicals called **neurotransmitters.** The distal ends of axons have one or more extensions called *synaptic knobs,* absent in dendrites, which contain many membranous sacs called *synaptic vesicles.* When an impulse reaches a synaptic knob, some of the synaptic vesicles release neurotransmitter (figs. 9.9 and 9.10). The neurotransmitter diffuses across the synaptic cleft and reacts with specific receptors on the postsynaptic neuron membrane.

Once the neurotransmitter binds to receptors on a postsynaptic cell, the effect is either excitatory (stimulating an impulse) or inhibitory (preventing an impulse). The net effect on the postsynaptic cell depends on the combined effect of the excitatory and inhibitory inputs from as few as one and as many as 10,000 presynaptic neurons.

9.6 | Cell Membrane Potential

The surface of a cell membrane (including a nonstimulated or *resting* neuron) is usually electrically charged, or *polarized,* with respect to the inside. This polarization arises from an unequal distribution of positive and negative ions across the membrane, and it is particularly important in the conduction of impulses in muscle cells and neurons. A characteristic change in neuron membrane polarization and return to the resting state, called an *action potential,* forms an impulse that is propagated along an axon.

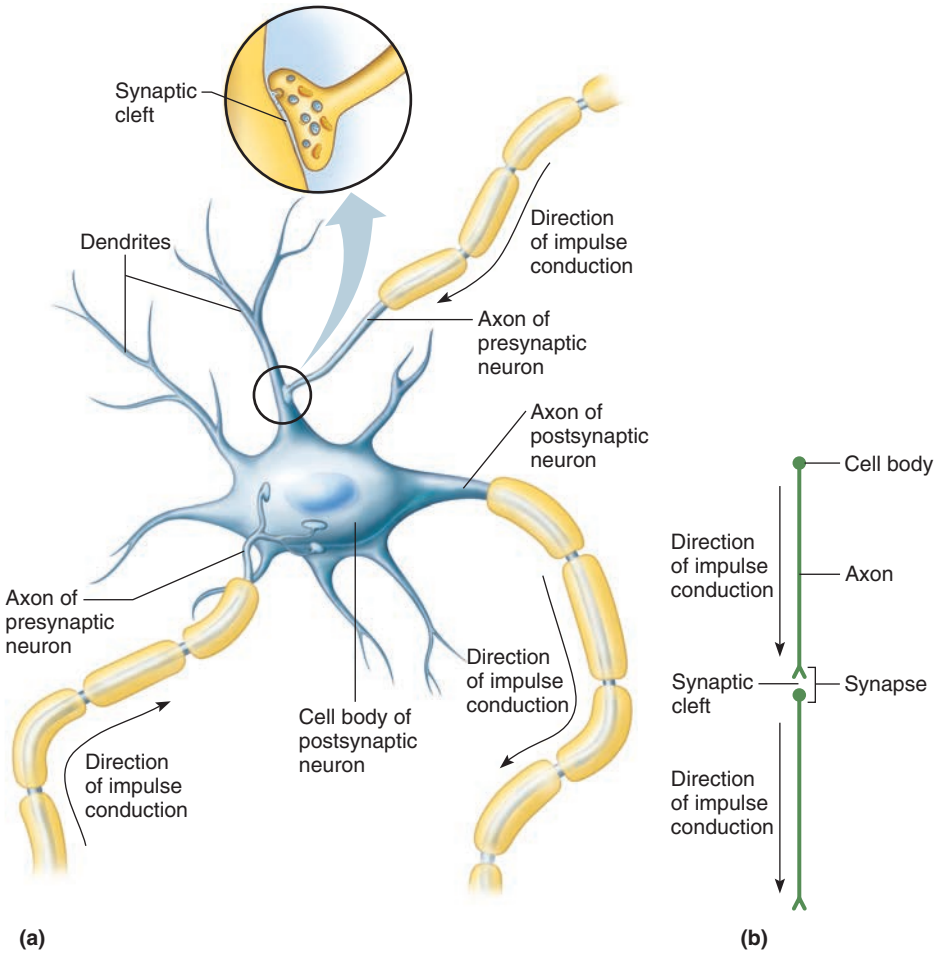


FIGURE 9.8 AP|R Synapses separate neurons. **(a)** For an impulse to continue on a postsynaptic neuron, neurotransmitter must cross the synapse and stimulate the postsynaptic neuron. A synapse is usually between an axon and a dendrite or between an axon and a cell body. **(b)** A schematic representation of presynaptic and postsynaptic neurons.

Distribution of Ions

Because of the active transport of sodium and potassium ions, cells throughout the body have a greater concentration of sodium ions (Na^+) outside and a greater concentration of potassium ions (K^+) inside (see chapter 3, pp. 75–76). The cytoplasm of these cells has many large, negatively charged particles, including phosphate ions (PO_4^{-3}), sulfate ions (SO_4^{-2}), and proteins, that cannot diffuse across the cell membranes.

Chapter 3 (p. 62) introduced cell membranes as selectively permeable phospholipid bilayers. Channels in the cell membranes partly determine the distribution of ions inside and outside of cells (see chapter 3, p. 64). Some channels are always open. Others, called "gated" channels, can be opened or closed. Furthermore, channels can be selective; that is, a channel may allow one kind of ion to pass through and exclude other kinds (fig. 9.11).

Potassium ions pass through cell membranes much more easily than sodium ions. This makes potassium ions a major contributor to membrane polarization. Calcium ions are less able to cross the resting cell membrane than either sodium ions or potassium ions, and have a special role in nerve function, described on page 239.

Resting Potential

Sodium and potassium ions follow the laws of diffusion discussed in chapter 3 (pp. 70–73) and show a net movement from high concentration to low concentration as permeabilities permit. Because a resting cell membrane is more permeable to potassium ions than to sodium ions, potassium ions diffuse out of the cell more rapidly than sodium ions can diffuse in (fig. 9.12*a*). Every millisecond, more positive charges leave the cell by diffusion than enter it. As a result, the outside of the

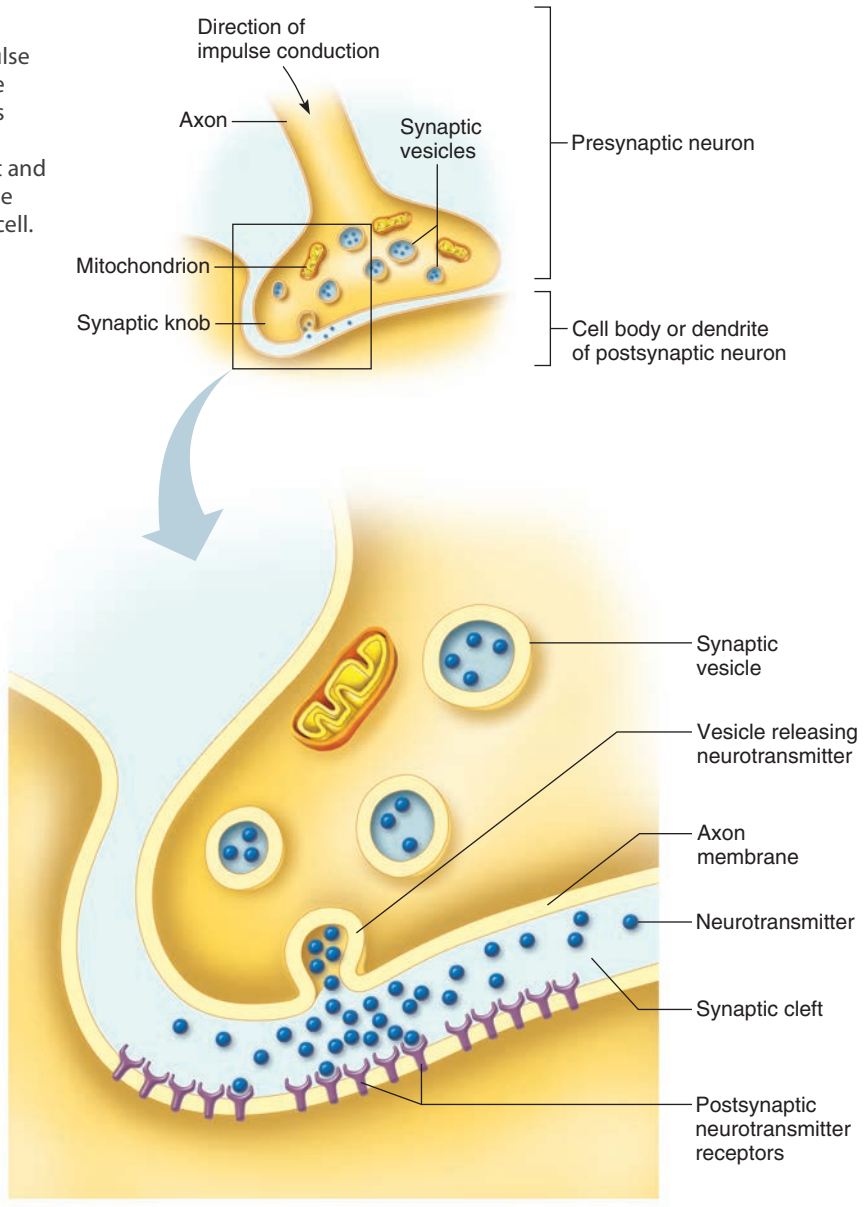


FIGURE 9.9 AP|R Action across a synapse. When an impulse reaches the synaptic knob at the end of an axon, synaptic vesicles release a neurotransmitter that diffuses across the synaptic cleft and binds to specific receptors on the membrane of the postsynaptic cell.

CLINICAL APPLICATION 9.1

Factors Affecting Synaptic Transmission

Impulses reaching synaptic knobs too rapidly can exhaust neurotransmitter supplies, and impulse conduction ceases until more neurotransmitters are synthesized. This happens during an epileptic seizure. Abnormal and too rapid impulses originate from certain brain cells and reach skeletal muscle fibers, stimulating violent contractions. In time, the synaptic knobs run out of neurotransmitters and the seizure subsides.

A drug called Dilantin (diphenylhydantoin) treats seizure disorders by blocking gated sodium channels, thereby limiting the frequency at which action potentials can occur. Many other drugs affect synaptic transmission. For example, caffeine in coffee, tea, and cola drinks stimulates nervous system activity by lowering the thresholds at synapses so that neurons are more easily excited. Antidepressants called "selective serotonin reuptake inhibitors" keep the neurotransmitter serotonin in synapses longer, compensating for a still little-understood deficit that presumably causes depression.

cell membrane gains a slight surplus of positive charges, and the inside is left with a slight surplus of impermeant negative charges (fig. 9.12*b*).

The difference in electrical charge between two regions is called a *potential difference.* In a resting nerve cell, the potential difference between the region inside the membrane and the region outside the membrane is called a **resting potential.** As long as a nerve cell membrane is undisturbed, the membrane remains in this polarized state. At the same time, the cell continues to expend energy to drive the Na^+/K^+ "pumps" that actively transport sodium and potassium ions in opposite directions. The pump maintains the concentration gradients responsible for diffusion of these ions in the first place (fig. 9.12*c*).

Recall from chapter 5 (p. 122) that neurons can conduct electrical signals. The key to understanding how this happens is the **action potential**, which is a rapid change in the membrane potential, first in a positive direction, then in a negative direction, returning to the resting potential (figure 9.13). When a neuron conducts an electrical current, that current is in the form of a

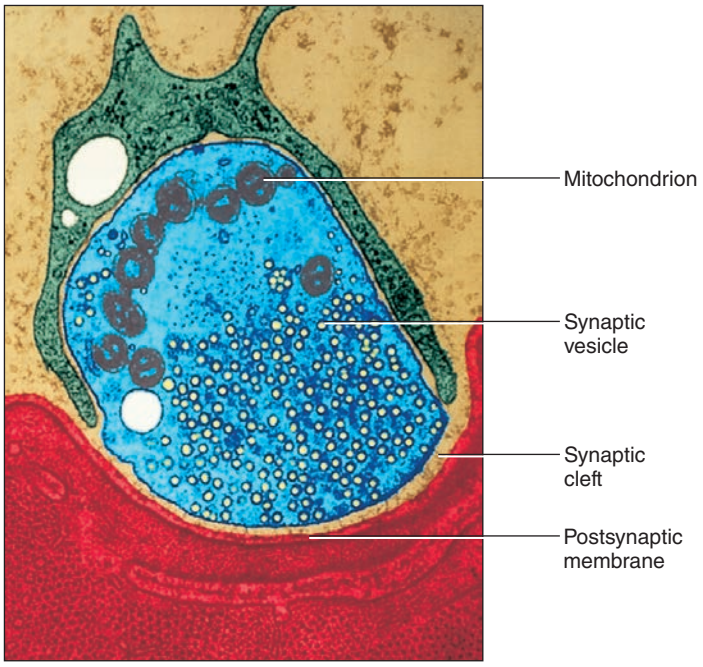


FIGURE 9.10 This transmission electron micrograph of a synaptic knob shows abundant synaptic vesicles, which are filled with neurotransmitter molecules (37,500x).

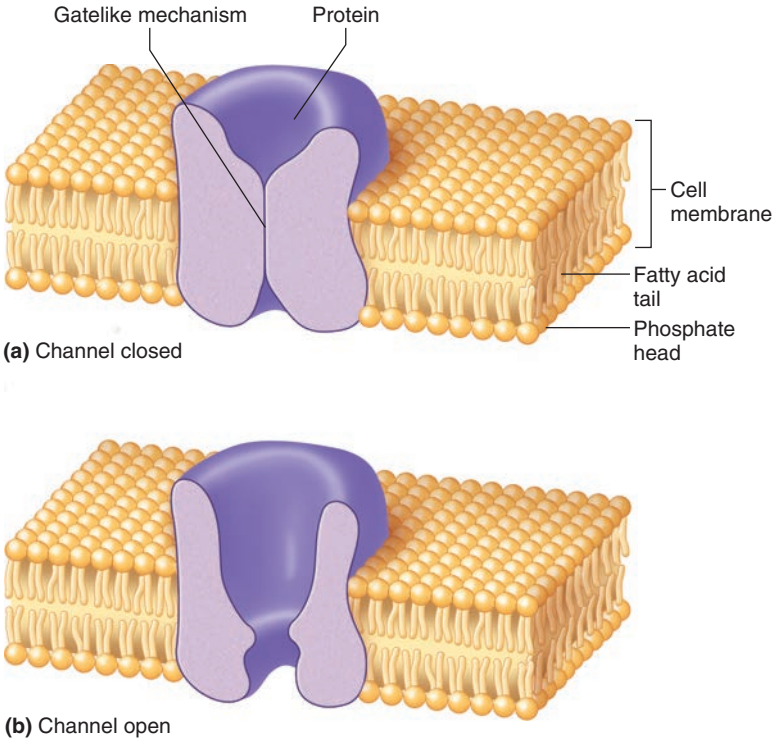
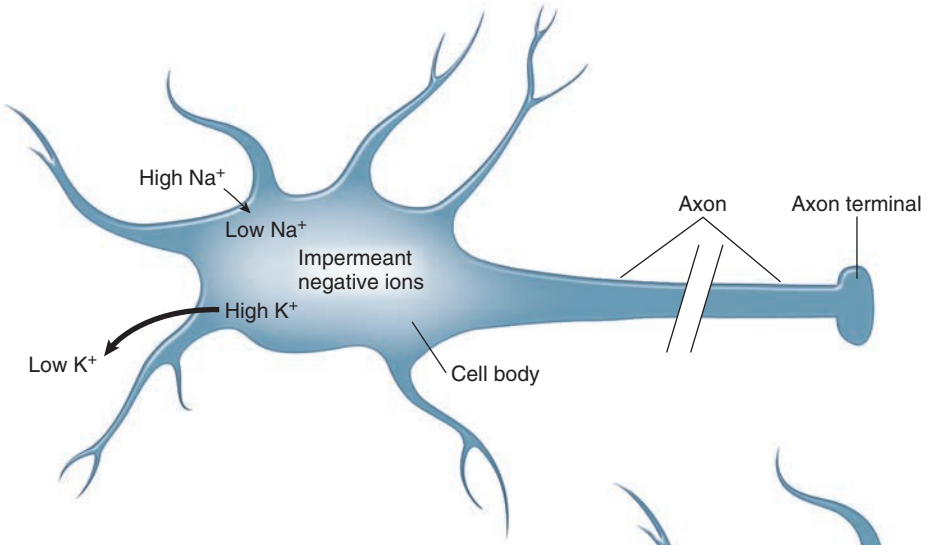
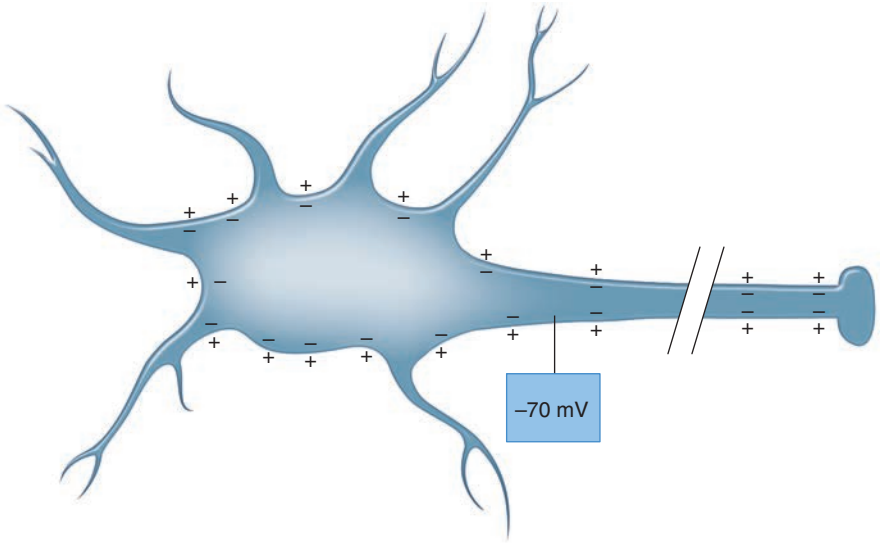


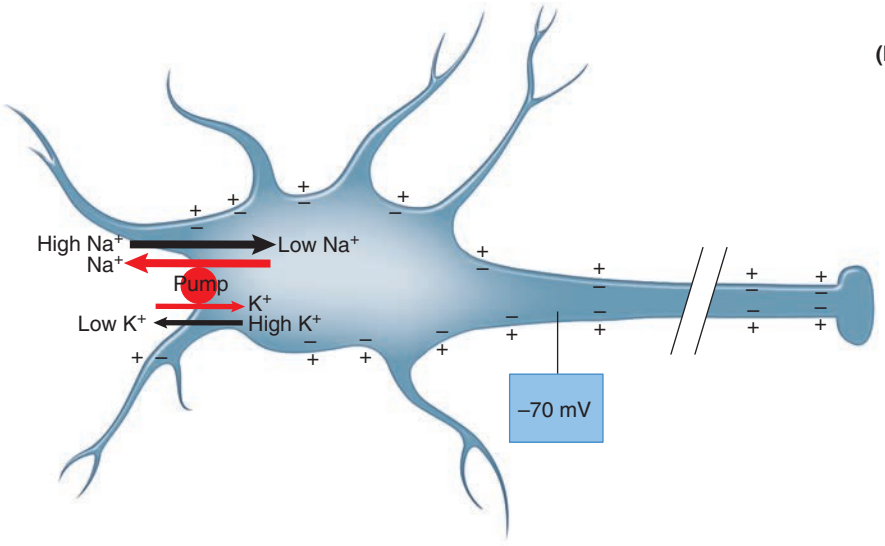
FIGURE 9.11 Channels in cell membranes partly determine the distribution of ions inside and outside of cells. A gatelike mechanism can **(a)** close or **(b)** open some of the channels in cell membranes through which ions pass.



(a) If we imagine a neuron before the membrane potential is established, concentration gradients are such that diffusion of potassium ions out of the cell exceeds diffusion of sodium ions into the cell, causing a net loss of positive charge from the cell.



(b) The net loss of positive charges from the inside of the cell has left the inside of the cell membrane slightly negative compared to the outside of the membrane, which is left slightly positive. This difference (an electrical "potential difference") is measured as –70 millivolts (mV) in a typical neuron, and is called the resting membrane potential.



(c) With the membrane potential established, sodium diffusion into the cell is now aided, and potassium diffusion opposed, by the negative charge on the inside of the membrane. As a result, slightly more sodium ions enter the cell than potassium ions leave, but the action of the sodium/potassium pump balances these movements, and as a result the concentrations of these ions, and the resting membrane potential, are maintained.

FIGURE 9.12 The resting potential. **(a)** Conditions that lead to the resting potential. **(b)** In the resting neuron, the inside of the membrane is negative relative to the outside. **(c)** The Na^+/K^+ pump maintains the concentration gradients for Na^+ and K^+ ions.

Q *Constant activity of the Na^+/K^+ pump requires a constant supply of which substance?*

Answer can be found in Appendix F on page 582.

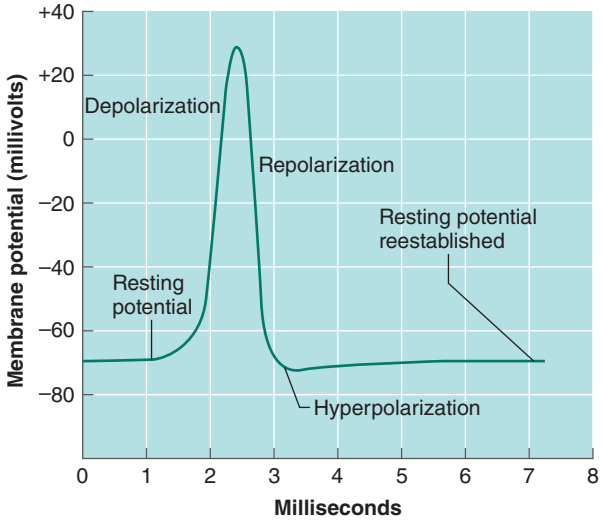


FIGURE 9.13 A recording of an action potential.

series of action potentials occurring in sequence along the axon, from the cell body to the axon terminal. The next sections discuss how all of this happens.

Potential Changes

Nerve cells are excitable; that is, they can respond to changes in their surroundings. Some nerve cells, for example, are specialized to detect changes in temperature, light, or pressure from outside the body. Many neurons respond to neurotransmitters from other neurons. Such changes (or stimuli) usually affect the resting potential in a particular region of a nerve cell membrane. If the membrane's resting potential decreases (as the inside of the membrane becomes less negative when compared to the outside), the membrane is said to be *depolarized* (fig. 9.14*a*).

Local potential changes are graded. This means that the magnitude of change in the resting potential is directly proportional to the intensity of the stimulus. That is, if the membrane is being depolarized, then the greater the stimulus, the greater the depolarization. If, and only if, neurons are depolarized sufficiently, the membrane potential reaches a level called the **threshold potential,** which is approximately –55 millivolts. If threshold is reached, an **action potential** results (figs. 9.14*b* and 9.15).

Action Potential

Recall that the axon arises from the cell body as a thickened cone-shaped region called the axon hillock. Functionally, this region is referred to as the trigger zone. At the threshold potential, permeability changes at the trigger zone of the neuron being stimulated. Here, gated channels sensitive to changes in membrane potential, and highly selective for sodium ions, open and allow sodium to diffuse freely inward (figs. 9.14*b* and 9.15*b*). The negative electrical condition on the inside of the membrane aids this movement by attracting the positively-charged sodium ions.

As sodium ions diffuse inward, inside the membrane loses its negative electrical charge and becomes depolarized (more positive). At almost the same time, however, gated membrane channels open that allow potassium ions to pass through, and as these positive ions diffuse outward, the inside of the membrane becomes negatively charged once more (fig. 9.15*c*). The membrane potential may briefly become overly negative (*hyperpolarization*), but the membrane quickly returns to the resting potential (*repolarization*), and it remains in this state until stimulated again.

This rapid sequence of depolarization and repolarization, which takes about one-thousandth of a second (one millisecond), is the action potential (see fig. 9.13). Because only a small fraction of the sodium and potassium ions move through the membrane during an action potential, action potentials can occur again and again, and resting potentials can be reestablished, before the original concentrations of these ions change significantly. Also, active transport across the membrane maintains the original concentrations of sodium and potassium ions on either side.

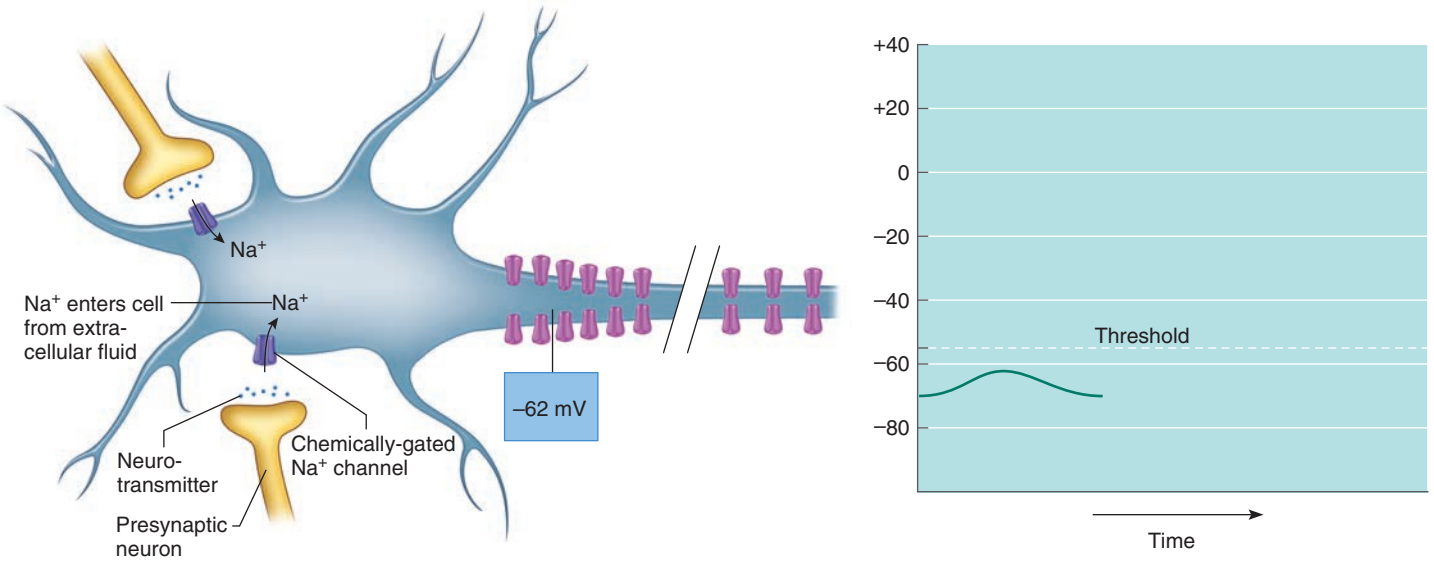
PRACTICE

14. Describe the events that occur at a synapse.
15. Summarize how a nerve fiber becomes polarized.
16. List the major events of an action potential.

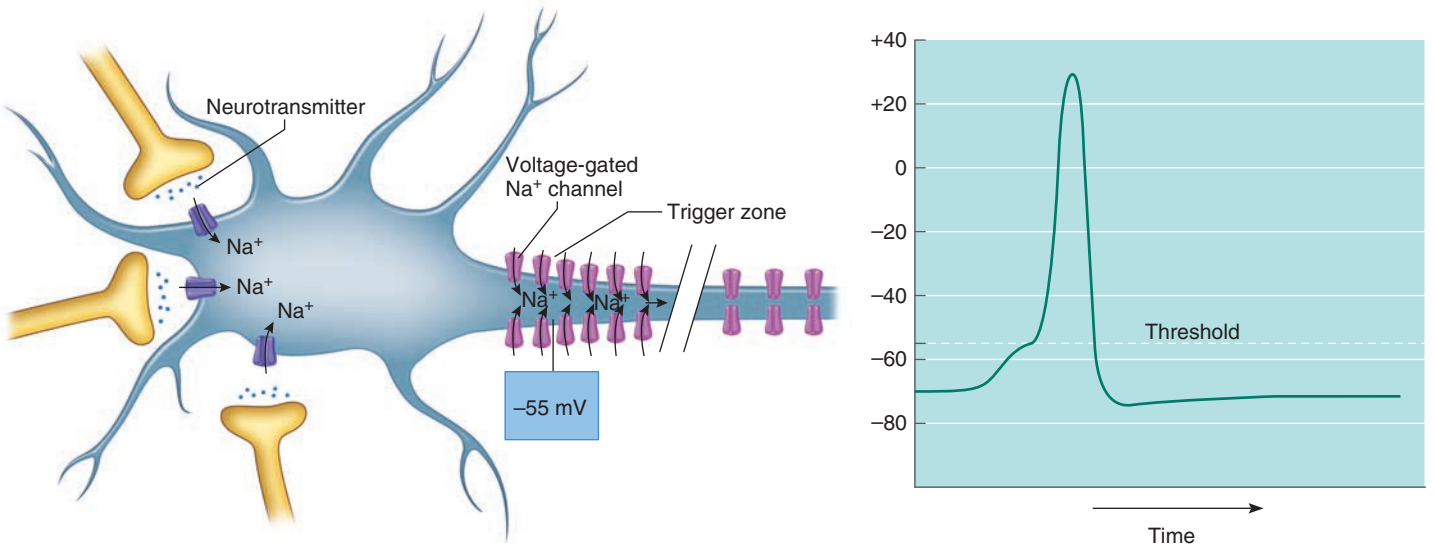
9.7 | Impulse Conduction

Axons are capable of action potentials, but the cell bodies and dendrites of most neurons are not. An action potential at the trigger zone of an axon causes a bioelectric current to flow to adjacent regions of the axon membrane. This *local current* stimulates the adjacent membrane to its threshold level and triggers another action potential. This, in turn, stimulates the next adjacent region. In this way, a wave of action potentials moves down the axon to the end (fig. 9.16). Table 9.1 summarizes the conduction of an impulse.

An unmyelinated axon conducts an impulse along its entire length. A myelinated axon functions differently because myelin insulates and prevents almost all ion flow through the membrane it encloses. The myelin sheath would prevent an impulse altogether if the sheath was continuous. However, nodes of Ranvier between Schwann cells interrupt the sheath (see fig. 9.4). Action potentials occur at these nodes,



(a) If sodium or potassium channels open, more of that particular ion will cross the cell membrane, and the resting membrane potential will be altered. Here we see the effect of sodium channels opening in response to a neurotransmitter. As sodium ions enter the cell, the membrane potential becomes more positive (or less negative), changing from –70 millivolts to –62 millivolts in this example. This change in a positive direction is called depolarization. In this case it is a subthreshold depolarization, and does not generate an action potential.



(b) If enough sodium ions enter the cell, and the membrane potential depolarizes to a value called threshold (here shown to be –55 millivolts), a threshold depolarization causes another type of sodium channel to open. These channels are found along the axon of the neuron, especially near the beginning in an area known as the "trigger zone," and their opening is what triggers the action potential.

FIGURE 9.14 AP|R Action potentials. **(a)** A subthreshold depolarization will not result in an action potential. **(b)** Stimulation from multiple presynaptic neurons may cause the postsynaptic neuron to reach threshold, opening voltage-gated channels at the trigger zone.

where the exposed axon membrane has sodium and potassium channels. In this case, the adjacent membrane that is brought to threshold is at the next node down the axon. An impulse traveling along a myelinated axon thus appears to jump from node to node. This type of impulse conduction, termed saltatory, is many times faster than conduction on an unmyelinated axon.

The speed of an impulse is proportional to the diameter of the axon—the greater the diameter, the faster the impulse. For example, an impulse on a relatively thick myelinated axon, such as that of a motor neuron associated with a skeletal muscle, might travel 120 meters per second. An impulse on a thin, unmyelinated axon, such as that of a sensory neuron associated with the skin, might move only 0.5 meter per second.

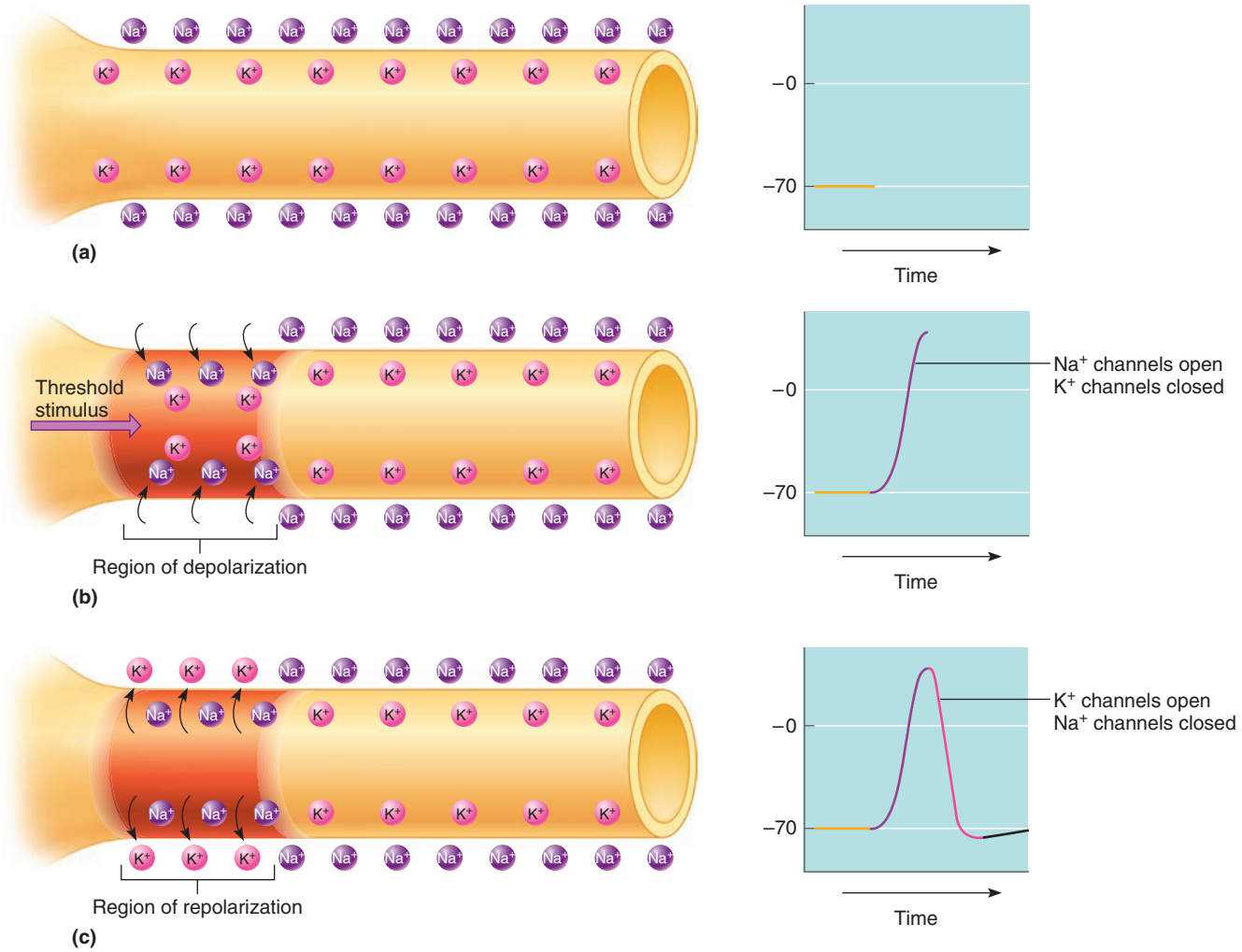


FIGURE 9.15 AP|R Action potential. **(a)** At rest, the membrane potential is negative. **(b)** When the membrane reaches threshold, sodium channels open, some sodium (Na^+) diffuses into the axon, and the membrane is depolarized. **(c)** Soon afterward, potassium channels open, potassium (K^+) diffuses out of the axon, and the membrane is repolarized. (For simplicity, negative ions are not shown.)

TABLE 9.1 Conduction of an Impulse

1. Neuron membrane maintains resting potential.
2. Threshold stimulus is received.
3. Sodium channels in the trigger zone of the axon open.
4. Sodium ions diffuse inward, depolarizing the axon membrane.
5. Potassium channels in the axon membrane open.
6. Potassium ions diffuse outward, repolarizing the axon membrane.
7. The resulting action potential causes a local bioelectric current that stimulates adjacent portions of the axon membrane.
8. A wave of action potentials travels the length of the axon as an impulse.

All-or-None Response

An action potential is not graded; rather it is an *all-or-none response.* That is, if a neuron responds at all, it responds completely. Thus, an action potential occurs whenever a stimulus of threshold intensity or above is applied to an axon, and all action potentials propagated on that axon are of the same strength. A greater intensity of stimulation does not produce a stronger action potential; instead it produces more action potentials per second.

For a very short time following an action potential, a threshold stimulus will not trigger another action potential on that axon. This brief period, called the *refractory period,* limits the frequency of action potentials, along an

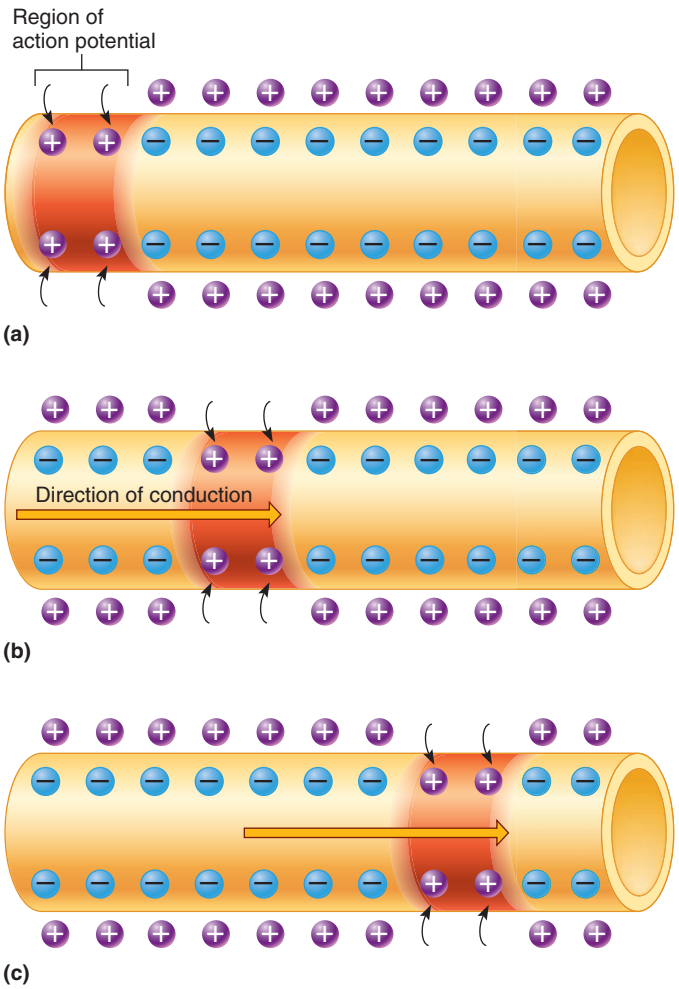


FIGURE 9.16 AP|R Conduction of an impulse. **(a)** An action potential in one region stimulates the adjacent region, and **(b)** and **(c)** a wave of action potentials (an impulse) moves along the axon.

axon. It also ensures that the impulse is conducted in only one direction—down the axon, because the area upstream from where the action potential has just occurred is still in the refractory period from the previous action potential. Although a frequency of 700 impulses per second is possible, 100 impulses per second is more common.

PRACTICE

17. What is the relationship between action potentials and impulses?
18. Explain how impulse conduction differs in myelinated and unmyelinated nerve fibers.
19. Define *all-or-none response* as it relates to impulse conduction.

9.8 | Synaptic Transmission

Neurotransmitters have various effects when they diffuse across the synaptic cleft and react with specific receptor molecules in the postsynaptic neuron membrane.

Excitatory and Inhibitory Actions

Neurotransmitters that increase postsynaptic membrane permeability to sodium ions will bring the postsynaptic membrane closer to threshold and may trigger impulses. Such neurotransmitters are **excitatory.** Neurotransmitters that make reaching threshold less likely are called **inhibitory,** because they decrease the chance that an impulse will occur.

The synaptic knobs of a thousand or more neurons may communicate with the dendrites and cell body of a single postsynaptic neuron. Neurotransmitters released by some of these knobs have an excitatory action, while those from other knobs have an inhibitory action. The overall effect on the postsynaptic neuron depends on which presynaptic knobs are activated from moment to moment. If more excitatory than inhibitory neurotransmitters are released, the postsynaptic neuron's threshold may be reached, and an action potential triggered. Conversely, if most of the neurotransmitters released are inhibitory, threshold may not be reached.

Neurotransmitters

More than 100 neurotransmitters have been identified in the nervous system. Some neurons release only one, while others produce two or three. The neurotransmitters include *acetylcholine,* which stimulates skeletal muscle contractions (see chapter 8, p. 193); a group of compounds called *biogenic amines* (such as epinephrine, norepinephrine, dopamine, and serotonin), which form from modified amino acids; several *amino acids* (such as glycine, glutamic acid, aspartic acid, and gamma-aminobutyric acid—GABA); and more than 50 *neuropeptides,* which are short chains of amino acids. Acetylcholine and norepinephrine are excitatory. GABA and glycine are inhibitory. Neurotransmitters are usually synthesized in the cytoplasm of the synaptic knobs and stored in the synaptic vesicles. Table 9.2 lists some neurotransmitters and their actions.

When an action potential reaches the membrane of a synaptic knob, it increases the membrane's permeability to calcium ions by opening calcium ion channels in the membrane. Consequently, calcium ions diffuse inward, and in response some synaptic vesicles fuse with the membrane and release their contents into the synaptic cleft. After being released, some neurotransmitters are decomposed by enzymes. For example, the enzyme *acetylcholinesterase* decomposes acetylcholine and is present in the synapse and on the postsynaptic

TABLE 9.2 Some Neurotransmitters and Representative Actions

Neurotransmitter	Location	Major Actions
Acetylcholine	CNS	Controls skeletal muscle actions
	PNS	Stimulates skeletal muscle contraction at neuromuscular junctions; may excite or inhibit at autonomic nervous system synapses
Monoamines		
Norepinephrine	CNS	Creates a sense of feeling good; low levels may lead to depression
	PNS	May excite or inhibit autonomic nervous system actions, depending on receptors
Dopamine	CNS	Creates a sense of feeling good; deficiency in some brain areas is associated with Parkinson disease
	PNS	Limited actions in autonomic nervous system; may excite or inhibit, depending on receptors
Serotonin	CNS	Primarily inhibitory; leads to sleepiness; action is blocked by LSD, enhanced by selective serotonin reuptake inhibitor drugs
Histamine	CNS	Release in hypothalamus promotes alertness
Amino acids		
GABA	CNS	Generally inhibitory
Glutamic acid	CNS	Generally excitatory
Neuropeptides		
Substance P	PNS	Excitatory; pain perception
Endorphins, enkephalins	CNS	Generally inhibitory; reduce pain by inhibiting substance P release
Gases		
Nitric oxide	PNS	Vasodilation
	CNS	May play a role in memory

membrane of neuromuscular junctions, which control skeletal muscle contraction. Other neurotransmitters are transported back into the synaptic knob that released them (reuptake) or into nearby neurons or neuroglia. Decomposition or removal of neurotransmitters prevents continuous stimulation of postsynaptic neurons. Table 9.3 summarizes the events leading to the release of a neurotransmitter.

TABLE 9.3 Events Leading to the Release of a Neurotransmitter

1. Action potential passes along an axon and over the surface of its synaptic knob.
2. Synaptic knob membrane becomes more permeable to calcium ions, and they diffuse inward.
3. In the presence of calcium ions, synaptic vesicles fuse to synaptic knob membrane.
4. Synaptic vesicles release their neurotransmitter into synaptic cleft.

PRACTICE

20. Distinguish between the actions of excitatory and inhibitory neurotransmitters.
21. What types of chemicals function as neurotransmitters?
22. What are possible fates of neurotransmitters?

9.9 | Impulse Processing

The way the nervous system processes and responds to impulses reflects, in part, the organization of neurons and their axons in the brain and spinal cord.

Neuronal Pools

Neurons in the CNS are organized into **neuronal pools.** These are groups of neurons that make hundreds of synaptic connections with each other and work together to perform a common function. Each pool receives input from neurons (which may be part of other pools), and each pool generates output. Neuronal pools may have excitatory or inhibitory effects on other pools or on peripheral effectors.

Facilitation

As a result of incoming impulses and neurotransmitter release, a particular neuron of a neuronal pool may receive excitatory and inhibitory input. If the net effect of the input is excitatory, threshold may be reached, and an outgoing impulse triggered. If the net effect is excitatory but subthreshold, an impulse is not triggered, but another immediate release of neurotransmitter will be more likely to bring the postsynaptic cell to threshold. This is called **facilitation** (fah-sil″ĭ-ta′shun).

Convergence

Any single neuron in a neuronal pool may receive impulses from two or more incoming axons. Axons originating from different parts of the nervous system and leading to the same neuron exhibit **convergence** (kon-ver′jens) (fig. 9.17*a*).

Convergence makes it possible for impulses arriving from different sources to have an additive effect on a neuron. For example, if a neuron is facilitated by receiving subthreshold stimulation from one input neuron, it may reach threshold if it receives additional stimulation from a second input neuron. As a result, an impulse may travel to a particular effector and evoke a response.

Incoming impulses often bring information from several sensory receptors that detect changes. Convergence allows the nervous system to collect a variety of kinds of information, process it, and respond to it in a special way.

Divergence

Impulses leaving a neuron of a neuronal pool often exhibit **divergence** (di-ver′jens) by passing into several other output neurons (fig. 9.17*b*). For example, an impulse from one neuron may stimulate two others; each of these, in turn, may stimulate several others, and so forth. Divergence can amplify an impulse—that is, spread it to more neurons in the pool. As a result of divergence, an impulse originating from a single neuron in the CNS may be amplified so that impulses reach enough motor units within a skeletal muscle to cause forceful contraction (see chapter 8, pp. 199–200). Similarly, an impulse originating from a sensory receptor may diverge and reach several different regions of the CNS, where the resulting impulses are processed and acted upon.

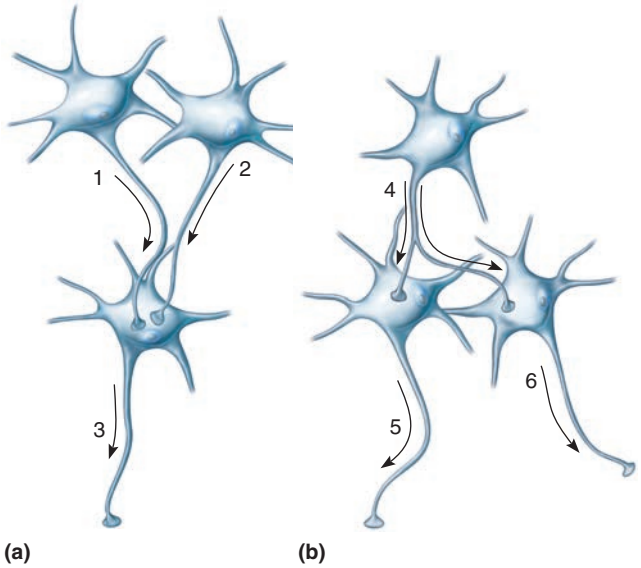


FIGURE 9.17 Impulse processing in neuronal pools. **(a)** Axons of neurons 1 and 2 converge to the cell body of neuron 3. **(b)** The axon of neuron 4 diverges to the cell bodies of neurons 5 and 6.

PRACTICE

23. Define *neuronal pool.*
24. Distinguish between convergence and divergence.

9.10 | Types of Nerves

Recall from section 9.1 (p. 224) that nerves are bundles of axons. An axon is often referred to as a nerve fiber. Because of this, we will refer to the neuron processes that bring sensory information into the CNS as **sensory fibers,** or **afferent fibers.** In contrast, **motor fibers** or **efferent fibers** carry impulses from the CNS to effectors (muscles or glands). A nerve is a cordlike bundle (or group of bundles) of nerve fibers within layers of connective tissue (fig. 9.18).

> The terminology used to describe muscle and nerve fibers is somewhat inconsistent. "Muscle fiber" refers to a muscle cell, whereas "nerve fiber" refers to an axon, which is part of a cell. However, names for the associated connective tissues are similar. Both muscle and nerve fibers are bundled into fascicles. Recall from figure 8.1 (pp. 189–190) that epimysium, perimysium, and endomysium connective tissue separates muscle tissue into compartments. Similarly, a nerve is defined by an outer *epineurium,* with *perineurium* surrounding a nerve fascicle within the nerve, and *endoneurium* surrounding an individual nerve fiber.

Like neurons, nerves that conduct impulses to the brain or spinal cord are called **sensory nerves,** and those that carry impulses to muscles or glands are termed **motor nerves.** Most nerves include both sensory and motor fibers and are called **mixed nerves.**

PRACTICE

25. What is a nerve?
26. How does a mixed nerve differ from a sensory nerve? From a motor nerve?

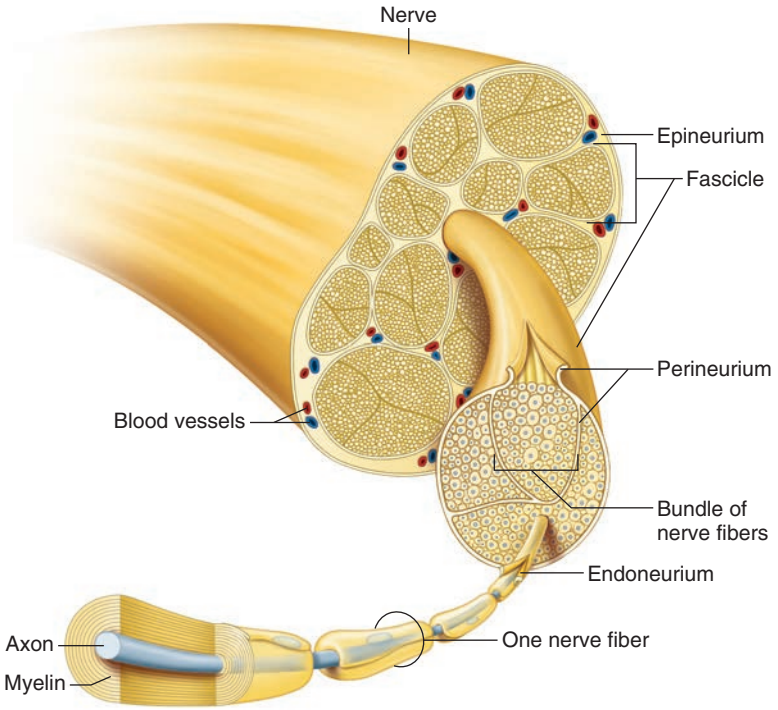


FIGURE 9.18 Connective tissue binds a bundle of nerve fibers, forming a fascicle. Many fascicles form a nerve.

9.11 | Nerve Pathways

The routes impulses follow as they travel through the nervous system are called *nerve pathways.* The simplest of these pathways includes only a few neurons and is called a **reflex** (re′fleks) **arc.** It constitutes the structural and functional basis for involuntary actions called **reflexes.**

Reflex Arcs

A reflex arc begins with a receptor at the end of a sensory (or afferent) neuron. This neuron usually leads to several interneurons in the CNS, which serve as a processing center, or *reflex center.* These interneurons can connect with interneurons in other parts of the nervous system. They also communicate with motor (or efferent) neurons, whose axons pass outward from the CNS to effectors, usually muscles or glands (fig. 9.19).

Reflex Behavior

Reflexes are automatic responses to changes (stimuli) within or outside the body. They help maintain homeostasis by controlling many involuntary processes, such as heart rate, breathing rate, blood pressure, and digestion. Reflexes also carry out the automatic actions of swallowing, sneezing, coughing, and vomiting.

The *patellar reflex* (knee-jerk reflex) is an example of a simple reflex involving a pathway of only two neurons—a sensory neuron communicating directly with a motor neuron. Striking the patellar ligament just below the patella initiates this reflex. The quadriceps femoris muscle group, which is attached to the patella by a tendon, is pulled slightly, stimulating stretch receptors in these muscles. These receptors, in turn, trigger impulses that pass along the axon of a sensory neuron into the spinal cord. Within the spinal cord, the sensory axon synapses with a motor neuron. An impulse is then triggered along the axon of the motor neuron and travels back to the quadriceps femoris group. The muscle group contracts in response, and the reflex is completed as the leg extends (fig. 9.20).

The patellar reflex helps maintain upright posture. If the knee begins to bend from the force of gravity when a person is standing still, the quadriceps femoris group is stretched, the reflex is triggered, and the leg straightens again.

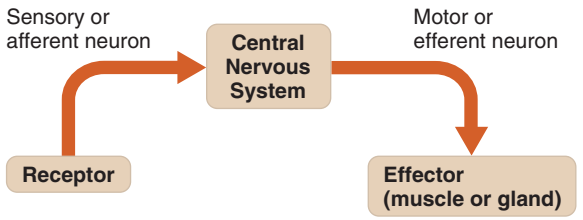


FIGURE 9.19 AP|R A reflex arc is the simplest nerve pathway. It involves a sensory neuron that sends a message to the CNS, and a motor neuron that sends the message from the CNS to a muscle or gland.

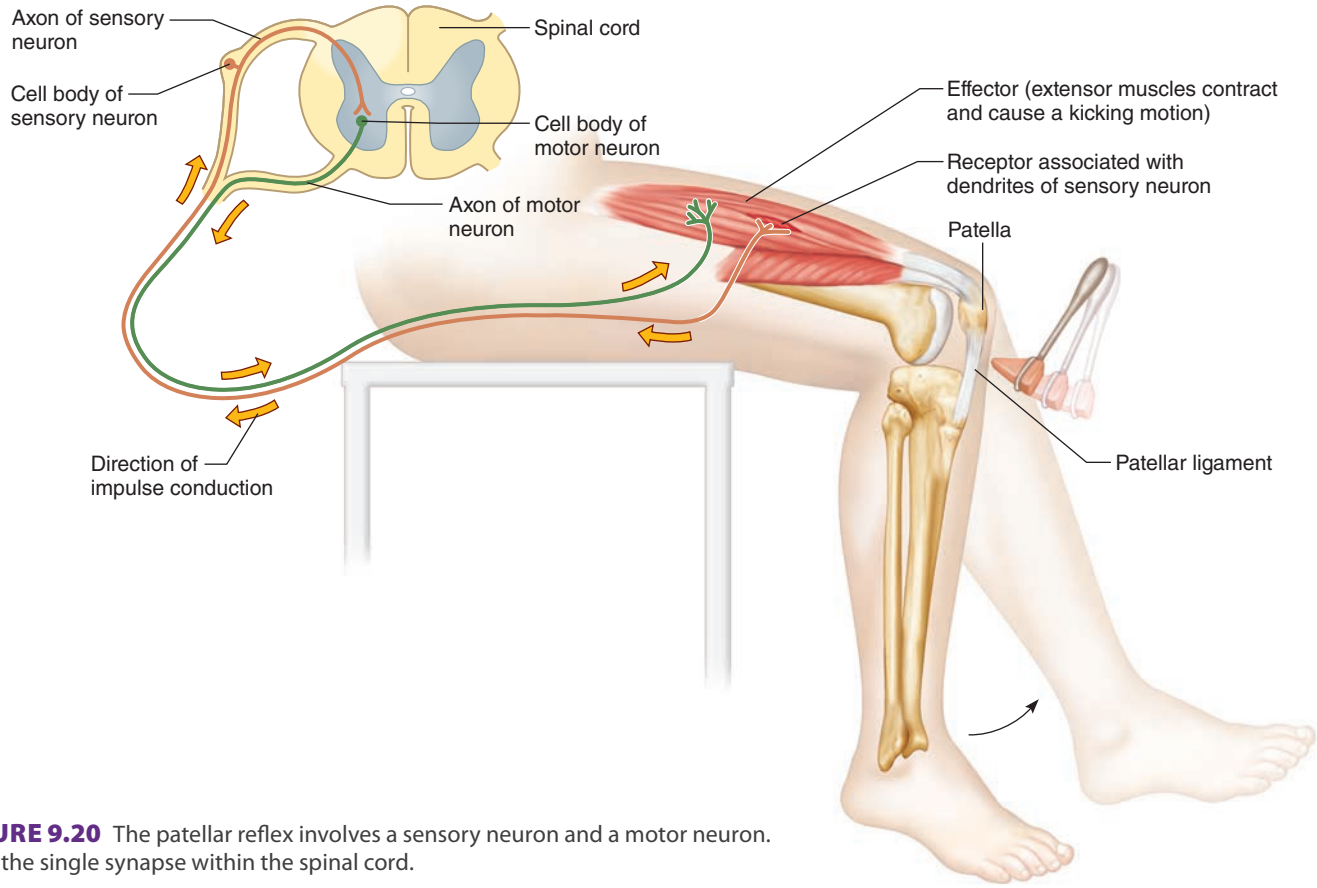


FIGURE 9.20 The patellar reflex involves a sensory neuron and a motor neuron. Note the single synapse within the spinal cord.

Another type of reflex, called a *withdrawal reflex,* occurs when a person unexpectedly touches a body part to something painful, such as stepping on a tack. This activates skin receptors and sends sensory impulses to the spinal cord. There, the impulses pass to the interneurons of a reflex center and are directed to motor neurons. The motor neurons activate fibers in the flexor muscles of the leg and thigh, which contract in response, pulling the foot away from the painful stimulus. At the same time, the antagonistic extensor muscles are inhibited. This inhibition of antagonists allows the flexor muscles to effectively withdraw the affected part. Concurrent with the withdrawal reflex, other interneurons carry sensory impulses to the brain and the person becomes aware of the experience and may feel pain (fig. 9.21). A withdrawal reflex is protective because it may limit tissue damage caused by touching something harmful. Table 9.4 summarizes the parts of a reflex arc.

Reflexes provide information about the condition of the nervous system. An anesthesiologist may try to initiate a reflex in a patient being anesthetized to determine how well the anesthetic drug is affecting nerve functions. A neurologist may test reflexes to determine the location and extent of damage from a nervous system injury.

PRACTICE

27. What is a nerve pathway?
28. List the parts of a reflex arc.
29. Define *reflex.*
30. List the actions that occur during a withdrawal reflex.

9.12 | Meninges

Bones, membranes, and fluid surround the organs of the CNS. The brain lies in the cranial cavity of the skull, and the spinal cord occupies the vertebral canal in the vertebral column. Layered membranes called **meninges** (mĕ-nin′jēz) (singular, *meninx*) lie between these bony coverings and the soft tissues of the CNS, protecting the brain and spinal cord (fig. 9.22*a*).

The meninges have three layers—dura mater, arachnoid mater, and pia mater (fig. 9.22*b*). The **dura mater** (du′rah ma′ter) is the outermost layer. It is composed primarily of tough, white, fibrous connective tissue and contains many blood vessels and nerves. It attaches to the inside of the cranial cavity and forms the internal periosteum of the surrounding skull bones. In some regions, the dura mater extends inward between

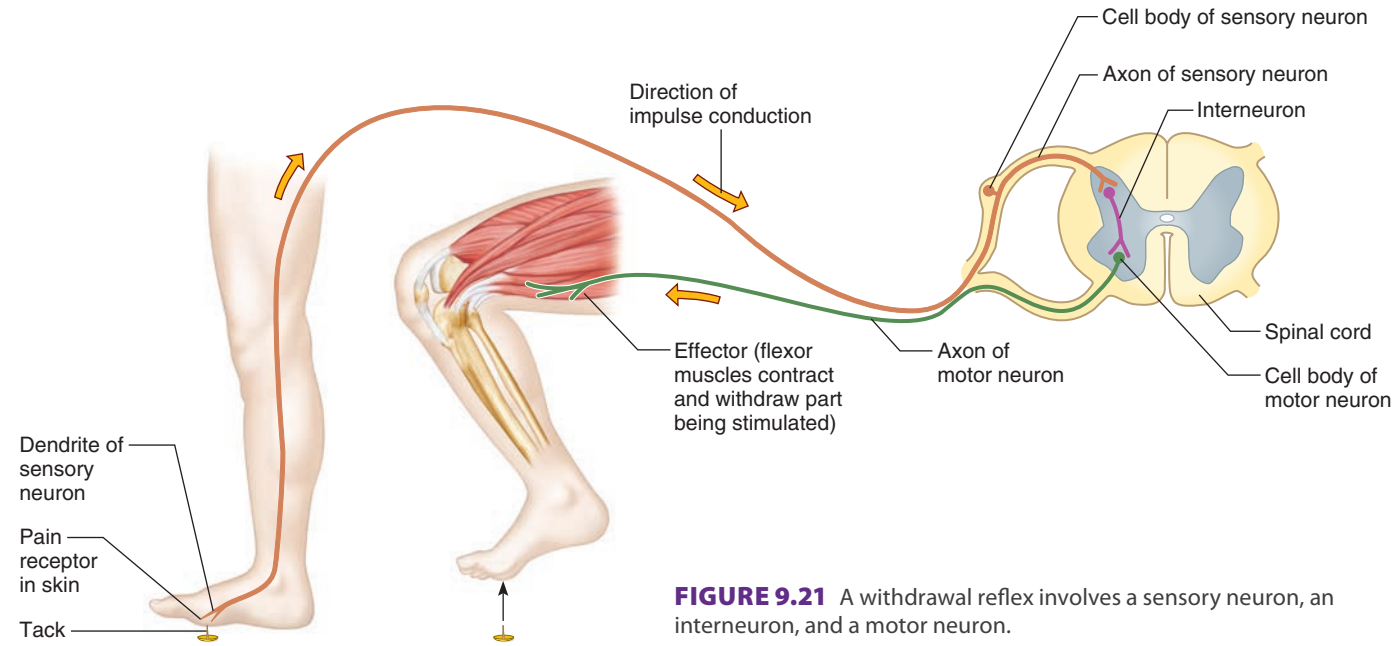


FIGURE 9.21 A withdrawal reflex involves a sensory neuron, an interneuron, and a motor neuron.

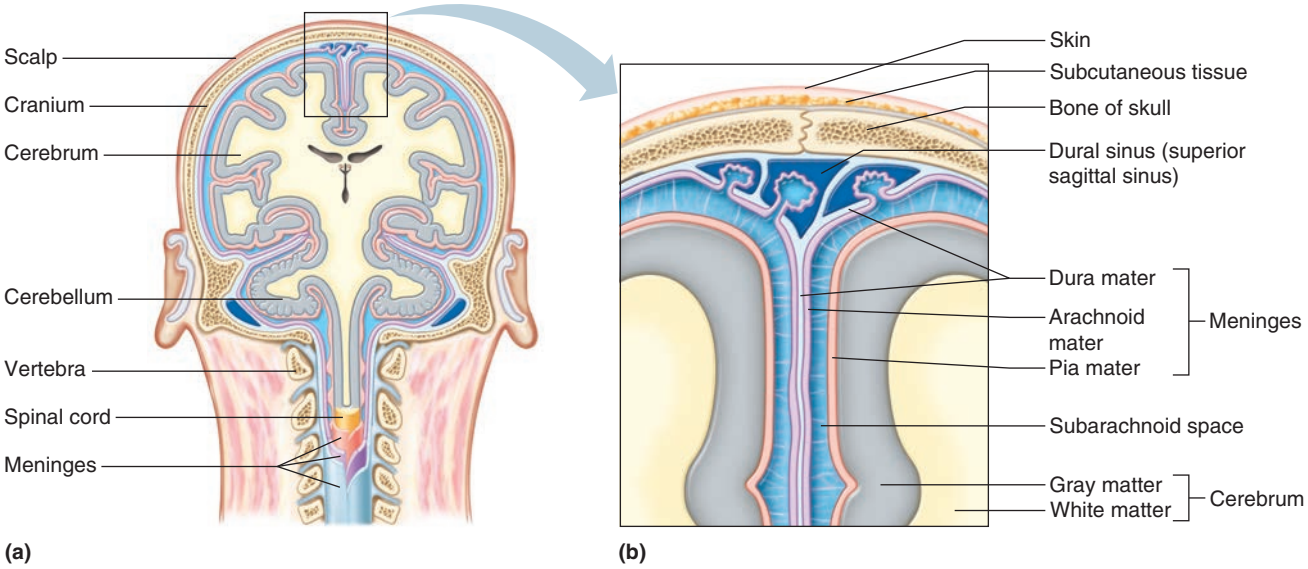


FIGURE 9.22 AP|R Meninges. **(a)** Membranes called meninges enclose the brain and spinal cord. **(b)** The meninges include three layers: dura mater, arachnoid mater, and pia mater.

lobes of the brain and forms partitions that support and protect these parts.

The dura mater continues into the vertebral canal as a strong, tubular sheath that surrounds the spinal cord. It terminates as a blind sac below the end of the cord. The membrane around the spinal cord is not attached directly to the vertebrae but is separated by an *epidural space,* which lies between the dural sheath and the bony walls (fig. 9.23). This space contains loose connective and adipose tissues, which pad the spinal cord.

The **arachnoid mater** is a thin, weblike membrane without blood vessels that lies between the dura and pia maters. A *subarachnoid space* contains the clear, watery **cerebrospinal fluid (CSF).** The **pia mater** (pi′ah ma′ter) is very thin and contains many nerves and blood vessels that nourish underlying cells of the brain and spinal cord. This layer hugs the surfaces of these organs and follows their irregular contours, passing over high areas and dipping into depressions.

TABLE 9.4 Parts of a Reflex Arc

Part	Description	Function
Receptor	Receptor end of a dendrite or a specialized receptor cell in a sensory organ	Senses specific type of internal or external change
Sensory neuron	Dendrite, cell body, and axon of a sensory neuron	Carries information from receptor into brain or spinal cord
Interneuron	Dendrite, cell body, and axon of a neuron within the brain or spinal cord	Carries information from sensory neuron to motor neuron
Motor neuron	Dendrite, cell body, and axon of a motor neuron	Carries instructions from brain or spinal cord out to effector
Effector	Muscle or gland	Responds to stimulation by motor neuron and produces reflex or behavioral action

A blow to the head may break some blood vessels associated with the brain, and escaping blood may collect beneath the dura mater. Such a *subdural hematoma* increases pressure between the rigid bones of the skull and the soft tissues of the brain. Unless the accumulating blood is evacuated, compression of the brain may lead to functional losses or even death.

PRACTICE

31. Describe the meninges.
32. State the location of cerebrospinal fluid.

9.13 | Spinal Cord

The **spinal cord** is a slender nerve column that passes downward from the brain into the vertebral canal. Although continuous with the brain, the spinal cord begins where nervous tissue leaves the cranial cavity at the level of the foramen magnum. The spinal cord tapers to a point and terminates near the intervertebral disc that separates the first and second lumbar vertebrae (fig. 9.24).

Structure of the Spinal Cord

The spinal cord consists of thirty-one segments, each of which gives rise to a pair of **spinal nerves.** These nerves (part of the peripheral nervous system) branch

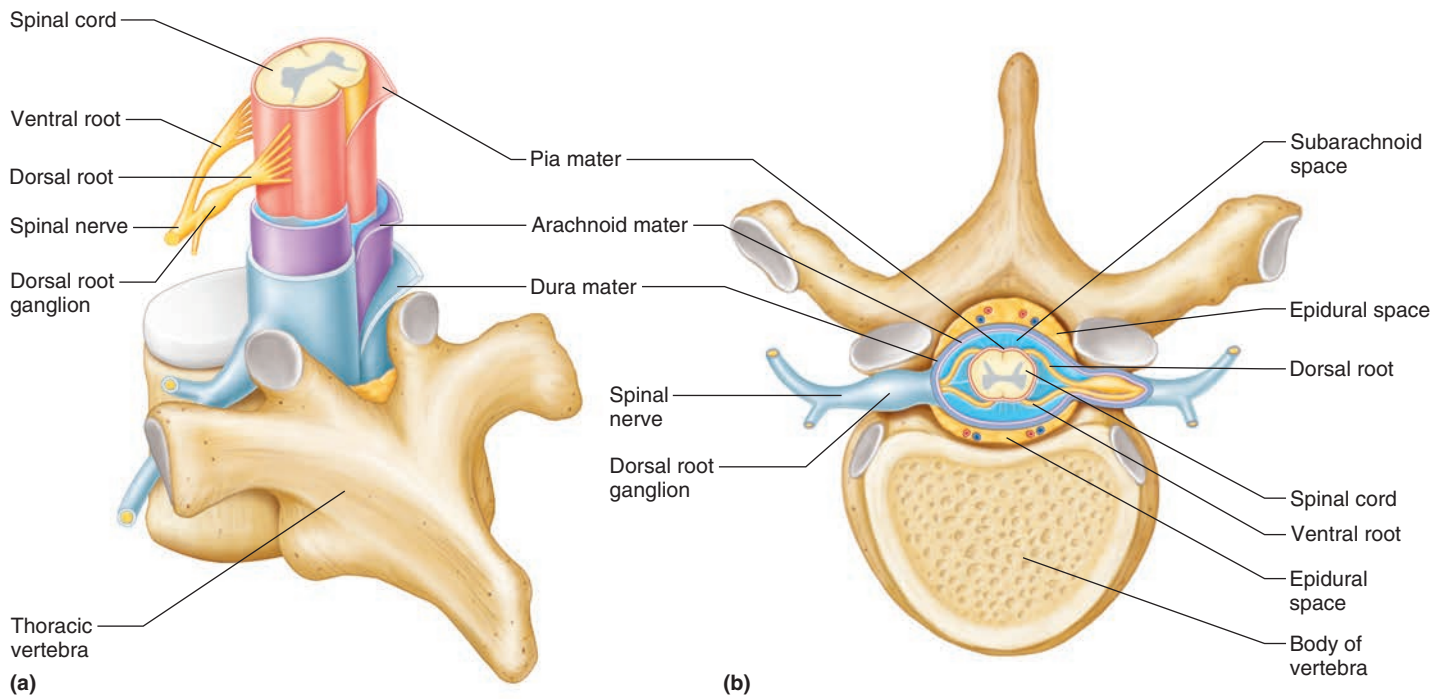


FIGURE 9.23 AP|R Meninges of the spinal cord. **(a)** The dura mater ensheaths the spinal cord. **(b)** Tissues forming a protective pad around the cord fill the epidural space between the dural sheath and the bone of the vertebra.

to various body parts and connect them with the CNS (see fig. 9.36).

In the neck region, a thickening in the spinal cord, called the *cervical enlargement,* supplies nerves to the upper limbs. A similar thickening in the lower back, the *lumbar enlargement,* gives off nerves to the lower limbs (fig. 9.24).

Two grooves, a deep *anterior median fissure* and a shallow *posterior median sulcus,* extend the length of the spinal cord, dividing it into right and left halves (fig. 9.25). A cross section of the cord reveals a core of gray matter within white matter. The pattern of gray matter roughly resembles a butterfly with its wings spread. The posterior and anterior wings of gray matter are called the *posterior horns* and *anterior horns,* respectively. Between them on either side in the thoracic and upper lumbar segments is a protrusion of gray matter called the *lateral horn.*

Neurons with large cell bodies located in the anterior horns give rise to motor fibers that pass out through spinal nerves to skeletal muscles. However, the majority of neurons in the gray matter of the spinal cord are interneurons.

Gray matter divides the white matter of the spinal cord into three regions on each side—the *anterior, lateral,* and *posterior funiculi* (fig. 9.25*a*). Each funiculus consists of longitudinal bundles of myelinated axons that comprise major neural pathways. In the central nervous system, such bundles of axons are called **tracts.**

A horizontal bar of gray matter in the middle of the spinal cord, the *gray commissure,* connects the wings of the gray matter on the right and left sides. This bar surrounds the **central canal,** which contains cerebrospinal fluid.

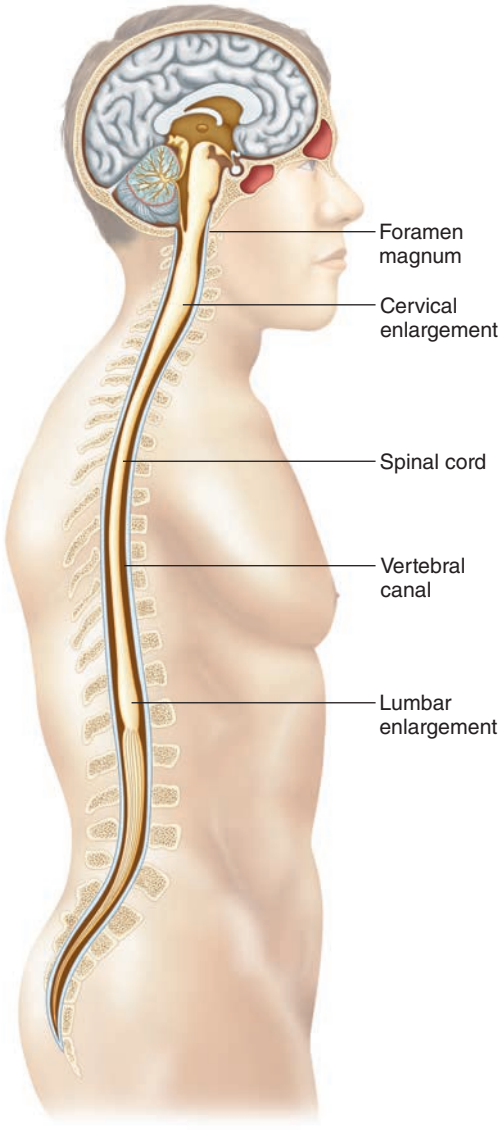


FIGURE 9.24 AP|R The spinal cord begins at the level of the foramen magnum and ends near the intervertebral disc between the first and second lumbar vertebrae.

Functions of the Spinal Cord

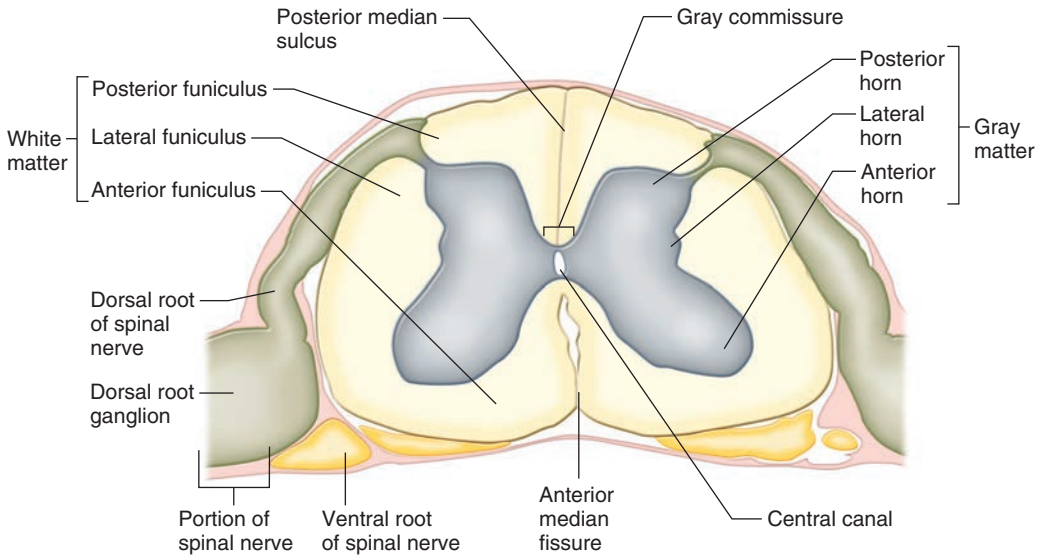
The spinal cord has two major functions—conducting impulses and serving as a center for spinal reflexes. The tracts of the spinal cord consist of axons that provide a two-way communication system between the brain and the body parts outside the nervous system. The tracts that carry sensory information to the brain are called **ascending tracts** (fig. 9.26); those that carry motor instructions from the brain to muscles and glands are called **descending tracts** (fig. 9.27).

All the axons in a given tract typically originate from neuron cell bodies in the same part of the nervous system and terminate together in another part. The names that identify tracts often reflect these common origins and terminations. For example, a *spinothalamic tract* begins in the spinal cord and carries sensory impulses associated with the sensations of pain, touch, and temperature to the thalamus of the brain. A *corticospinal tract* originates in the cortex of the brain and carries motor impulses downward through the spinal cord and spinal nerves. These impulses control skeletal muscle movements.

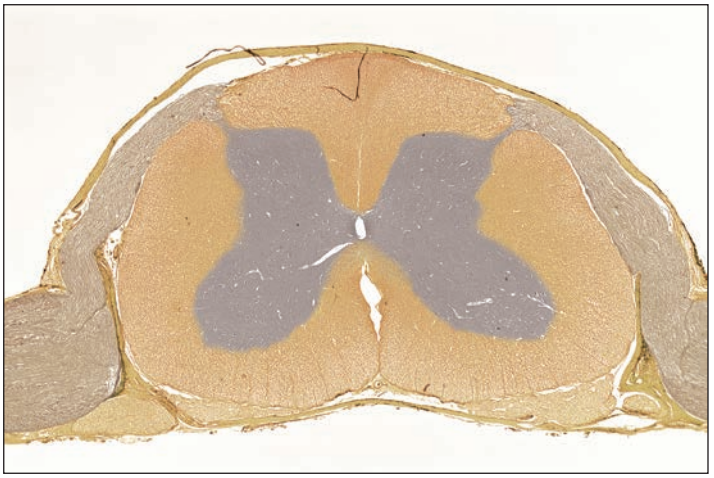
Corticospinal tracts are also called *pyramidal tracts* after the pyramid-shaped areas in the medulla oblongata of the brain through which they pass. Other descending tracts, called *extrapyramidal tracts,* control motor activities associated with maintaining balance and posture.

In addition to providing a pathway for tracts, the spinal cord functions in many reflexes, including the patellar and withdrawal reflexes described previously. These are called **spinal reflexes** because their reflex arcs pass through the spinal cord.

FACTS OF LIFE Some axons extend from the base of the spinal cord to the toes. If you stub your toe, a sensory message reaches the spinal cord in less than one hundredth of a second.



(a)



(b)

FIGURE 9.25 AP|R The spinal cord. **(a)** A cross section of the spinal cord. **(b)** Identify the parts of the spinal cord in this micrograph (10×).

PRACTICE

33. Describe the structure of the spinal cord.
34. Describe the general functions of the spinal cord.
35. Distinguish between an ascending and a descending tract.

9.14 | Brain

The **brain** is composed of about 100 billion (10^{11}) multipolar neurons, which communicate with one another and with neurons in other parts of the nervous system. As figure 9.28 shows, the brain can be divided into four major portions—the cerebrum, the diencephalon, the brainstem, and the cerebellum. The *cerebrum,* the largest part, includes nerve centers associated with sensory and motor functions and provides higher mental functions, including memory and reasoning. The *diencephalon* also processes sensory information. Nerve pathways in the *brainstem* connect parts of the nervous system and regulate certain visceral activities. The *cerebellum* includes centers that coordinate voluntary muscular movements.

Structure of the Cerebrum

The **cerebrum** (ser′ĕ-brum) consists of two large masses called the left and right **cerebral hemispheres** (ser″ĕ-bral hem′ĭ-sfērz), which are essentially mirror images of each other. A broad, flat bundle of axons called the **corpus callosum** (kor′pus kah-lo′sum) connects the cerebral hemispheres. A layer of dura mater (falx cerebri) separates them.

The surface of the cerebrum has many ridges (convolutions) or **gyri** (ji′ri) (singular, *gyrus*), separated by grooves. A shallow groove is called a **sulcus** (sul′kus), and a deep groove is called a **fissure.** The structural organization of these elevations and depressions is

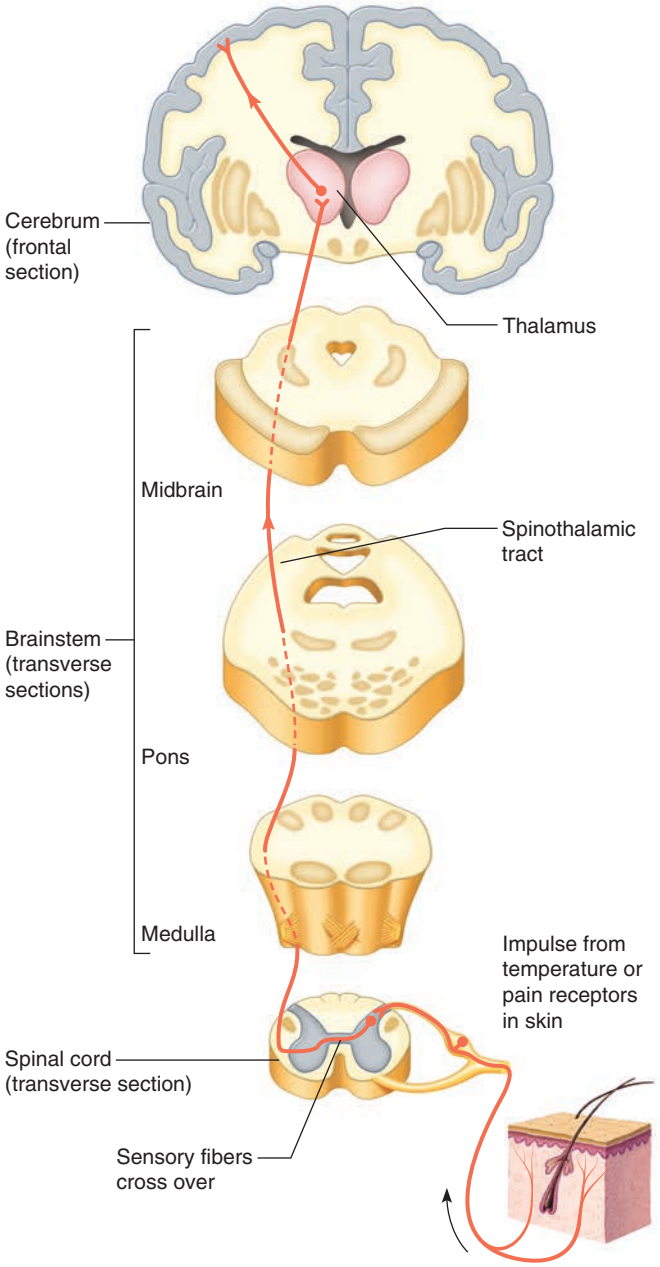


FIGURE 9.26 Ascending tracts. Sensory impulses originating in skin receptors cross over in the spinal cord and ascend to the brain. Other sensory tracts cross over in the medulla oblongata.

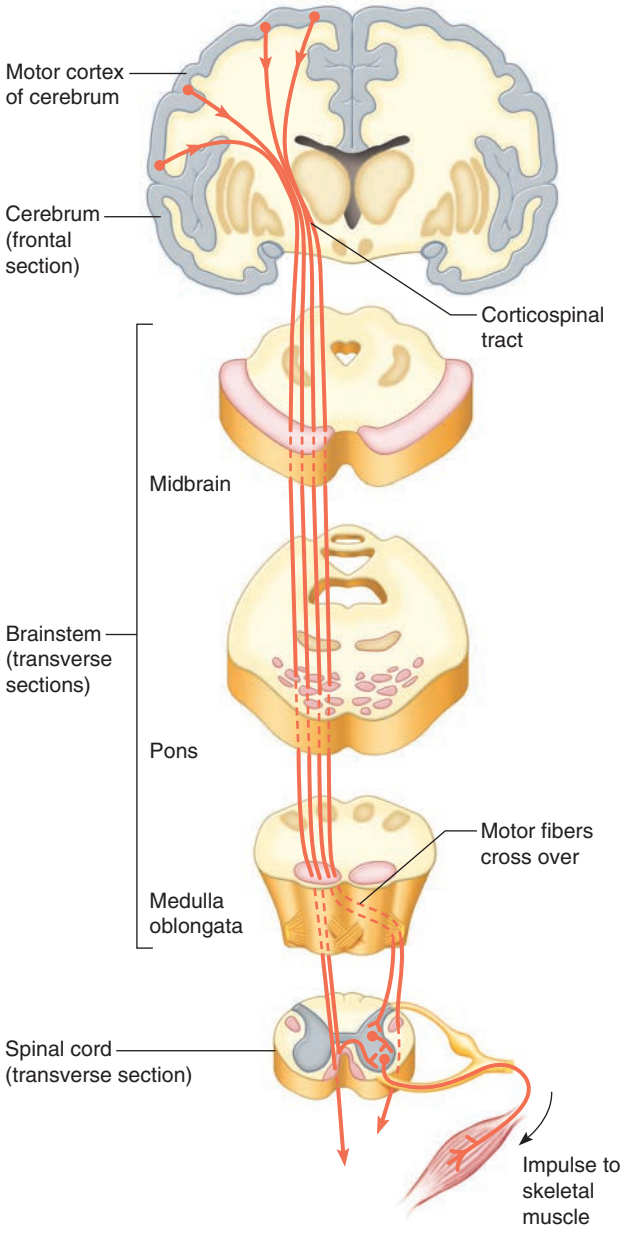
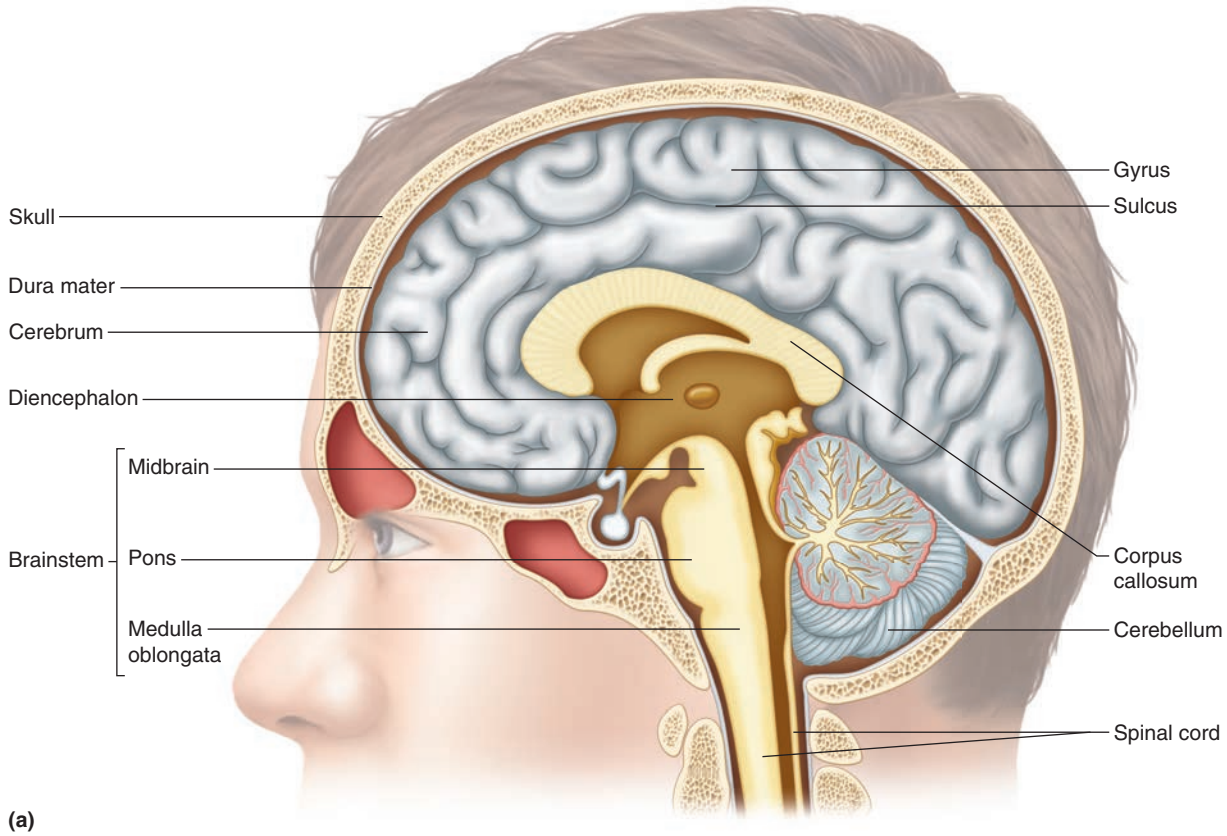


FIGURE 9.27 Descending tracts. Motor fibers of the corticospinal tract begin in the cerebral cortex, cross over in the medulla oblongata, and descend in the spinal cord. There, they synapse with neurons whose fibers lead to the spinal nerves that supply skeletal muscles.

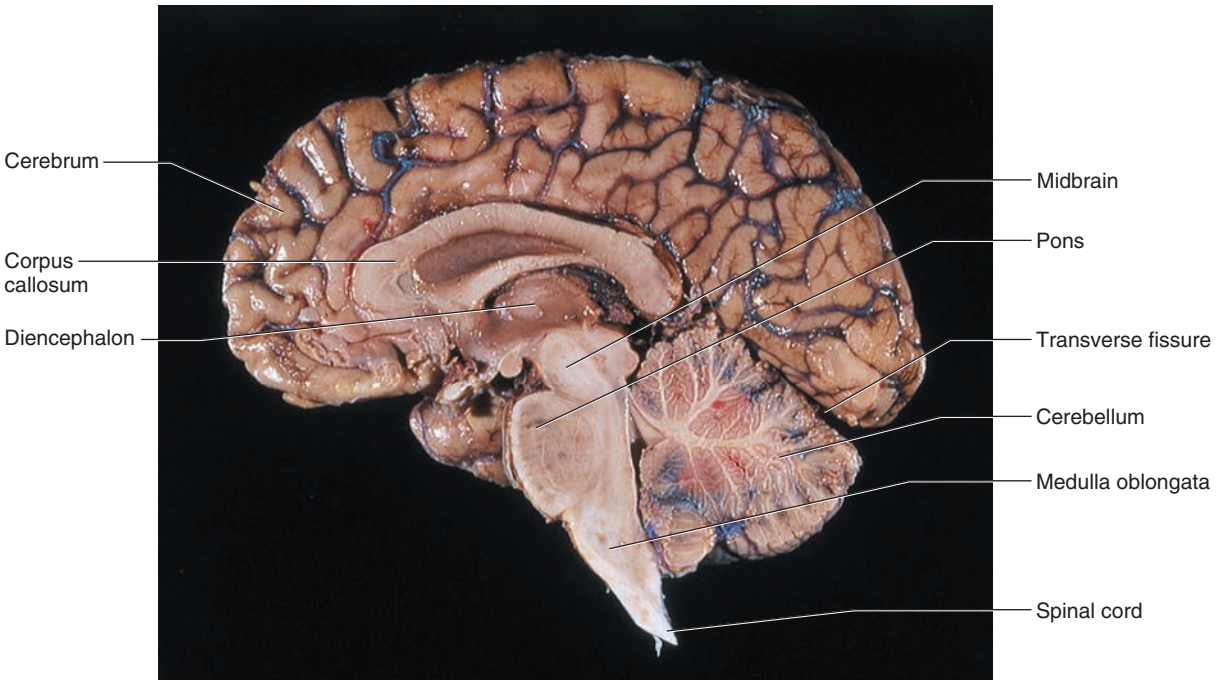
complex, but they form distinct patterns in all normal brains. For example, a *longitudinal fissure* separates the right and left cerebral hemispheres, a *transverse fissure* separates the cerebrum from the cerebellum, and several sulci divide each hemisphere into lobes.

The lobes of the cerebral hemispheres are named after the skull bones they underlie (fig. 9.29). They include:

1. **Frontal lobe** The frontal lobe forms the anterior part of each cerebral hemisphere. It is bordered posteriorly by a *central sulcus,* which extends from the longitudinal fissure at a right angle, and inferiorly by a *lateral sulcus,* which extends from the undersurface of the brain along its sides.
2. **Parietal lobe** The parietal lobe is posterior to the frontal lobe and separated from it by the central sulcus.
3. **Temporal lobe** The temporal lobe lies below the frontal and parietal lobes and is separated from them by the lateral sulcus.
4. **Occipital lobe** The occipital lobe forms the posterior part of each cerebral hemisphere and



(a)



(b)

FIGURE 9.28 AP|R The major portions of the brain are the cerebrum, the diencephalon, the brainstem, and the cerebellum. (**a** and **b**)

is separated from the cerebellum by a shelflike extension of dura mater (tentorium cerebelli). The boundary between the occipital lobe and the parietal and temporal lobes is not distinct.

5. **Insula** (in′su-lah) The insula is deep in the lateral sulcus and is covered by parts of the frontal, parietal, and temporal lobes. A *circular sulcus* separates the insula from the other lobes.

A thin layer of gray matter called the **cerebral cortex** (ser″ĕ-bral kor′teks) is the outermost part of the cerebrum. This layer covers the gyri and dips into the sulci and fissures. It contains nearly 75% of all the neuron cell bodies in the nervous system.

Just beneath the cerebral cortex is a mass of white matter that makes up the bulk of the cerebrum. This mass contains bundles of myelinated axons that connect neuron cell bodies of the cortex with other parts of the nervous system. Some of these fibers pass from one cerebral hemisphere to the other by way of the corpus callosum, and others carry sensory or motor impulses from parts of the cortex to nerve centers in the brain or spinal cord.

In a condition called lissencephaly, which means "smooth brain," sulci and gyri are absent. Lissencephaly is associated with intellectual disability, developmental delay, and seizures.

Functions of the Cerebrum

The cerebrum provides higher brain functions. It has centers for interpreting sensory impulses arriving from sense organs and centers for initiating voluntary muscular movements. The cerebrum stores the information that constitutes memory and utilizes it to reason. Intelligence and personality also stem from cerebral activity.

Functional Regions of the Cerebral Cortex

Specific regions of the cerebral cortex perform specific functions. Although functions overlap among regions, the cortex can be divided into sensory, association, and motor areas.

Sensory areas in several lobes of the cerebrum interpret impulses that arrive from sensory receptors, producing feelings or sensations. For example, sensations from all parts of the skin (cutaneous senses) arise in the anterior parts of the parietal lobes along the central sulcus (fig. 9.29). The posterior parts of the occipital lobes affect vision (visual area), and the temporal lobes contain the centers for hearing (auditory area). The sensory areas for taste are located near the bases of the central sulci along the lateral sulci, and the sense of smell arises from centers deep within the cerebrum.

Like motor fibers, sensory fibers cross over either in the spinal cord or in the brainstem (see fig. 9.26). Thus, the centers in the right cerebral hemisphere interpret impulses originating from the left side of the body, and vice versa.

Not all sensory areas are bilateral. The *sensory speech area* or *Wernicke's* (ver′nĭ-kēz) *area* is in the temporal lobe, adjacent to the parietal lobe near the posterior end of the lateral sulcus, usually in the left hemisphere. This area receives and relays input from both the visual cortex and auditory cortex and is important for understanding written or spoken language.

Association areas are neither primarily sensory nor primarily motor. They connect with one another and with other brain structures. Association areas analyze and interpret sensory experiences and oversee memory, reasoning, verbalizing, judgment, and emotion. Association areas occupy the anterior portions of the frontal lobes and are widespread in the lateral parts of the parietal, temporal, and occipital lobes (fig. 9.29).

The functions of the insula are not as well known as those of the other lobes, because its location deep within the cerebrum makes it impossible to study with surface electrodes. However, studies that use functional MRI scanning suggest that the insula serves as a crossroads for translating sensory information into appropriate emotional responses, such as feeling disgust at the sight of a cat regurgitating a hairball, or a feeling of joy when hearing a symphony or when biting into a slice of pizza. Some researchers hypothesize that the insula is, in some complex way, responsible for some of the qualities that make us human.

The association areas of the frontal lobes control a number of higher intellectual processes. These include concentrating, planning, complex problem solving, and judging the possible consequences of behavior. Association areas of the parietal lobes help in understanding speech and choosing words to express thoughts and feelings.

Wernicke's area corresponds closely to a brain region that has been referred to as a "general interpretive area," near where the occipital, parietal, and temporal lobes meet. It plays a role in integrating visual, auditory, and other sensory information, and then interpretating a situation. For example, you hear a familiar voice, look up from your notes, see a friend from class, and realize that it is time for your study group.

The association areas of the temporal lobes and the regions of the posterior ends of the lateral sulcus store memory of visual scenes, music, and other complex sensory patterns. Association areas of the occipital lobes that are adjacent to the visual centers are important in analyzing visual patterns and combining visual images with other sensory experiences, as when one recognizes another person or an object.

The primary **motor areas** of the cerebral cortex lie in the frontal lobes, just in front of the central sulcus (fig. 9.29). The nervous tissue in these regions contains many large *pyramidal cells,* named for their pyramid-shaped cell bodies. These cells are also termed *upper motor neurons,* because of their location.

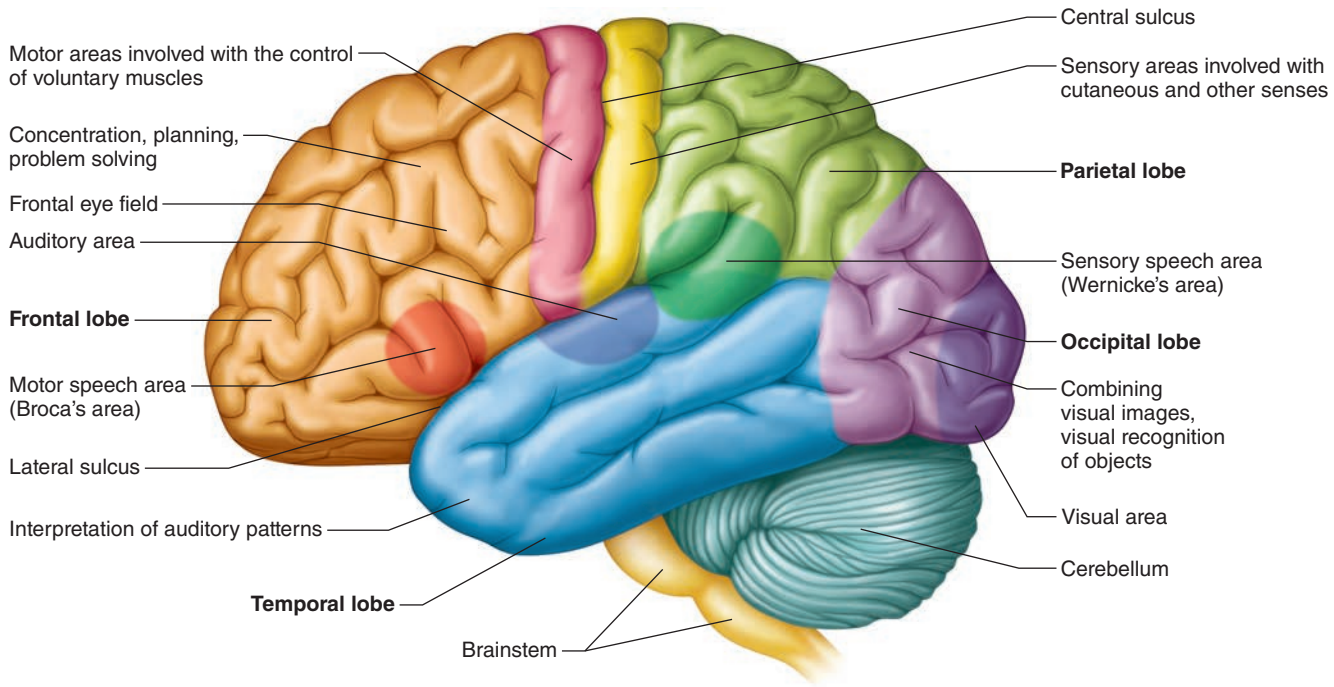


FIGURE 9.29 AP|R Some sensory, association, and motor areas of the left cerebral cortex.

Impulses from the pyramidal cells travel downward through the brainstem and into the spinal cord on the corticospinal tracts (see fig. 9.27). Here they form synapses with *lower motor neurons* whose axons leave the spinal cord and reach skeletal muscle fibers. Most of the axons in these tracts cross over from one side of the brain to the other within the brainstem. As a result, the motor area of the right cerebral hemisphere generally controls skeletal muscles on the left side of the body, and vice versa.

In addition to the primary motor areas, certain other regions of the frontal lobe affect motor functions. For example, a region called the *motor speech area,* or *Broca's* (bro′kahz) *area,* is usually in the left hemisphere, just anterior to the primary motor cortex and superior to the lateral sulcus. This area generates the movements of muscles necessary for speech (fig. 9.29).

Above the motor speech area is a region called the *frontal eye field.* The motor cortex in this area controls voluntary movements of the eyes and eyelids. Another region just in front of the primary motor area controls the muscular movements of the hands and fingers that make skills such as writing possible.

PRACTICE

36. List the major divisions of the brain.
37. Describe the cerebral cortex.
38. Describe the major functions of the cerebrum.
39. Locate the major functional regions of the cerebral cortex.

The effects of injuries to the cerebral cortex depend on the location and extent of the damage. For example, injury to the motor areas of one frontal lobe causes partial or complete paralysis on the opposite side of the body. Damage to the association areas of the frontal lobe may impair concentration on complex mental tasks, making a person appear disorganized and easily distracted. Damage to association areas of the temporal lobes may impair recognition of printed words or arranging words into meaningful thoughts.

Hemisphere Dominance

Both cerebral hemispheres participate in basic functions, such as receiving and analyzing sensory impulses, controlling skeletal muscles, and storing memory. However, in most persons, one side of the cerebrum is the **dominant hemisphere,** controlling the ability to use and understand language.

In most people the left hemisphere is dominant for the language-related activities of speech, writing, and reading, and for complex intellectual functions requiring verbal, analytical, and computational skills. In other persons, the right hemisphere is dominant for language-related abilities, or the hemispheres are equally dominant. Broca's area in the dominant hemisphere controls the muscles that function in speaking.

In addition to carrying on basic functions, the nondominant hemisphere specializes in nonverbal functions, such as motor tasks that require orientation of the body in space, understanding and interpreting musical

patterns, and nonverbal visual experiences. The nondominant hemisphere also controls emotional and intuitive thinking.

Nerve fibers of the corpus callosum, which connect the cerebral hemispheres, allow the dominant hemisphere to control the motor cortex of the nondominant hemisphere (see fig. 9.28). These fibers also transfer sensory information reaching the nondominant hemisphere to the dominant one, where the information can be used in decision making.

Deep within each cerebral hemisphere are several masses of gray matter called **basal nuclei**, also called basal ganglia (fig. 9.30). They are the *caudate nucleus,* the *putamen,* and the *globus pallidus.* The basal nuclei produce the inhibitory neurotransmitter *dopamine.* The neurons of the basal nuclei interact with other brain areas, including the motor cortex, thalamus, and cerebellum. These interactions, through a combination of stimulation and inhibition, facilitate voluntary movement.

The signs of Parkinson disease and Huntington disease result from altered activity of basal nuclei neurons. In Parkinson disease, nearby neurons release less dopamine, and the basal nuclei become overactive, inhibiting movement. In Huntington disease, basal nuclei neurons gradually deteriorate, resulting in unrestrained movement.

Ventricles and Cerebrospinal Fluid

Interconnected cavities called **ventricles** lie within the cerebral hemispheres and brainstem (fig. 9.31). These spaces are continuous with the central canal of the spinal cord, and like it, they contain cerebrospinal fluid.

The largest ventricles are the *lateral ventricles* (first and second ventricles), which extend into the cerebral hemispheres and occupy parts of the frontal, temporal, and occipital lobes. A narrow space that constitutes the *third ventricle* is in the midline of the brain, beneath the corpus callosum. This ventricle communicates with the lateral ventricles through openings (interventricular foramina) in its anterior end. The *fourth ventricle* is in the brainstem just anterior to the cerebellum. A narrow canal, the *cerebral aqueduct,* connects it to the third ventricle and passes lengthwise through the brainstem. The fourth ventricle is continuous with the central canal of the spinal cord and has openings in its roof that lead into the subarachnoid space of the meninges.

Tiny, reddish, cauliflower-like masses of specialized capillaries from the pia mater, called **choroid plexuses** (plek′sus-ez), secrete cerebrospinal fluid (fig. 9.32). These structures project into the ventricles. Most of the cerebrospinal fluid is formed in the lateral ventricles. From there, it circulates slowly into the third and fourth ventricles and into the central canal of the spinal cord. Cerebrospinal fluid also enters the subarachnoid space of the meninges through the wall of the fourth ventricle near the cerebellum and completes its circuit by being reabsorbed into the blood.

Cerebrospinal fluid completely surrounds the brain and spinal cord because it occupies the subarachnoid space of the meninges. In effect, these organs float in the fluid, which supports and protects them by absorbing forces that might otherwise jar and damage them. Cerebrospinal fluid also maintains a stable ionic concentration in the CNS and provides a pathway to the blood for wastes.

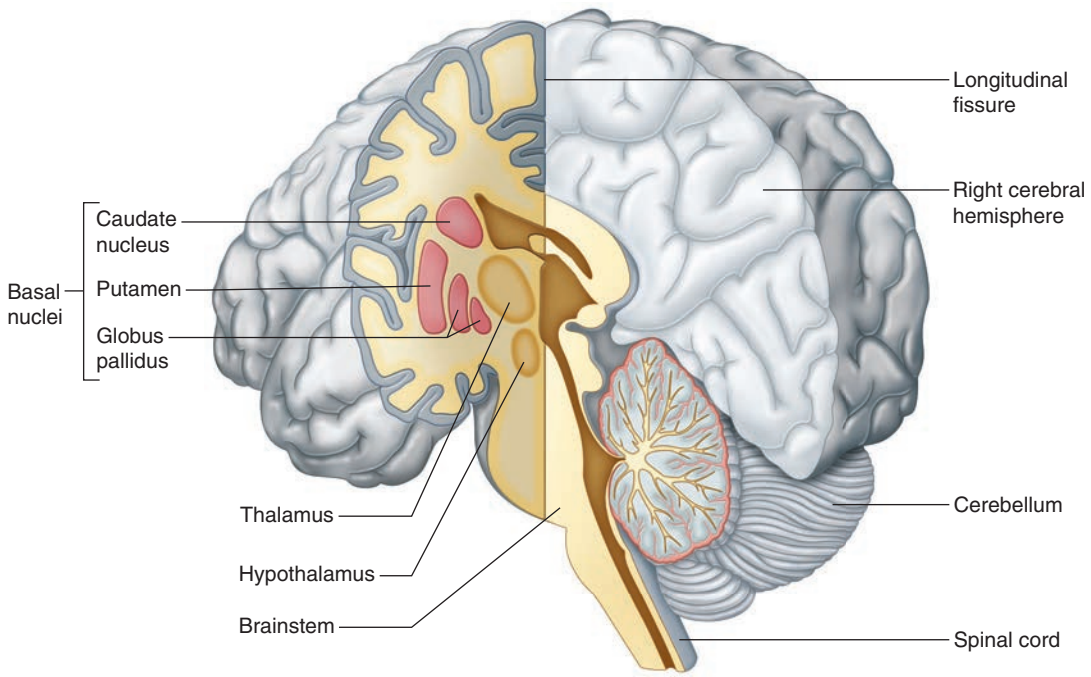


FIGURE 9.30 AP|R A frontal (coronal) section of the left cerebral hemisphere (posterior view) reveals some of the basal nuclei.

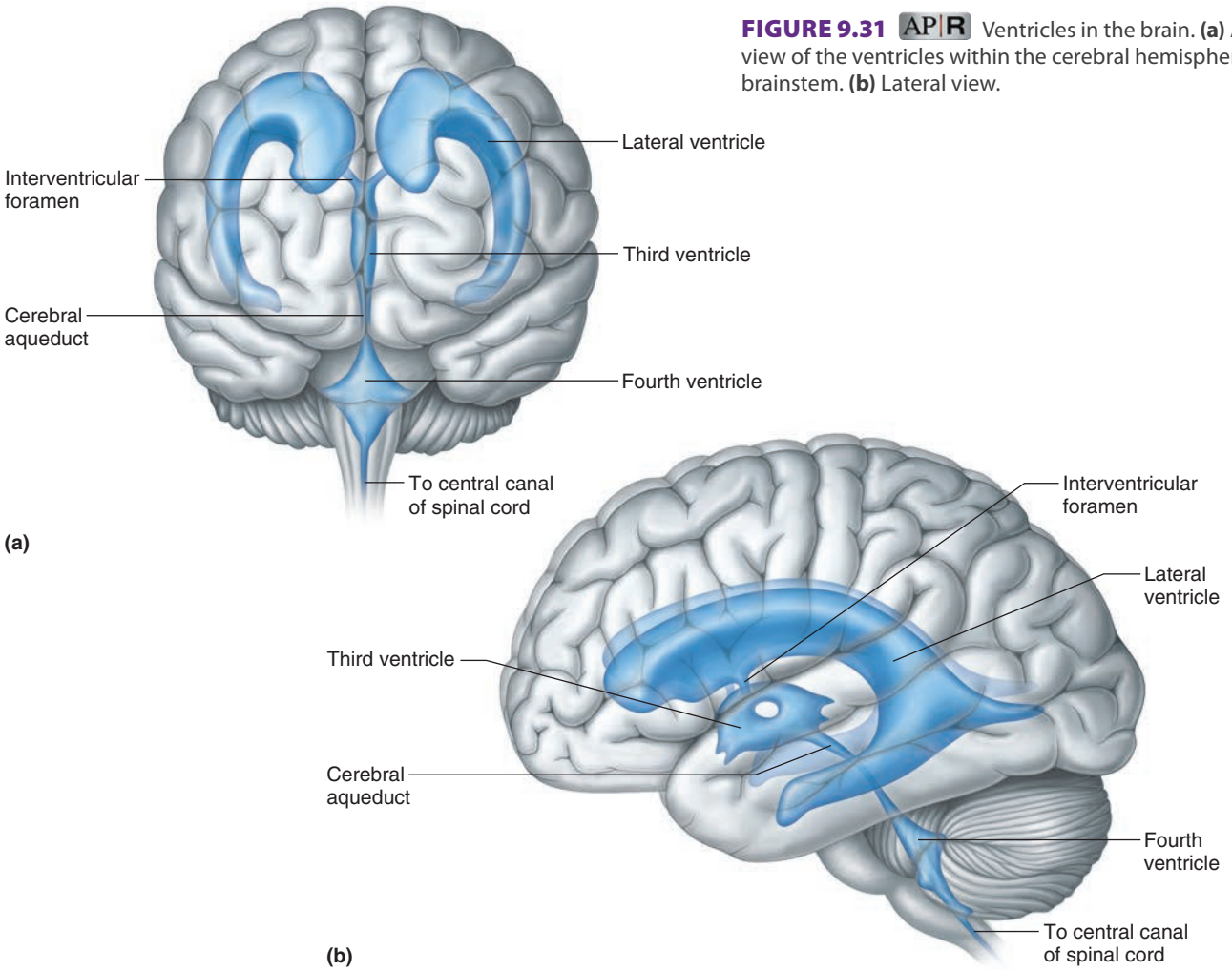


FIGURE 9.31 AP|R Ventricles in the brain. **(a)** Anterior view of the ventricles within the cerebral hemispheres and brainstem. **(b)** Lateral view.

The fluid pressure in the ventricles normally remains relatively constant because cerebrospinal fluid is secreted and reabsorbed continuously and at equal rates. An infection, a tumor, or a blood clot can interfere with fluid circulation, increasing pressure in the ventricles and thus in the cranial cavity (intracranial pressure). This can injure the brain by forcing it against the rigid skull.

A *lumbar puncture* (spinal tap) measures the pressure of cerebrospinal fluid. A very thin hollow needle is inserted into the subarachnoid space between the third and fourth or between the fourth and fifth lumbar vertebrae and an instrument called a *manometer* measures the pressure.

PRACTICE

40. What is hemisphere dominance?
41. What are the major functions of the dominant hemisphere? The nondominant one?
42. Where are the ventricles of the brain?
43. Describe the circulation of cerebrospinal fluid.

Diencephalon

The **diencephalon** (di″en-sef′ah-lon) is located between the cerebral hemispheres and above the midbrain. It surrounds the third ventricle and is composed largely of gray matter. Within the diencephalon, a dense mass called the **thalamus** bulges into the third ventricle from each side (see figs. 9.30 and 9.33*b*). Another region of the diencephalon that includes many nuclei (masses of gray matter) is the **hypothalamus.** It lies below the thalamus and forms the lower walls and floor of the third ventricle.

The thalamus is a central relay station for sensory impulses ascending from other parts of the nervous system to the cerebral cortex. It receives all sensory impulses (except those associated with the sense of smell) and channels them to the appropriate regions of the cortex for interpretation. In addition, all regions of the cerebral cortex can communicate with the thalamus by means of descending fibers. The cerebral cortex pinpoints the origin of sensory stimulation, and the thalamus produces a general awareness of certain sensations, such as pain, touch, and temperature.

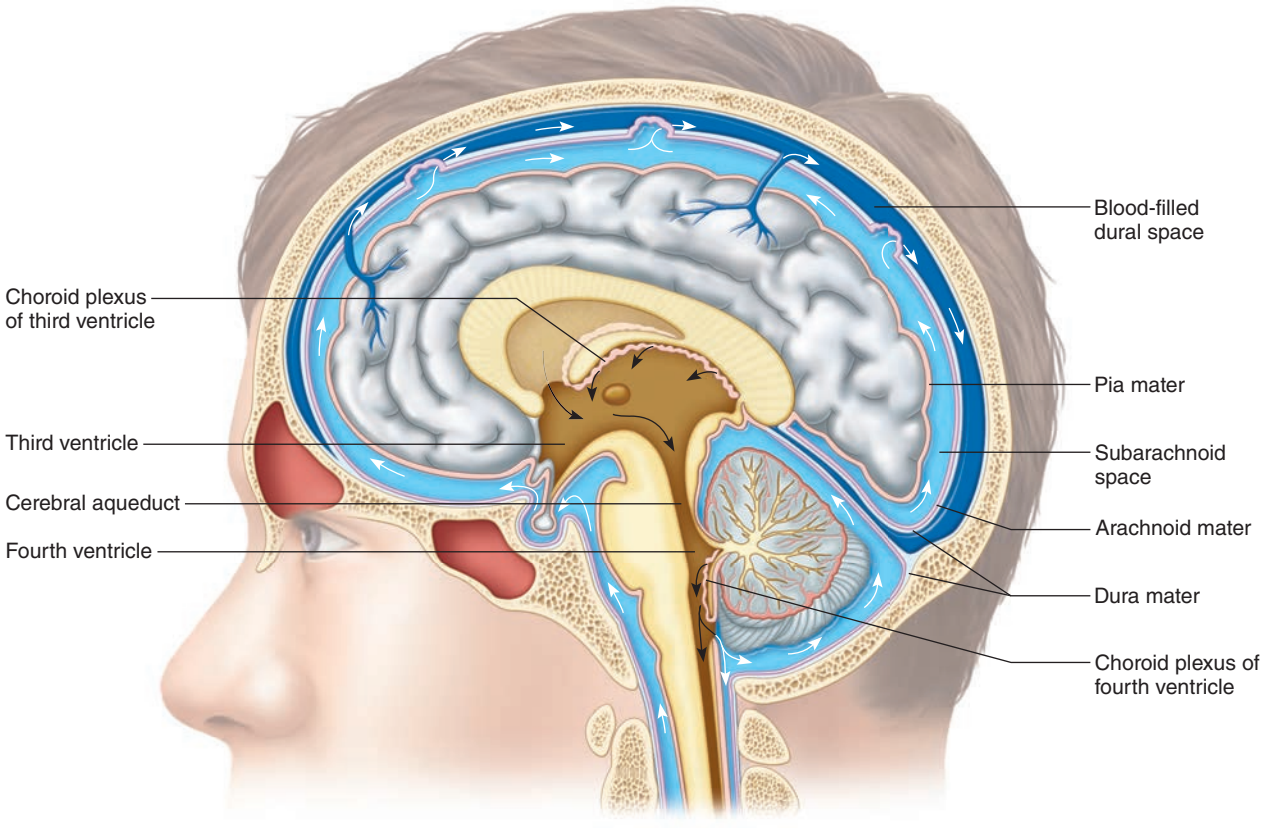


FIGURE 9.32 AP|R The choroid plexuses in the walls of the ventricles secrete cerebrospinal fluid. The fluid circulates through the ventricles and central canal, enters the subarachnoid space, and is reabsorbed into the blood.

Nerve fibers connect the hypothalamus to the cerebral cortex, thalamus, and other parts of the brainstem. The hypothalamus maintains homeostasis by regulating a variety of visceral activities and by linking the nervous and endocrine systems. The hypothalamus regulates:

1. Heart rate and arterial blood pressure
2. Body temperature
3. Water and electrolyte balance
4. Control of hunger and body weight
5. Control of movements and glandular secretions of the stomach and intestines
6. Production of neurosecretory substances that stimulate the pituitary gland to secrete hormones
7. Sleep and wakefulness

Structures in the general region of the diencephalon also control emotional responses. For example, regions of the cerebral cortex in the medial parts of the frontal and temporal lobes interconnect with a number of deep masses of gray matter, including the hypothalamus, thalamus, and basal nuclei. Together, these structures compose a complex called the **limbic system.**

The limbic system controls emotional experience and expression. It can modify the way a person acts by producing such feelings as fear, anger, pleasure, and sorrow. The limbic system recognizes upsets in a person's physical or psychological condition that might threaten life. By causing pleasant or unpleasant feelings about experiences, the limbic system guides a person into behavior that is likely to increase the chance of survival.

A whiff of a certain scent may elicit vivid memories because sensory information from olfactory receptors (the sense of smell) also goes to the limbic system. Olfactory input to the limbic system is also why odors can alter mood. For example, the scent of just-mowed grass or an ocean breeze makes us feel good.

Other parts of the diencephalon include: (1) the **optic tracts** and the **optic chiasma** that is formed by optic nerve fibers crossing over each other; (2) the **infundibulum,** a conical process behind the optic chiasma to which the pituitary gland attaches; (3) the **posterior pituitary gland,** which hangs from the floor of the hypothalamus; (4) the **mammillary bodies,** which appear as two rounded structures behind the infundibulum; and (5) the **pineal gland** (pin′e-al gland), a cone-shaped structure attached to the upper part of the diencephalon (see chapter 11, p. 320).

Brainstem

The **brainstem** is a bundle of nervous tissue that connects the cerebrum to the spinal cord. It consists of many tracts and several nuclei. The parts of the brainstem include the midbrain, pons, and medulla oblongata (figs. 9.28 and 9.33).

Midbrain

The **midbrain** is a short section of the brainstem between the diencephalon and the pons (see fig. 9.28). It contains bundles of myelinated axons that join lower parts of the brainstem and spinal cord with higher parts of the brain. Two prominent bundles of axons on the underside of the midbrain are the corticospinal tracts and are the main motor pathways between the cerebrum and lower parts of the nervous system.

The midbrain includes several masses of gray matter that serve as reflex centers. For example, the midbrain contains the centers for certain visual reflexes, such as those responsible for moving the eyes to view something as the head turns. It also contains the auditory reflex centers that enable a person to move the head to hear sounds more distinctly.

Pons

The **pons** (ponz) is a rounded bulge on the underside of the brainstem, where it separates the midbrain from the medulla oblongata (see fig. 9.28). The dorsal part of the pons consists largely of longitudinal nerve fibers, which relay impulses to and from the medulla oblongata and the cerebrum. The ventral part of the pons has large bundles of transverse nerve fibers, which transmit impulses from the cerebrum to centers in the cerebellum.

Several nuclei of the pons relay sensory impulses from peripheral nerves to higher brain centers. Other nuclei may contribute to the rhythm of breathing (see chapter 16, p. 469).

Medulla Oblongata

The **medulla oblongata** (mĕ-dul′ah ob″long-gah′tah) extends from the pons to the foramen magnum of the skull (see fig. 9.28). Its dorsal surface flattens to form the floor of the fourth ventricle, and its ventral surface is marked by the corticospinal tracts, most of whose fibers cross over at this level (see fig. 9.27).

All of the ascending and descending nerve fibers connecting the brain and spinal cord must pass through the medulla oblongata because of its location. In the spinal cord the white matter surrounds a central mass of gray matter. Here in the medulla oblongata, however, nerve fibers separate the gray matter into nuclei, some of which relay ascending impulses to the other side of the brainstem and then on to higher brain centers.

Other nuclei in the medulla oblongata control vital visceral activities. These centers include:

1. **Cardiac center** Impulses originating in the cardiac center are transmitted to the heart on peripheral nerves, altering heart rate.
2. **Vasomotor center** Certain cells of the vasomotor center initiate impulses that travel to smooth muscle in the walls of certain blood vessels and stimulate the smooth muscle to contract. This constricts the blood vessels (vasoconstriction), maintaining blood pressure. Other cells of the vasomotor center produce the opposite effect—dilating blood vessels (vasodilation) and consequently dropping blood pressure.
3. **Respiratory center** The respiratory center maintains breathing rhythm and adjusts the rate and depth of breathing.

Still other nuclei in the medulla oblongata are centers for the reflexes associated with coughing, sneezing, swallowing, and vomiting.

Reticular Formation

Scattered throughout the medulla oblongata, pons, and midbrain is a complex network of nerve fibers associated with tiny islands of gray matter. This network, the **reticular formation** (rĕ-tik′u-lar for-ma′shun), also called the reticular activating system, extends from the upper part of the spinal cord into the diencephalon. Its nerve fibers join centers of the hypothalamus, basal nuclei, cerebellum, and cerebrum with fibers in all the major ascending and descending tracts.

When sensory impulses reach the reticular formation, it responds by activating the cerebral cortex into a state of wakefulness. Without this arousal, the cortex remains unaware of stimulation and cannot interpret sensory information or carry on thought processes. Thus, decreased activity in the reticular formation results in sleep. If the reticular formation is injured so that it cannot function, the person remains unconscious and cannot be aroused, even with strong stimulation. This is called a comatose state. Barbiturate drugs, which dampen CNS activity, affect the reticular formation (see Clinical Application 9.2).

PRACTICE

44. What are the major functions of the thalamus? The hypothalamus?
45. How may the limbic system influence behavior?
46. List the structures of the brainstem.
47. Which vital reflex centers are in the brainstem?
48. What is the function of the reticular formation?

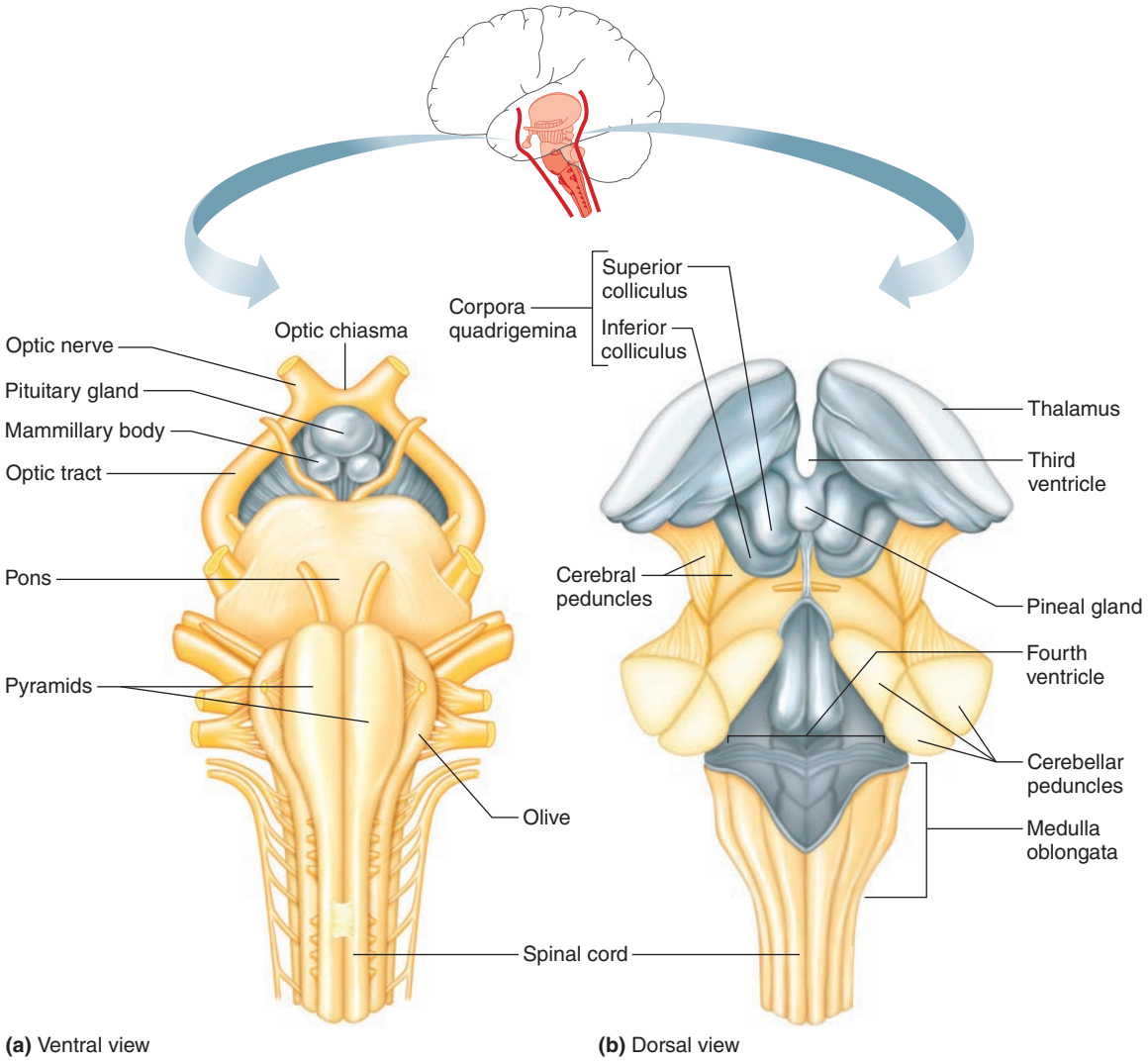


FIGURE 9.33 AP|R The brainstem. **(a)** Ventral view of the brainstem. **(b)** Dorsal view of the brainstem with the cerebellum removed, exposing the fourth ventricle.

What is the relative position of the fourth ventricle to the third ventricle?
Answer can be found in Appendix F on page 582.

Cerebellum

The **cerebellum** (ser″ĕ-bel′um) is a large mass of tissue located below the occipital lobes of the cerebrum and posterior to the pons and medulla oblongata (see fig. 9.28). It consists of two lateral hemispheres partially separated by a layer of dura mater (falx cerebelli) and connected in the midline by a structure called the *vermis*. Like the cerebrum, the cerebellum is composed primarily of white matter, with a thin layer of gray matter, the **cerebellar cortex,** on its surface.

The cerebellum communicates with other parts of the CNS by means of three pairs of nerve tracts called *cerebellar peduncles* (figs. 9.33 and 9.34). One pair (the inferior peduncles) brings sensory information concerning the position of the limbs, joints, and other body parts to the cerebellum. Another pair (the middle peduncles) transmits signals from the cerebral cortex to the cerebellum concerning the desired positions of these parts. After integrating and analyzing this information, the cerebellum sends correcting impulses via a third pair (the superior peduncles) to the midbrain. These corrections are incorporated into motor impulses that travel downward through the pons, medulla oblongata, and spinal cord in the appropriate patterns to move the body in the desired way.

The cerebellum is a reflex center for integrating sensory information concerning the position of body parts and for coordinating complex skeletal muscle movements. It also helps maintain posture. Damage to the cerebellum is likely to result in tremors, inaccurate movements of voluntary muscles, loss of muscle tone, a reeling walk, and loss of equilibrium.

CLINICAL APPLICATION 9.2
Drug Abuse

Drug abuse is the chronic self-administration of a drug in doses high enough to cause *addiction*—a physical or psychological dependence in which the user is preoccupied with locating and taking the drug. Stopping drug use causes intense, unpleasant withdrawal symptoms. Prolonged and repeated abuse of a drug may also result in *drug tolerance,* in which the physiological response to a particular dose of the drug becomes less intense over time. Drug tolerance results as the drug increases synthesis of certain liver enzymes, which metabolize the drug more rapidly, so that the addict needs the next dose sooner. Drug tolerance also arises from physiological changes that lessen the drug's effect on its target cells. The most commonly abused drugs are CNS depressants ("downers"), CNS stimulants ("uppers"), hallucinogens, and anabolic steroids (see Clinical Application 8.1, p. 198).

CNS depressants include barbiturates, benzodiazepines, opiates, and cannabinoids. *Barbiturates* act uniformly throughout the brain, but the reticular formation is particularly sensitive to their effects. CNS depression occurs due to inhibited secretion of certain excitatory and inhibitory neurotransmitters. Effects range from mild calming of the nervous system (sedation) to sleep, loss of sensory sensations (anesthesia), respiratory distress, cardiovascular collapse, and death.

The *benzodiazepines,* such as diazepam, depress activity in the limbic system and the reticular formation. Low doses relieve anxiety, and higher doses cause sedation, sleep, or anesthesia. These drugs increase either the activity or release of the inhibitory neurotransmitter GABA. When benzodiazepines are metabolized, they may form other biochemicals that have depressing effects.

The *opiates* include heroin (which has no legal use in the United States), codeine, morphine, meperidine, and methadone. These drugs stimulate certain receptors (opioid receptors) in the CNS, and when taken in prescribed dosages, they sedate and relieve pain (analgesia). Opiates cause both physical and psychological dependence. Effects of overdose include a feeling of well-being (euphoria), respiratory distress, convulsions, coma, and possible death. On the other hand, these drugs are very important in treating chronic, severe pain. For example, cancer patients find pain relief with oxycodone, which is taken twice daily in a timed-release pill.

The *cannabinoids* include marijuana and hashish, both derived from the hemp plant. Hashish is several times more potent than marijuana. These drugs depress higher brain centers and release lower brain centers from the normal inhibitory influence of the higher centers. This induces an anxiety-free state, characterized by euphoria and a distorted perception of time and space. *Hallucinations* (sensory perceptions that have no external stimuli), respiratory distress, and vasomotor depression may occur with higher doses.

CNS stimulants include amphetamines and cocaine (including "crack"). These drugs have great abuse potential and may quickly produce psychological dependence. Cocaine, especially when smoked or inhaled, produces euphoria but may also change personality, cause seizures, and constrict certain blood vessels, leading to sudden death from stroke or cardiac arrhythmia. Cocaine's very rapid effect, and perhaps its addictiveness, reflect its rapid entry and metabolism in the brain. Cocaine arrives at the basal nuclei in four to six minutes and is mostly cleared within thirty minutes. The drug inhibits transporter molecules that remove dopamine from synapses after it is released. "Ecstasy" is a type of amphetamine.

Hallucinogens alter perceptions. They cause *illusions,* which are distortions of vision, hearing, taste, touch, and smell; *synesthesia,* such as "hearing" colors or "feeling" sounds; and hallucinations. The most commonly abused and most potent hallucinogen is lysergic acid diethylamide (LSD). LSD may act as an excitatory neurotransmitter. Persons under the influence of LSD may greatly overestimate their physical capabilities, such as believing they can fly off the top of a high building. Phencyclidine (PCP) is another abused hallucinogen. Its use can lead to prolonged psychosis that may provoke assault, murder, and suicide.

A traumatic brain injury (TBI) results from mechanical force. Mild TBI, also called a concussion, causes loss of consciousness or altered mental status. Disturbed sleep and problems with memory and balance may follow. A concussion is a temporary condition. However, repeated blows to the head, as can occur in playing football, can cause chronic traumatic encephalopathy. This more serious condition can lead to depression, headaches, and dementia. Severe TBI occurs in combat situations and is also called "blast-related brain injury." It may affect cognition (thinking) many years later.

PRACTICE

49. Where is the cerebellum located?
50. What are the major functions of the cerebellum?

9.15 | Peripheral Nervous System

The peripheral nervous system (PNS) consists of nerves that branch from the CNS and connect it to other body parts. The PNS includes the cranial nerves, which arise

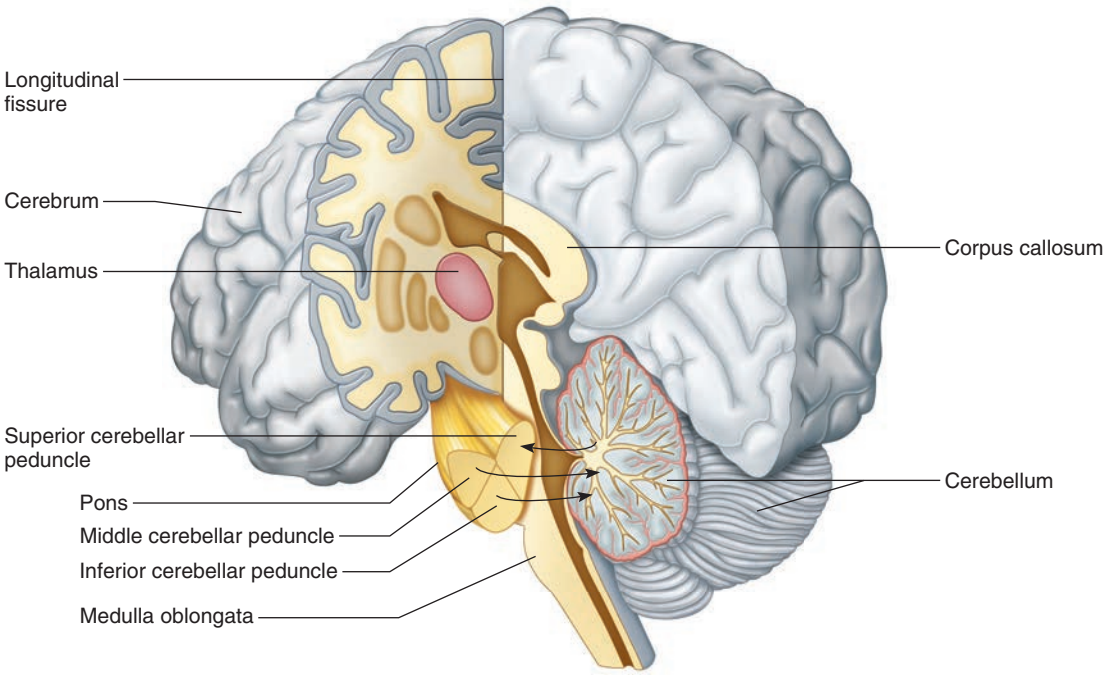


FIGURE 9.34 AP|R The cerebellum, which is located below the occipital lobes of the cerebrum, communicates with other parts of the nervous system by means of the cerebellar peduncles.

from the brain, and the spinal nerves, which arise from the spinal cord.

The PNS can also be subdivided into the somatic and autonomic nervous systems. Generally, the **somatic** (so-mat′ik) **nervous system** consists of the cranial and spinal nerve fibers that connect the CNS to the skin and skeletal muscles; it oversees conscious activities. The **autonomic** (aw″to-nom′ik) **nervous system** includes fibers that connect the CNS to viscera, such as the heart, stomach, intestines, and glands; it controls unconscious activities. Table 9.5 outlines the subdivisions of the nervous system (see fig. 9.2).

Cranial Nerves

Twelve pairs of **cranial nerves** arise from the underside of the brain (fig. 9.35). Except for the first pair, which begins in the cerebrum, these nerves originate from the brainstem. They pass from their sites of origin through foramina of the skull and lead to parts of the head, neck, and trunk.

Most of the cranial nerves are mixed nerves containing both sensory and motor nerve fibers, but some of those associated with special senses, such as smell and vision, contain only sensory fibers. Other cranial nerves that affect muscles and glands are composed primarily of motor fibers.

Sensory fibers present in the cranial nerves have neuron cell bodies that are outside the brain, usually in groups called *ganglia*. On the other hand, motor neuron cell bodies are typically in the gray matter of the brain.

Numbers or names designate the cranial nerves. The numbers indicate the order in which the nerves arise from the front to the back of the brain, and the names describe their primary functions or the general distribution of their fibers (fig. 9.35).

The first pair of cranial nerves, the **olfactory nerves (I),** are associated with the sense of smell and contain axons only of sensory neurons. These bipolar neurons, located in the lining of the upper nasal cavity, serve as *olfactory receptor cells.* Axons from these receptors pass upward through the cribriform plates of the ethmoid bone, carrying impulses to the olfactory neurons in the *olfactory bulbs,* which are extensions of the cerebral cortex just beneath the frontal lobes (see fig. 10.4, p. 279). Sensory impulses are conducted from the olfactory bulbs along *olfactory tracts* to cerebral centers, where they are interpreted. The result of this interpretation is the sensation of smell.

The second pair of cranial nerves, the **optic nerves (II),** lead from the eyes to the brain and are associated with vision. The sensory nerve cell bodies of these nerve fibers

TABLE 9.5 Subdivisions of the Nervous System

1. Central nervous system (CNS)
   a. Brain
   b. Spinal cord
2. Peripheral nervous system (PNS)
   a. Cranial nerves arising from the brain and brainstem
      (1) Somatic fibers connecting to skin and skeletal muscles
      (2) Autonomic fibers connecting to viscera
   b. Spinal nerves arising from the spinal cord
      (1) Somatic fibers connecting to skin and skeletal muscles
      (2) Autonomic fibers connecting to viscera

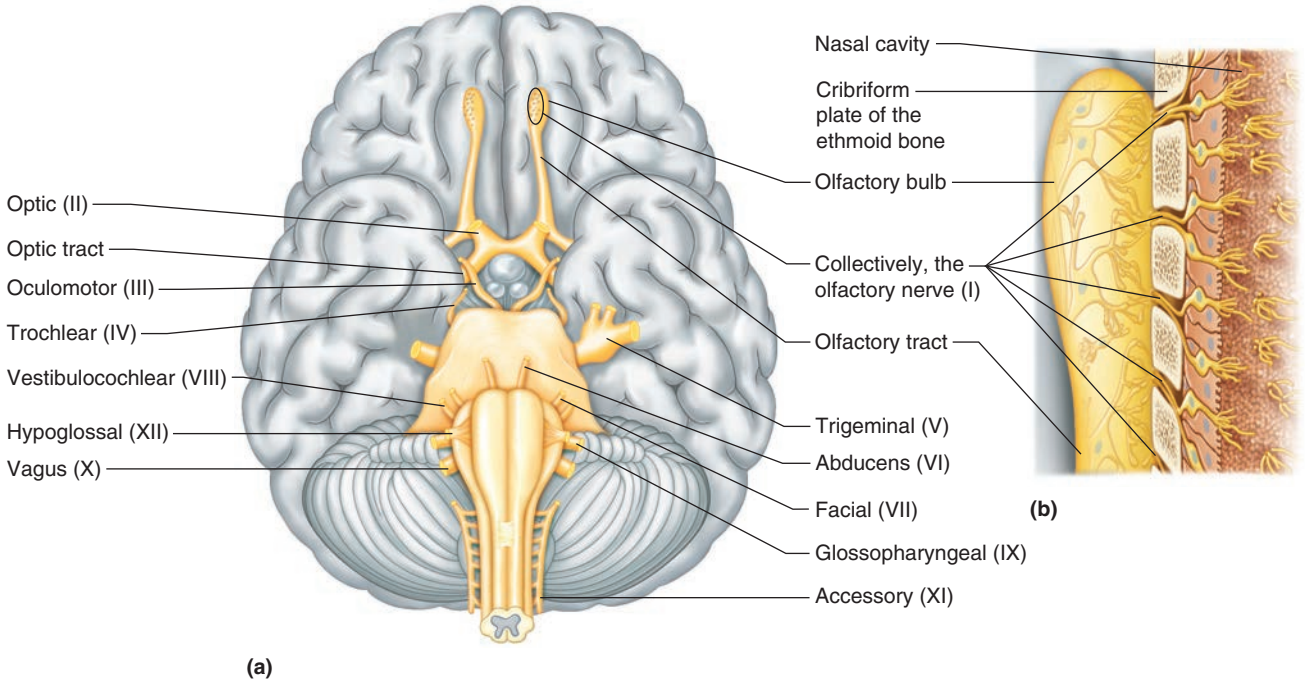


FIGURE 9.35 AP|R The cranial nerves, except for the first pair, arise from the brainstem. **(a)** They are identified by numbers indicating their order, by their function, or by the general distribution of their fibers. **(b)** The collection of nerve fibers passing through the cribriform plate comprise the olfactory nerve (I).

are in ganglion cell layers in the eyes, and their axons pass through the *optic foramina* of the orbits and continue into the visual nerve pathways of the brain (see chapter 10, pp. 297–298). Sensory impulses conducted on the optic nerves are interpreted in the visual cortices of the occipital lobes.

The third pair of cranial nerves, the **oculomotor nerves (III),** arise from the midbrain and pass into the orbits of the eyes. One component of each nerve connects to the voluntary muscles that raise the eyelid and to four of the six muscles that move the eye. A second component of each oculomotor nerve is part of the autonomic nervous system and innervates involuntary muscles in the eyes. These muscles adjust the amount of light entering the eyes and focus the lenses.

The fourth pair of cranial nerves, the **trochlear nerves (IV),** arise from the midbrain and are the smallest cranial nerves. Each nerve conducts motor impulses to a fifth voluntary muscle that moves the eye and is not innervated by the oculomotor nerve.

The fifth pair of cranial nerves, the **trigeminal nerves (V),** are the largest cranial nerves and arise from the pons. They are mixed nerves, with the sensory parts more extensive than the motor parts. Each sensory component includes three large branches, called the ophthalmic, maxillary, and mandibular divisions.

The *ophthalmic division* of the trigeminal nerves consists of sensory fibers that conduct impulses to the brain from the surface of the eyes, the tear glands, and the skin of the anterior scalp, forehead, and upper eyelids. The fibers of the *maxillary division* conduct sensory impulses from the upper teeth, upper gum, and upper lip, as well as from the mucous lining of the palate and the skin of the face. The *mandibular division* includes both motor and sensory fibers. The sensory branches conduct impulses from the scalp behind the ears, the skin of the jaw, the lower teeth, the lower gum, and the lower lip. The motor branches innervate the muscles of mastication and certain muscles in the floor of the mouth.

The sixth pair of cranial nerves, the **abducens nerves (VI),** are quite small and originate from the pons near the medulla oblongata. Each nerve enters the orbit of the eye and innervates motor impulses to the remaining muscle that moves the eye.

The seventh pair of cranial nerves, the **facial nerves (VII),** arise from the lower part of the pons and emerge on the sides of the face. Their sensory branches are associated with taste receptors on the anterior two-thirds of the tongue, and some of their motor fibers conduct impulses to the muscles of facial expression. Still other motor fibers of these nerves function in the autonomic nervous system and stimulate secretions from tear glands and salivary glands.

The eighth pair of cranial nerves, the **vestibulocochlear nerves (VIII),** are sensory nerves that arise from the medulla oblongata. Each of these nerves has two distinct parts—a vestibular branch and a cochlear branch.

The neuron cell bodies of the *vestibular branch* fibers are located in ganglia associated with parts of the inner ear. These parts contain the receptors involved with reflexes that help maintain equilibrium. The neuron cell bodies of the *cochlear branch* fibers are located in the parts of the inner ear that house the hearing receptors. Information from these branches reaches the

medulla oblongata and midbrain on its way to the temporal lobes, where it is interpreted.

The ninth pair of cranial nerves, the **glossopharyngeal nerves (IX),** are associated with the tongue and pharynx. These mixed nerves arise from the medulla oblongata, with predominantly sensory fibers. These sensory fibers conduct impulses from the linings of the pharynx, tonsils, and posterior third of the tongue to the brain. Fibers in the motor component innervate muscles of the pharynx that function in swallowing.

The tenth pair of cranial nerves, the **vagus nerves (X),** originate in the medulla oblongata and extend downward through the neck into the chest and abdomen. These nerves are mixed, containing both somatic and autonomic branches, with autonomic fibers predominant. Certain somatic motor fibers conduct impulses to muscles of the larynx that are associated with speech and swallowing. Autonomic motor fibers of the vagus nerves innervate the heart, smooth muscle, and glands in the thorax and abdomen.

The eleventh pair of cranial nerves, the **accessory nerves (XI),** originate in the medulla oblongata and the spinal cord; thus, they have both cranial and spinal branches. Each *cranial branch* joins a vagus nerve and conducts impulses to muscles of the soft palate, pharynx, and larynx. The *spinal branch* descends into the neck and innervates motor fibers to the trapezius and sternocleidomastoid muscles.

The twelfth pair of cranial nerves, the **hypoglossal nerves (XII),** arise from the medulla oblongata and pass into the tongue. They include motor fibers that conduct impulses to muscles that move the tongue in speaking, chewing, and swallowing. Table 9.6 summarizes the functions of the cranial nerves.

PRACTICE

51. Define *peripheral nervous system.*
52. Distinguish between somatic and autonomic nerve fibers.
53. Name the cranial nerves, and list the major functions of each.

TABLE 9.6 Functions of Cranial Nerves AP|R

Nerve	Type	Function
I Olfactory	Sensory	Sensory fibers conduct impulses associated with the sense of smell.
II Optic	Sensory	Sensory fibers conduct impulses associated with the sense of vision.
III Oculomotor	Primarily motor	Motor fibers conduct impulses to muscles that raise eyelids, move eyes, adjust the amount of light entering the eyes, and focus lenses.
		Some sensory fibers conduct impulses associated with the condition of muscles.
IV Trochlear	Primarily motor	Motor fibers conduct impulses to muscles that move the eyes.
		Some sensory fibers conduct impulses associated with the condition of muscles.
V Trigeminal	Mixed	
Ophthalmic division		Sensory fibers conduct impulses from the surface of the eyes, tear glands, scalp, forehead, and upper eyelids.
Maxillary division		Sensory fibers conduct impulses from the upper teeth, upper gum, upper lip, lining of the palate, and skin of the face.
Mandibular division		Sensory fibers conduct impulses from the skin of the jaw, lower teeth, lower gum, and lower lip.
		Motor fibers conduct impulses to muscles of mastication and to muscles in the floor of the mouth.
VI Abducens	Primarily motor	Motor fibers conduct impulses to muscles that move the eyes.
		Some sensory fibers conduct impulses associated with the condition of muscles.
VII Facial	Mixed	Sensory fibers conduct impulses associated with taste receptors of the anterior tongue. Motor fibers conduct impulses to muscles of facial expression, tear glands, and salivary glands.
VIII Vestibulocochlear	Sensory	
Vestibular branch		Sensory fibers conduct impulses associated with the sense of equilibrium.
Cochlear branch		Sensory fibers conduct impulses associated with the sense of hearing.
IX Glossopharyngeal	Mixed	Sensory fibers conduct impulses from the pharynx, tonsils, posterior tongue, and carotid arteries.
		Motor fibers conduct impulses to muscles of the pharynx used in swallowing and to salivary glands.
X Vagus	Mixed	Somatic motor fibers conduct impulses to muscles associated with speech and swallowing; autonomic motor fibers conduct impulses to the heart, smooth muscle, and glands in the thorax and abdomen.
		Sensory fibers conduct impulses from the pharynx, larynx, esophagus, and viscera of the thorax and abdomen.
XI Accessory	Primarily motor	
Cranial branch		Motor fibers conduct impulses to muscles of the soft palate, pharynx, and larynx.
Spinal branch		Motor fibers conduct impulses to muscles of the neck and back.
XII Hypoglossal	Primarily motor	Motor fibers conduct impulses to muscles that move the tongue.

The consequences of a cranial nerve injury depend on the injury's location and extent. Damage to one member of a nerve pair will not cause a total loss of function, but injury to both nerves may. If a nerve is severed completely, functional loss of that nerve is total; if the cut is incomplete, loss may be partial.

Spinal Nerves

Thirty-one pairs of **spinal nerves** originate from the spinal cord (fig. 9.36). All but the first pair are mixed nerves that provide two-way communication between the spinal cord and parts of the upper and lower limbs, neck, and trunk.

Spinal nerves are not named individually, but are grouped according to the level from which they arise. Each nerve is numbered in sequence. On each vertebra the vertebral notches, the major parts of the intervertebral foramina, are associated with the inferior part of their respective vertebrae. For this reason, each spinal nerve, as it passes through the intervertebral foramen, is associated with the vertebra above it. The cervical spinal nerves are an exception, because spinal nerve C1 passes superior to the vertebra C1. Thus, although there are seven cervical vertebrae, there are eight pairs of *cervical nerves* (numbered C1 to C8). There are twelve pairs of *thoracic nerves* (numbered T1 to T12), five pairs of *lumbar nerves* (numbered L1 to L5), five pairs of *sacral nerves* (numbered S1 to S5), and one pair of *coccygeal nerves* (Co).

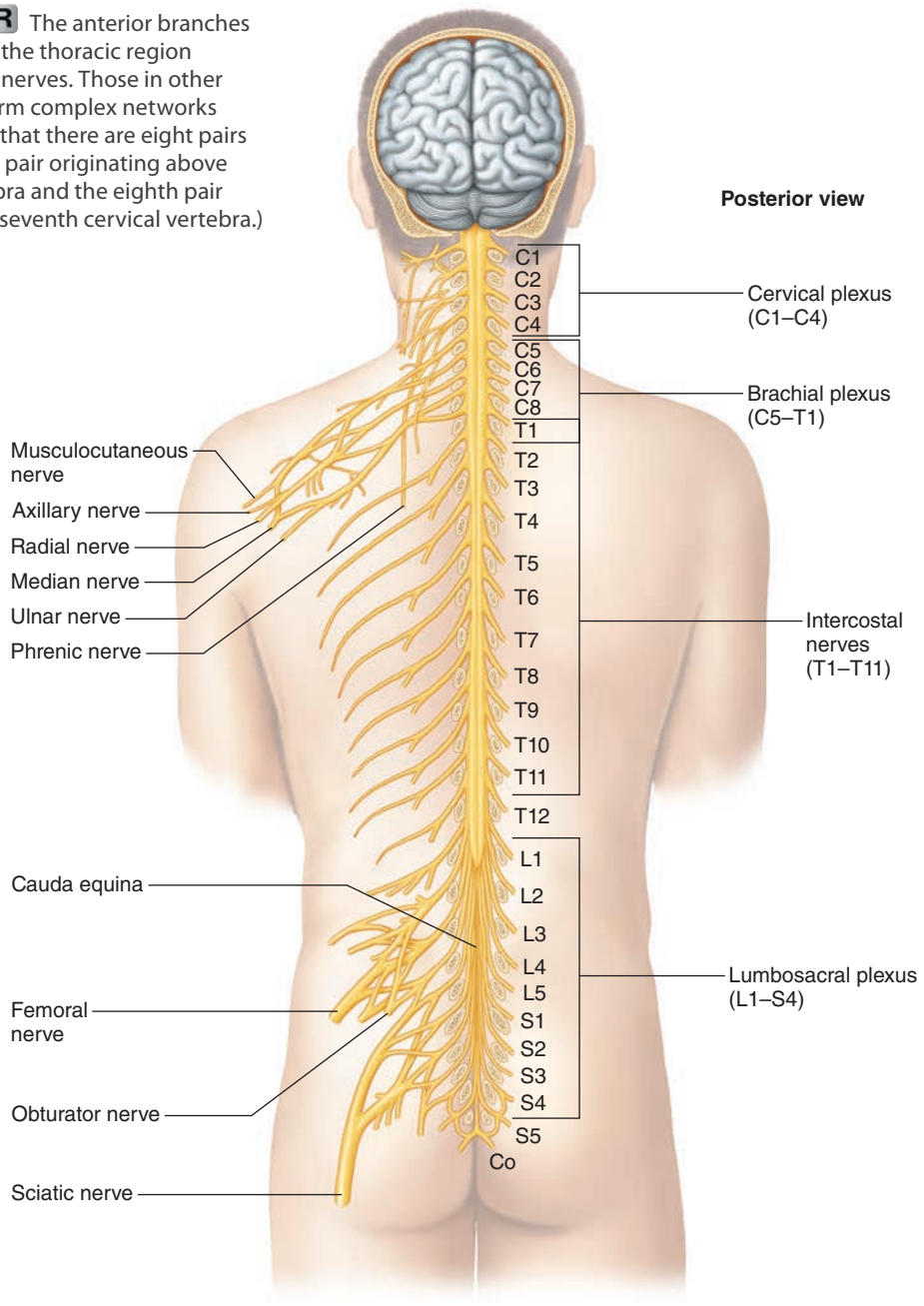


FIGURE 9.36 AP|R The anterior branches of the spinal nerves in the thoracic region give rise to intercostal nerves. Those in other regions combine to form complex networks called plexuses. (Note that there are eight pairs of cervical nerves, one pair originating above the first cervical vertebra and the eighth pair originating below the seventh cervical vertebra.)

The adult spinal cord ends at the level between the first and second lumbar vertebrae. The lumbar, sacral, and coccygeal nerves descend beyond the end of the cord, forming a structure called the *cauda equina* (horse's tail).

Each spinal nerve emerges from the cord by two short branches, or *roots,* which lie within the vertebral column. The **dorsal root** (posterior or sensory root) can be identified by an enlargement called the *dorsal root ganglion* (see fig. 9.23*a*). This ganglion contains the cell bodies of the unipolar sensory neurons whose axons (peripheral processes) conduct impulses inward from the peripheral body parts. The axons of these neurons (central processes) extend through the dorsal root and into the spinal cord, where they form synapses with dendrites of other neurons (see fig. 9.6). The **ventral root** (anterior or motor root) of each spinal nerve consists of axons from the motor neurons whose cell bodies are within the gray matter of the cord.

A ventral root and a dorsal root unite to form a spinal nerve, which extends outward from the vertebral canal through an *intervertebral foramen* (see fig. 7.17, p. 162). Just beyond its foramen, each spinal nerve divides into several parts.

Except in the thoracic region, the main parts of the spinal nerves combine to form complex networks called **plexuses** instead of continuing directly to peripheral body parts (fig. 9.36). In a plexus, spinal nerve axons are sorted and recombined so that axons that innervate a particular body part reach it in the same peripheral nerve, even though the axons originate from different spinal nerves.

Cervical Plexuses

The **cervical plexuses** lie deep in the neck on either side and form from the branches of the first four cervical nerves. Axons from these plexuses supply the muscles and skin of the neck. In addition, axons from the third, fourth, and fifth cervical nerves pass into the right and left **phrenic nerves,** which conduct motor impulses to the muscle fibers of the diaphragm.

Brachial Plexuses

Branches of the lower four cervical nerves and the first thoracic nerve give rise to the **brachial plexuses.** These networks of axons are deep within the shoulders between the neck and axillae (armpits). The major branches emerging from the brachial plexuses supply the muscles and skin of the arm, forearm, and hand, and include the **musculocutaneous, ulnar, median, radial,** and **axillary nerves.**

Lumbosacral Plexuses

The **lumbosacral plexuses** are formed on either side by the last thoracic nerve and the lumbar, sacral, and coccygeal nerves. These networks of axons extend from the lumbar region of the back into the pelvic cavity, giving rise to a number of motor and sensory axons associated with the muscles and skin of the lower abdominal wall, external genitalia, buttocks, thighs, legs, and feet. The major branches of these plexuses include the **obturator, femoral,** and **sciatic nerves.**

The anterior branches of the thoracic spinal nerves do not enter a plexus. Instead, they enter spaces between the ribs and become **intercostal nerves.** These nerves supply motor impulses to the intercostal muscles and the upper abdominal wall muscles. They also receive sensory impulses from the skin of the thorax and abdomen.

PRACTICE

54. How are spinal nerves grouped?
55. Describe how a spinal nerve joins the spinal cord.
56. Name and locate the major nerve plexuses.

Spinal nerves may be injured in a variety of ways, including stabs, gunshot wounds, birth injuries, dislocations and fractures of the vertebrae, and pressure from tumors in surrounding tissues. For example, a sudden extension followed by flexion of the neck, called *whiplash,* can occur during rear-end automobile collisions and may stretch the superficial nerves of the cervical plexuses. Whiplash may cause continuing headaches and pain in the neck and skin, which the cervical nerves supply.

9.16 | Autonomic Nervous System

The **autonomic nervous system** is the part of the PNS that functions independently (autonomously) and continuously without conscious effort. This system controls visceral functions by regulating the actions of smooth muscle, cardiac muscle, and glands. It regulates heart rate, blood pressure, breathing rate, body temperature, and other activities that maintain homeostasis. Parts of the autonomic nervous system respond to emotional stress and prepare the body to meet the demands of strenuous physical activity.

General Characteristics

Reflexes in which sensory signals originate from receptors in the viscera and the skin regulate autonomic activities. Axons conduct these signals to centers in the brain or spinal cord. In response, motor impulses travel out from these centers on axons in cranial and spinal nerves. These axons typically lead to ganglia. The impulses they conduct are integrated in these ganglia and relayed to effectors (muscles and glands) that respond by contracting, releasing secretions, or being inhibited. The integrative function of the ganglia provides the autonomic system with a degree of independence from the brain and spinal cord.

The autonomic nervous system includes two divisions—the **sympathetic** (sim″pah-thet′ik) and **parasympathetic** (par″ah-sim″pah-thet′ik) **divisions.** Some effectors are innervated by axons from each division. In

such cases, impulses on one set of axons may activate an organ, while impulses on the other set inhibit it. Thus, the divisions may act antagonistically, alternately activating or inhibiting the actions of effectors.

The functions of the autonomic divisions are mixed; that is, each activates some organs and inhibits others. However, the divisions have important functional differences. The sympathetic division prepares the body for energy-expending, stressful, or emergency situations, as part of the *fight-or-flight* response. Conversely, the parasympathetic division is most active under ordinary, restful conditions. It also counterbalances the effects of the sympathetic division and restores the body to a resting state following a stressful experience. For example, during an emergency the sympathetic division increases heart rate; following the emergency, the parasympathetic division decreases heart rate.

Autonomic Neurons

The neurons of the autonomic nervous system are motor neurons. However, unlike the motor pathways of the somatic nervous system, which usually include a single neuron between the brain or spinal cord and a skeletal muscle, those of the autonomic system include two neurons (fig. 9.37). The cell body of the first, or preganglionic, neuron is located in the brain or spinal cord. Its axon, the **preganglionic fiber** (pre″gang-gle-on′ik fi′ber), leaves the CNS and synapses with one or more neurons whose cell bodies are located in the PNS within an autonomic ganglion. The axon of such a second neuron, or postganglionic neuron, is called a **postganglionic fiber** (pō st″gang-gle-on′ik fi′ber), and it extends to a visceral effector.

Sympathetic Division

In the sympathetic division, the preganglionic fibers originate from neurons in the gray matter of the spinal cord (fig. 9.38). Their axons leave the cord through the ventral roots of spinal nerves in the first thoracic through the second lumbar segments. These fibers extend a short distance, then leave the spinal nerves, and each enters a member of a chain of sympathetic ganglia (*paravertebral ganglia*). One of these sympathetic chains extends longitudinally along each side of the vertebral column.

In paravertebral ganglia, preganglionic fibers form synapses with second neurons. The axons of these neurons, the postganglionic fibers, typically return to spinal nerves and extend to visceral effectors.

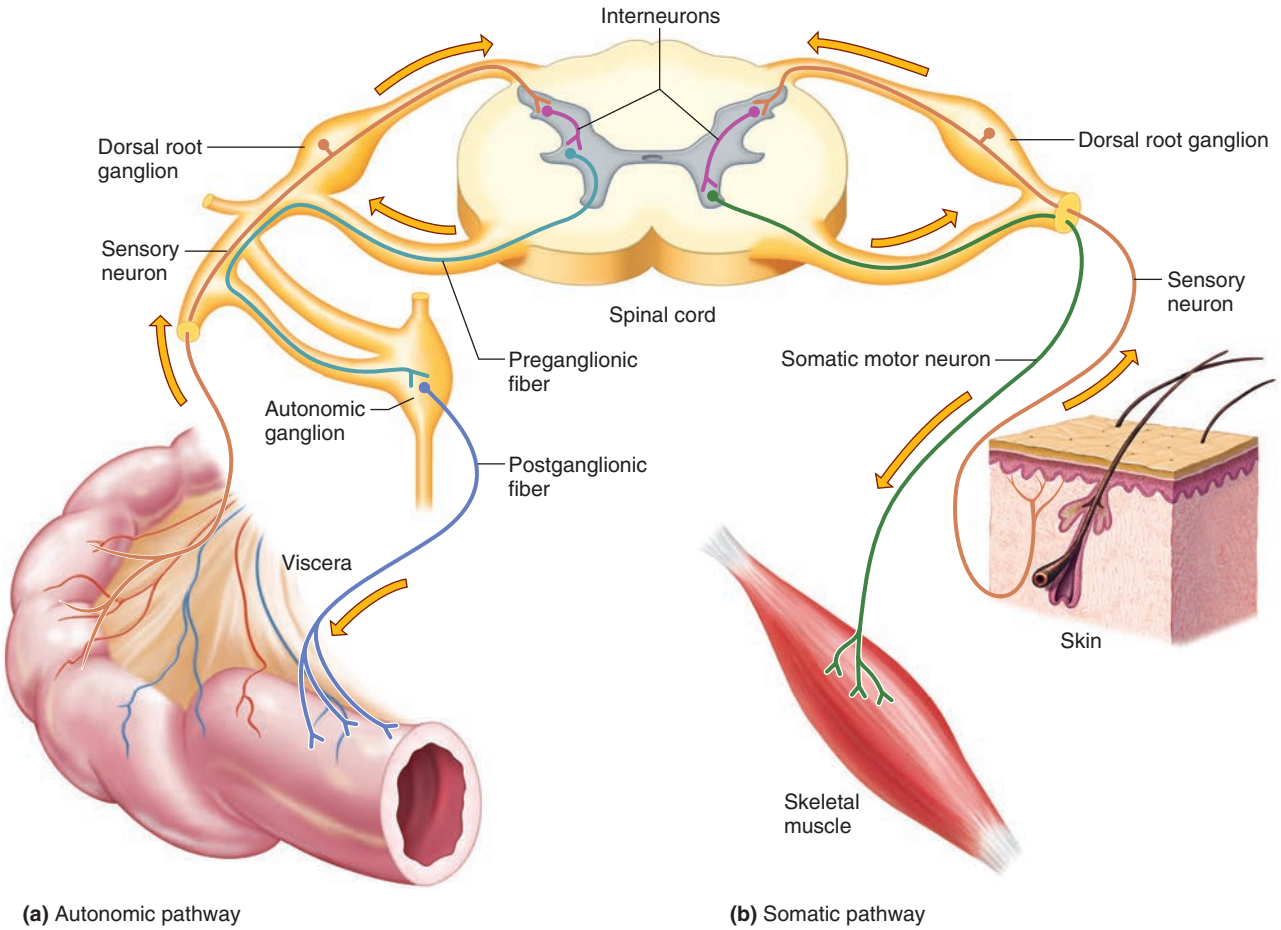


FIGURE 9.37 Motor pathways. **(a)** Autonomic pathways include two neurons between the CNS and an effector. **(b)** Somatic pathways usually have a single neuron between the CNS and an effector. Note that in both cases the motor fibers pass through the ventral root of the spinal cord.

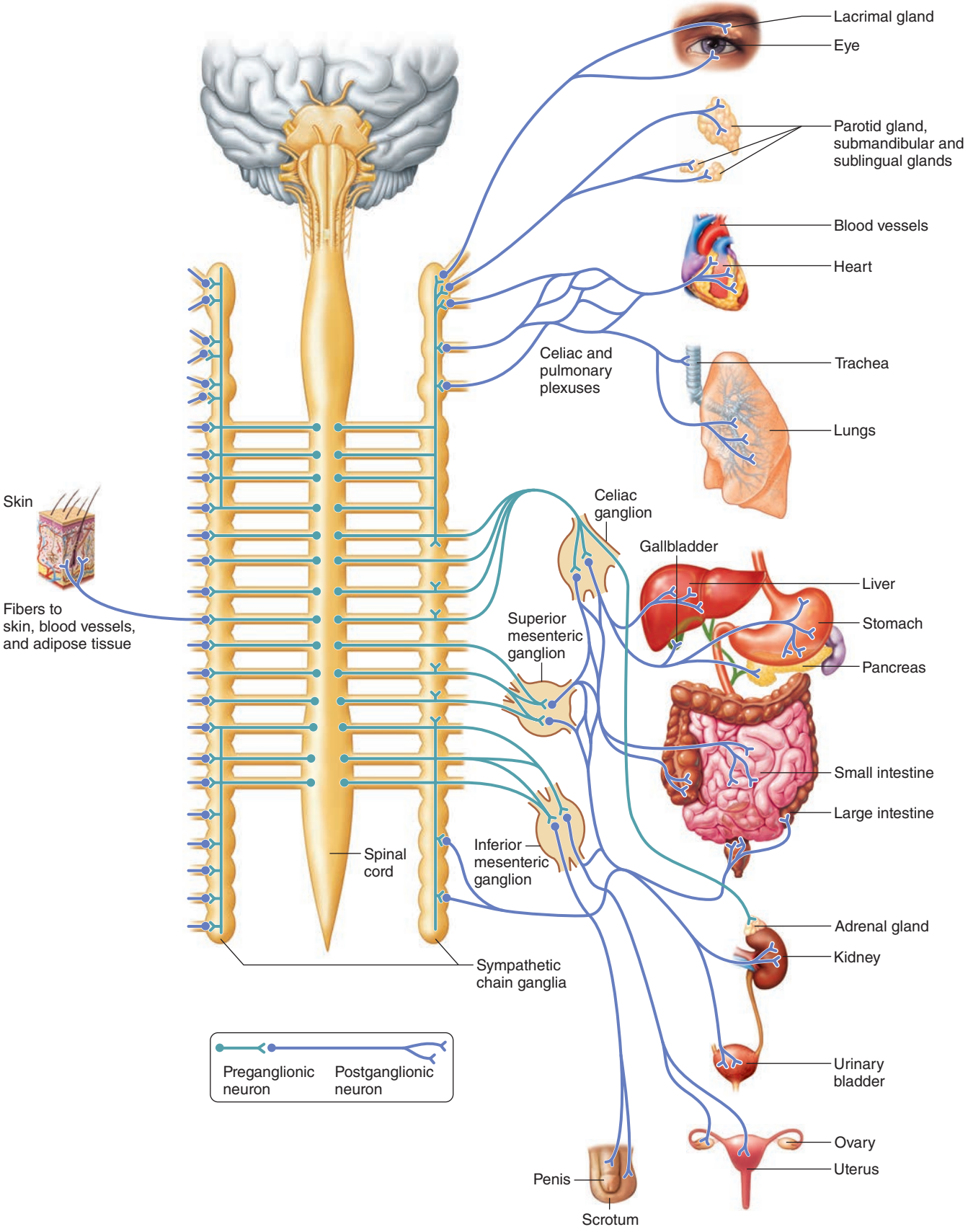


FIGURE 9.38 AP|R The preganglionic fibers of the sympathetic division of the autonomic nervous system arise from the thoracic and lumbar regions of the spinal cord (T1–L2). Note that the adrenal medulla is innervated directly by a preganglionic fiber.

Parasympathetic Division

The preganglionic fibers of the parasympathetic division arise from the brainstem and sacral region of the spinal cord (fig. 9.39). From there, they lead outward in cranial or sacral nerves to ganglia located near or in various viscera. The relatively short postganglionic fibers continue from the ganglia to specific muscles or glands in these viscera.

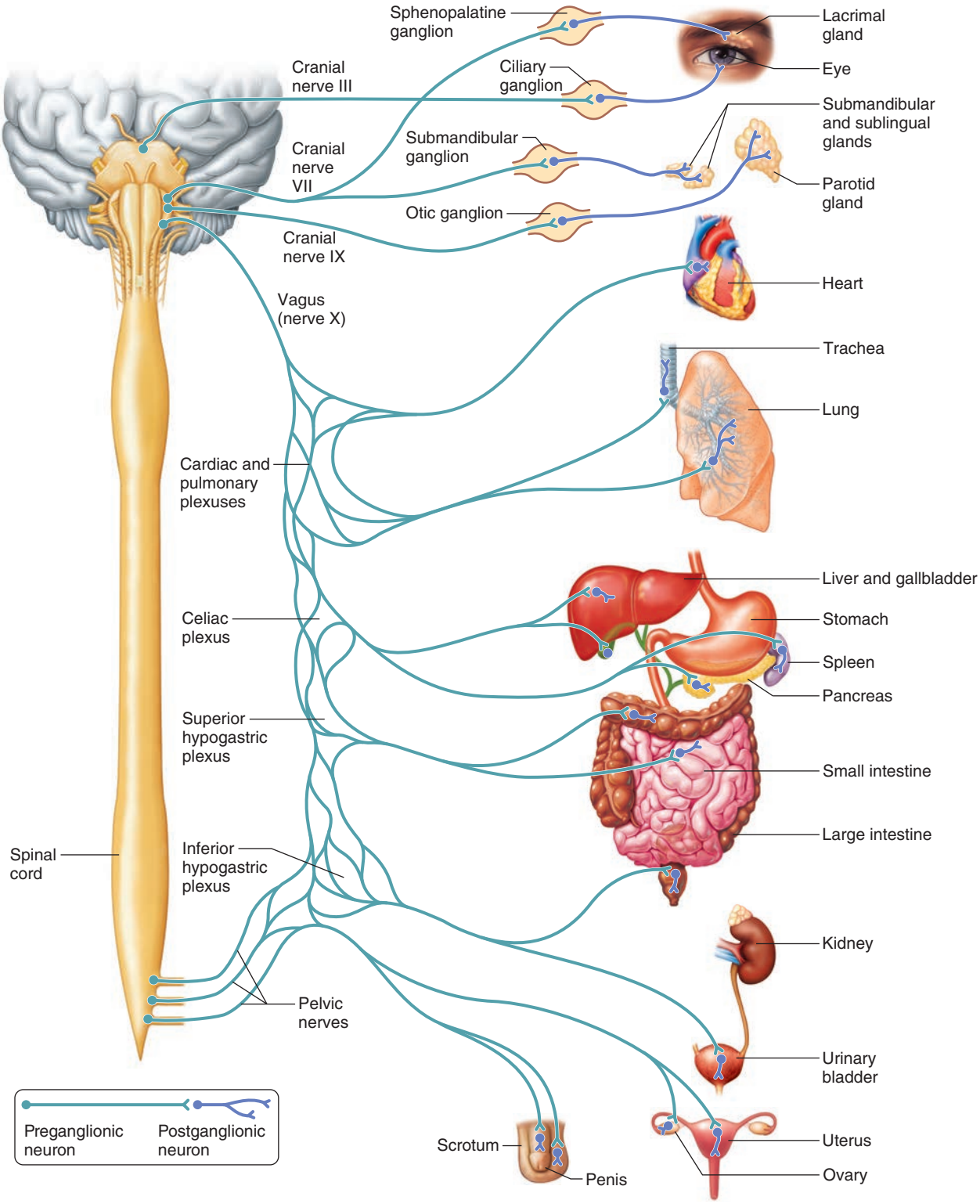


FIGURE 9.39 AP|R The preganglionic fibers of the parasympathetic division of the autonomic nervous system arise from the brainstem and sacral region of the spinal cord.

PRACTICE

57. Describe the parts of the autonomic nervous system.
58. Distinguish between the divisions of the autonomic nervous system.
59. Describe a sympathetic nerve pathway and a parasympathetic nerve pathway.

Autonomic Neurotransmitters

The preganglionic fibers of the sympathetic and parasympathetic divisions all secrete *acetylcholine* and are therefore called **cholinergic fibers** (ko″lin-er′jik fi′berz). The parasympathetic postganglionic fibers are also cholinergic. One exception, parasympathetic neurons that secrete nitric oxide, is described in chapter 19 (p. 525). However, most sympathetic postganglionic neurons secrete *norepinephrine* (noradrenalin) and are called **adrenergic fibers** (ad″ren-ur′jik fi′berz) (fig. 9.40). The different postganglionic neurotransmitters cause the different effects that the sympathetic and parasympathetic divisions have on their effector organs.

Most organs receive innervation from both sympathetic and parasympathetic divisions, usually with opposing actions. For example, parasympathetic activity increases activity of the digestive system, whereas sympathetic activity decreases it. Similarly, sympathetic stimulation increases heart rate, but parasympathetic action slows heart rate.

Some viscera are controlled primarily by one division or the other. That is, the divisions are not always actively antagonistic. For example, the sympathetic division regulates the diameter of most blood vessels, which lack parasympathetic innervation. Smooth muscle in the walls of these vessels is continuously stimulated and thus is in a state of partial contraction (sympathetic tone). Decreasing sympathetic stimulation relaxes the muscular walls of the vessels, which increases the diameter of the vessels (dilates). Conversely, increasing sympathetic stimulation constricts the vessels. Table 9.7 summarizes the effects of stimulation by adrenergic and cholinergic fibers on some visceral effectors.

Control of Autonomic Activity

The brain and spinal cord largely control the autonomic nervous system, although it has some independence resulting from the integrative function of its ganglia. For example, control centers in the medulla oblongata for cardiac, vasomotor, and respiratory activities receive sensory impulses from viscera on vagus nerve fibers and use autonomic nerve pathways to stimulate motor responses in the heart, blood vessels, and lungs. Similarly, the hypothalamus helps regulate body temperature, hunger, thirst, and water and electrolyte balance by influencing autonomic pathways.

More complex centers in the brain, including the limbic system and the cerebral cortex, control the autonomic nervous system during emotional stress. These structures utilize autonomic pathways to regulate emotional expression and behavior.

PRACTICE

60. Which neurotransmitters operate in the autonomic nervous system?
61. How do the divisions of the autonomic nervous system regulate visceral activities?
62. How are autonomic activities controlled?

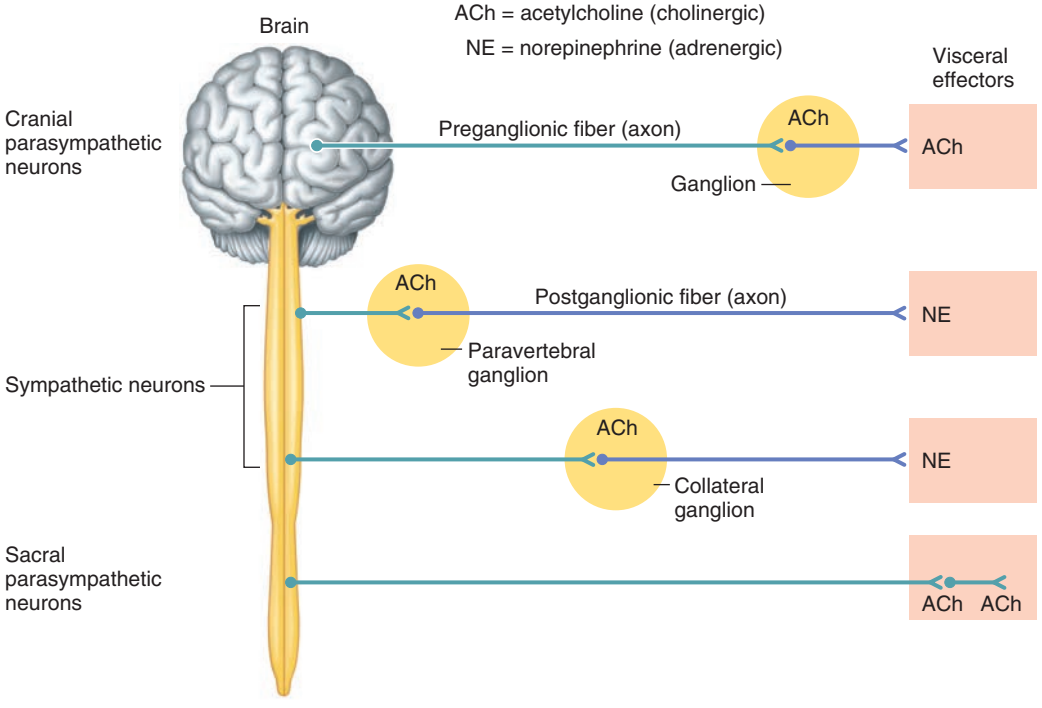
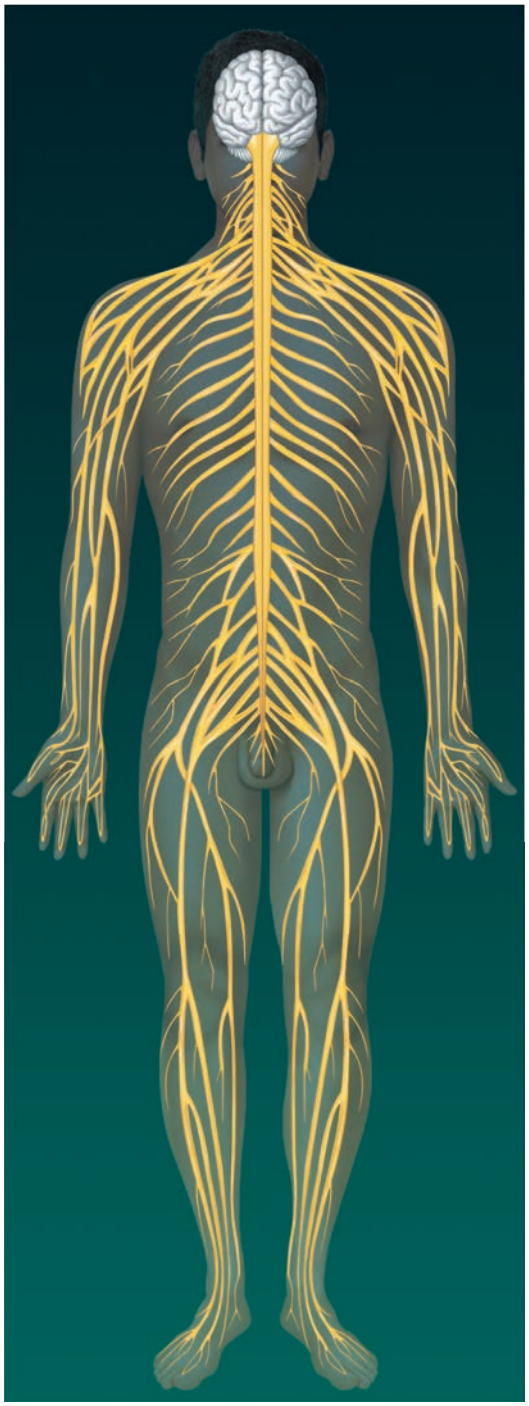


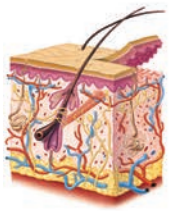
FIGURE 9.40 Most sympathetic fibers are adrenergic and secrete norepinephrine at the ends of the postganglionic fiber; parasympathetic fibers are cholinergic and secrete acetylcholine at the ends of the postganglionic fibers. Two arrangements of parasympathetic postganglionic fibers are seen in both the cranial and sacral portions. Similarly, sympathetic paravertebral and collateral ganglia are seen in both the thoracic and lumbar portions of the nervous system. (Note: This representation does not show dendrites.)

Nervous System



Neurons conduct impulses that allow body systems to communicate.

Integumentary System

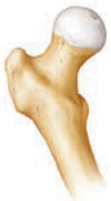


Sensory receptors provide the nervous system with information about the outside world.

Lymphatic System

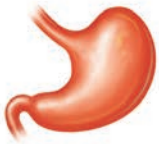
Stress may impair the immune response.

Skeletal System



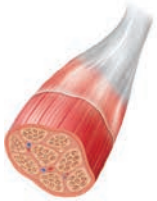
Bones protect the brain and spinal cord and help maintain plasma calcium, which is important to neuron function.

Digestive System



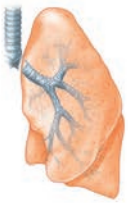
The nervous system can influence digestive function.

Muscular System



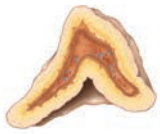
The nervous system controls movement and processes information about the position of body parts.

Respiratory System



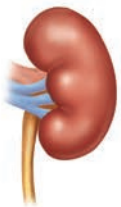
The nervous system alters respiratory activity to control oxygen levels and blood pH.

Endocrine System



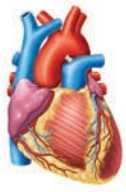
The hypothalamus controls secretion of many hormones.

Urinary System



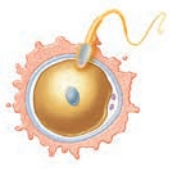
The nervous system plays a role in urine production and elimination.

Cardiovascular System



The nervous system helps control blood flow and blood pressure.

Reproductive System



The nervous system plays a role in egg and sperm formation, sexual pleasure, childbirth, and nursing.

TABLE 9.7 Effects of Neurotransmitter Substances on Visceral Effectors or Actions

Visceral Effector or Action	Response to Adrenergic Stimulation (Sympathetic)	Response to Cholinergic Stimulation (Parasympathetic)
Pupil of the eye	Dilation	Constriction
Heart rate	Increases	Decreases
Bronchioles of lungs	Dilation	Constriction
Muscles of intestinal wall	Slows peristaltic action	Speeds peristaltic action
Intestinal glands	Secretion decreases	Secretion increases
Blood distribution	More blood to skeletal muscles; less blood to digestive organs	More blood to digestive organs; less blood to skeletal muscles
Blood glucose concentration	Increases	Decreases
Salivary glands	Secretion decreases	Secretion increases
Tear glands	No action	Secretion
Muscles of gallbladder	Relaxation	Contraction
Muscles of urinary bladder	Relaxation	Contraction

Summary Outline

9.1 Introduction (p. 224)

1. Nervous tissue includes neurons, which are the structural and functional units of the nervous system, and neuroglia.
2. Organs of the nervous system are divided into the central and peripheral nervous systems.

9.2 General Functions of the Nervous System (p. 225)

1. Sensory functions involve receptors that detect internal and external changes.
2. Integrative functions collect sensory information and make decisions that motor functions carry out.
3. Motor functions stimulate effectors to respond.

9.3 Neuroglia (p. 226)

1. Neuroglia in the central nervous system include microglial cells, oligodendrocytes, astrocytes, and ependymal cells.
2. In the peripheral nervous system, Schwann cells form myelin sheaths.

9.4 Neurons (p. 228)

1. A neuron includes a cell body, dendrites, and an axon.
2. Dendrites and the cell body provide receptive surfaces.
3. A single axon arises from the cell body and may be enclosed in a myelin sheath and a neurilemma.
4. Classification of neurons
   a. Neurons are classified structurally as multipolar, bipolar, or unipolar.
   b. Neurons are classified functionally as sensory neurons, interneurons, or motor neurons.

9.5 The Synapse (p. 232)

A synapse is a junction between two neurons.

1. A presynaptic neuron conducts an impulse into a synapse; a postsynaptic neuron responds.
2. Axons have synaptic knobs at their distal ends, which secrete neurotransmitters.
3. A neurotransmitter is released when an impulse reaches the end of an axon.
4. A neurotransmitter reaching the postsynaptic neuron membrane is either excitatory or inhibitory.

9.6 Cell Membrane Potential (p. 232)

A cell membrane is usually polarized as a result of unequal ion distribution.

1. Distribution of ions
   a. Pores and channels in cell membranes that allow passage of some ions but not others set up differences in the concentrations of specific ions inside and outside a neuron.
   b. Potassium ions pass more easily through cell membranes than do sodium ions.
2. Resting potential
   a. A high concentration of sodium ions is outside a cell membrane, and a high concentration of potassium ions is inside.
   b. Many negatively charged ions are inside a cell.
   c. In a resting cell, more positive ions leave than enter, so the outside of the cell membrane develops a positive charge, while the inside develops a negative charge.
3. Potential changes
   a. Stimulation of a cell membrane affects the membrane's resting potential.
   b. When its resting potential becomes less negative, a membrane becomes depolarized.
   c. Potential changes are graded.
   d. Achieving threshold potential triggers an action potential.
4. Action potential
   a. At threshold, sodium channels open, and sodium ions diffuse inward, depolarizing the membrane.
   b. At almost the same time, potassium channels open, and potassium ions diffuse outward, repolarizing the membrane.
   c. This rapid sequence of depolarization and repolarization is an action potential.
   d. Many action potentials can occur in a neuron without disrupting the ion concentrations. Active transport contributes to maintaining these concentrations.

9.7 Impulse Conduction (p. 236)

A wave of action potentials is an impulse.

1. Impulse conduction (action potential propagation)
   a. Unmyelinated axons conduct action potentials along their entire lengths.
   b. Myelinated axons conduct impulses more rapidly.

   c. Axons with larger diameters conduct impulses faster than those with smaller diameters.
2. All-or-none response
   a. An action potential occurs in an all-or-none manner whenever a stimulus of threshold intensity is applied to an axon.
   b. All of the action potentials triggered on an axon are of the same strength.

9.8 Synaptic Transmission (p. 239)

1. Excitatory and inhibitory actions
   a. Neurotransmitters that trigger impulses are excitatory. Those that inhibit impulses are inhibitory.
   b. The net effect of synaptic knobs communicating with a neuron depends on which knobs are activated from moment to moment.
2. Neurotransmitters
   a. The nervous system produces many different neurotransmitters.
   b. Neurotransmitters include acetylcholine, biogenic amines, amino acids, and peptides.
   c. A synaptic knob releases neurotransmitters when an action potential increases membrane permeability to calcium ions.
   d. After being released, neurotransmitters are decomposed or removed from synaptic clefts.

9.9 Impulse Processing (p. 240)

How the nervous system processes and responds to impulses reflects the organization of neurons in the brain and spinal cord.

1. Neuronal pools
   a. Neurons form pools in the central nervous system.
   b. Each pool receives impulses, processes them, and conducts impulses away.
2. Facilitation
   a. Each neuron in a pool may receive excitatory and inhibitory stimuli.
   b. A neuron is facilitated when it receives subthreshold stimuli and becomes more excitable.
3. Convergence
   a. Impulses from two or more incoming axons may converge on a single neuron.
   b. Convergence enables impulses from different sources to have an additive effect on a neuron.
4. Divergence
   a. Impulses leaving a pool may diverge by passing into several output neurons.
   b. Divergence amplifies impulses.

9.10 Types of Nerves (p. 241)

1. Nerves are cordlike bundles (fascicles) of nerve fibers (axons).
2. Nerves are sensory, motor, or mixed, depending on which type of axons they contain.

9.11 Nerve Pathways (p. 242)

A nerve pathway is the route an impulse follows through the nervous system.

1. A reflex arc usually includes a sensory neuron, a reflex center composed of interneurons, and a motor neuron.
2. Reflex behavior
   a. Reflexes are automatic, subconscious responses to changes.
   b. They help maintain homeostasis.
   c. Two neurons carry out the patellar reflex. It is therefore monosynaptic.
   d. Withdrawal reflexes are protective.

9.12 Meninges (p. 243)

1. Bone and meninges surround the brain and spinal cord.
2. The meninges are the dura mater, arachnoid mater, and pia mater.
3. Cerebrospinal fluid fills the space between the arachnoid and pia maters.

9.13 Spinal Cord (p. 245)

The spinal cord is a nerve column that extends from the brain into the vertebral canal.

1. Structure of the spinal cord
   a. Each of the spinal cord's thirty-one segments gives rise to a pair of spinal nerves (two pairs are associated with C1).
   b. The spinal cord has a cervical enlargement and a lumbar enlargement.
   c. A central core of gray matter lies within white matter.
   d. White matter consists of bundles of myelinated axons called tracts.
2. Functions of the spinal cord
   a. The spinal cord provides a two-way communication system between the brain and other body parts and serves as a center for spinal reflexes.
   b. Ascending tracts conduct sensory impulses to the brain. Descending tracts conduct motor impulses to muscles and glands.

9.14 Brain (p. 247)

The brain is subdivided into the cerebrum, diencephalon, brainstem, and cerebellum.

1. Structure of the cerebrum
   a. The cerebrum consists of two cerebral hemispheres connected by the corpus callosum.
   b. The cerebral cortex is a thin layer of gray matter near the surface.
   c. White matter consists of myelinated axons that connect neurons in the nervous system and communicate with other body parts.
2. Functions of the cerebrum
   a. The cerebrum provides higher brain functions.
   b. The cerebral cortex consists of sensory, association, and motor, areas.
   c. One cerebral hemisphere usually dominates for certain intellectual functions.
3. Ventricles and cerebrospinal fluid
   a. Ventricles are interconnected cavities within the cerebral hemispheres and brainstem.
   b. Cerebrospinal fluid fills the ventricles.
   c. The choroid plexuses in the walls of the ventricles secrete cerebrospinal fluid.
4. Diencephalon
   a. The diencephalon contains the thalamus, which is a central relay station for incoming sensory impulses, and the hypothalamus, which maintains homeostasis.
   b. The limbic system produces emotions and modifies behavior.
5. Brainstem
   a. The brainstem consists of the midbrain, pons, and medulla oblongata.
   b. The midbrain contains reflex centers associated with eye and head movements.
   c. The pons relays impulses between the cerebrum and other parts of the nervous system and contains centers that may help regulate breathing.
   d. The medulla oblongata relays all ascending and descending impulses and contains several vital and nonvital reflex centers.
   e. The reticular formation filters incoming sensory impulses, arousing the cerebral cortex into wakefulness when significant impulses arrive.

6. Cerebellum
   a. The cerebellum consists of two hemispheres.
   b. It functions primarily as a reflex center for integrating sensory information required in the coordination of skeletal muscle movements and the maintenance of equilibrium.

9.15 Peripheral Nervous System (p. 257)

The peripheral nervous system consists of cranial and spinal nerves that branch from the brain and spinal cord to all body parts. It is also subdivided into the somatic and autonomic systems.

1. Cranial nerves
   a. Twelve pairs of cranial nerves connect the brain to parts in the head, neck, and trunk.
   b. Most cranial nerves are mixed, but some are purely sensory, and others are primarily motor.
   c. The names of the cranial nerves indicate their primary functions or the general distributions of their fibers.
2. Spinal nerves
   a. Thirty-one pairs of spinal nerves originate from the spinal cord.
   b. These mixed nerves provide a two-way communication system between the spinal cord and parts of the upper and lower limbs, neck, and trunk.
   c. Spinal nerves are grouped according to the levels from which they arise, and they are numbered in sequence.
   d. Each spinal nerve emerges by a dorsal and a ventral root.
   e. Each spinal nerve divides into several branches just beyond its foramen.
   f. Most spinal nerves combine to form plexuses in which nerve fibers are sorted and recombined so that those fibers associated with a particular part reach it together.

9.16 Autonomic Nervous System (p. 262)

The autonomic nervous system functions without conscious effort. It regulates the visceral activities that maintain homeostasis.

1. General characteristics
   a. Autonomic functions are reflexes controlled from nerve centers in the brain and spinal cord.
   b. The autonomic nervous system consists of two divisions—the sympathetic and the parasympathetic.
   c. The sympathetic division responds to stressful and emergency conditions.
   d. The parasympathetic division is most active under ordinary conditions.
2. Autonomic nerve fibers
   a. Autonomic nerve fibers are motor fibers.
   b. Sympathetic fibers leave the spinal cord and synapse in paravertebral ganglia.
   c. Parasympathetic fibers begin in the brainstem and sacral region of the spinal cord and synapse in ganglia near viscera.
3. Autonomic neurotransmitters
   a. Sympathetic and parasympathetic preganglionic fibers secrete acetylcholine.
   b. Parasympathetic postganglionic fibers secrete acetylcholine. Sympathetic postganglionic fibers secrete norepinephrine.
   c. The different effects of the autonomic divisions are due to the different neurotransmitters the postganglionic fibers release.
   d. The two divisions usually have opposite actions.
4. Control of autonomic activity
   a. The autonomic nervous system is somewhat independent.
   b. Control centers in the medulla oblongata and hypothalamus utilize autonomic nerve pathways.
   c. The limbic system and cerebral cortex control the autonomic system during emotional stress.

CHAPTER ASSESSMENTS

9.1 Introduction

1. The general function of neurons is to _____ , whereas the general functions of neuroglia are to _____ . (p. 224)

2. Match the neuron part on the left to its description on the right. (p. 224)

(1) dendrite	A. a cell process that sends information
(2) axon	B. one of usually several cell processes that receive information
(3) cell body	C. the rounded part of a neuron

3. Explain the relationship between the CNS and the PNS. (p. 225)

9.2 General Functions of the Nervous System

4. List the general functions of the nervous system. (p. 225)

9.3 Neuroglia

5. Match the types of neuroglia to their functions. (p. 226)

(1) ependymal cells	A. form a myelin sheath around peripheral nerves
(2) oligodendrocytes	B. phagocytize cellular debris and bacteria
(3) astrocytes	C. line inner parts of ventricles and spinal cord
(4) Schwann cells	D. form scar tissue and regulate ion and nutrient concentrations in the CNS
(5) microglial cells	E. form a myelin sheath around neurons in the CNS

9.4 Neurons

6. Describe three structures found in neurons that are also in other cell types, and describe two structures that are unique to neurons. (p. 228)

7. The part of a Schwann cell that contributes to the myelin sheath is the _____ , and the part that contributes to the neurilemma is the _____ . (p. 228)

8. Distinguish between myelinated and unmyelinated axons. (p. 228)

9. Distinguish among multipolar, bipolar, and unipolar neurons. (pp. 228–231)

10. Distinguish among sensory neurons, interneurons, and motor neurons. (p. 231)

11. Distinguish between ganglia and nuclei. (p. 231)

9.5 The Synapse

12. Define *synapse.* (p. 232)

13. Explain how information passes from one neuron to another. (p. 232)

9.6 Cell Membrane Potential

14. Explain how a membrane becomes polarized. (p. 232)

15. Describe how ions associated with nerve cell membranes are distributed. (p. 233)

16. Define *resting potential.* (p. 234)

17. Explain the relationship between threshold potential and an action potential. (p. 236)

18. List the events that occur during an action potential. (p. 236)

9.7 Impulse Conduction

19. Choose the correct sequence of events along an axon: (p. 236)
a. Resting potentials are propagated along a stimulated axon, causing a very small action potential.
b. A threshold stimulus opens K^+ channels and the ions diffuse in, depolarizing the cell membrane. Then Na^+ channels open, Na^+ exits, and the cell membrane repolarizes, generating an action potential that stimulates adjacent cell membrane, forming the impulse.
c. A threshold stimulus opens Na^+ channels and the ions diffuse in, depolarizing the cell membrane. Then K^+ channels open, K^+ exits, and the cell membrane repolarizes, generating an action potential that stimulates adjacent cell membrane, forming the impulse.
d. A threshold stimulus opens Na^+ channels and the ions diffuse in, depolarizing the cell membrane. Then K^+ channels open, K^+ exits, and the cell membrane repolarizes, generating an action potential that inhibits adjacent cell membrane, forming the impulse.

20. Explain why a myelin sheath covering an entire axon (with no nodes of Ranvier) would inhibit conduction of an impulse. (p. 236)

21. "All-or-none" response in impulse conduction means that _____ . (p. 238)

9.8 Synaptic Transmission

22. Distinguish between excitatory and inhibitory actions of neurotransmitters. (p. 239)

23. Neurotransmitters are synthesized in _____ and are stored in _____ . (p. 239)

24. Match the neurotransmitter to its description on the right. (p. 239)

(1) biogenic amine	A. short chains of amino acids
(2) acetylcholine	B. a modified amino acid
(3) neuropeptide	C. an amino acid
(4) GABA	D. stimulates skeletal muscle contraction

25. Explain what happens to neurotransmitters after they are released. (pp. 239–240)

9.9 Impulse Processing

26. Describe the components of a neuronal pool. (p. 240)

27. "Facilitation in a neuronal pool" refers to _____. (p. 241)

28. Distinguish between convergence and divergence in a neuronal pool. (p. 241)

9.10 Types of Nerves

29. Describe how sensory, motor, and mixed nerves differ. (p. 241)

9.11 Nerve Pathways

30. Distinguish between a reflex arc and a reflex. (p. 242)

31. Describe the components of a reflex arc and their functions. (p. 242)

32. List three body functions that reflexes control. (p. 242)

9.12 Meninges

33. Match each layer of the meninges to its description. (pp. 243–244)

(1) dura mater	A. the thin, innermost layer, containing blood vessels and nerves
(2) arachnoid mater	B. the tough, outermost layer, consisting mostly of connective tissue
(3) pia mater	C. the lacy membrane, lacking blood vessels, sandwiched between the other two layers

9.13 Spinal Cord

34. Describe the structure of the spinal cord. (p. 245)

35. Distinguish between the ascending and descending tracts of the spinal cord. (p. 246)

9.14 Brain

36. Name the four major parts of the brain and describe their general functions. (p. 247)

37. The area of the brain that contains centers controlling visceral activities is the _____ . (p. 247)
a. cerebrum
b. cerebellum
c. brainstem
d. diencephalon

38. The structure that connects the cerebral hemispheres is the _____ . (p. 247)

39. Distinguish between a sulcus and a fissure. (p. 247)

40. Relate the lobes of the cerebral hemispheres to the skull bones. (p. 248)

41. Locate the sensory, association, and motor areas of the cerebral cortex, and describe the general functions of each. (p. 250)

42. Define *hemisphere dominance.* (p. 251)

43. The function of the basal nuclei is to _____ . (p. 252)

44. Locate the ventricles in the brain. (p. 252)

45. Explain how cerebrospinal fluid is produced and how it functions. (p. 252)

46. The part of the diencephalon that regulates hunger, weight, water and electrolyte balance, sleep and wakefulness, temperature, arterial blood pressure, heart rate, production of substances that stimulate the pituitary gland, and movement and secretion in areas of the digestive tract is the _____ . (p. 254)
a. thalamus
b. pineal gland
c. infundibulum
d. hypothalamus

47. Define *limbic system,* and explain its functions. (p. 254)

48. The parts of the brainstem are the _____ , _____ , and _____ . (p. 255)

49. List the functions of the three parts of the brainstem. (p. 255)

50. Vomiting is controlled by _____ . (p. 255)
a. the reticular formation
b. the medulla oblongata
c. the midbrain
d. the pons

51. Describe what happens to the body when the reticular formation receives sensory impulses, and what happens when it does not receive stimulation. (p. 255)

52. Describe the functions of the cerebellum. (p. 256)

9.15 Peripheral Nervous System

53. Distinguish between cranial nerves and spinal nerves. (pp. 257–258)

54. Distinguish between the somatic nervous system and the autonomic nervous system. (p. 258)

55. Match the cranial nerves to the body parts or functions that they affect. More than one nerve pair may correspond to the same structure or function. (pp. 258–260)

(1) olfactory nerves (I)	A. vision
(2) optic nerves (II)	B. hearing and equilibrium
(3) oculomotor nerves (III)	C. muscles of the larynx, pharynx, soft palate, sternocleidomastoid and trapezius muscles
(4) trochlear nerves (IV)	
(5) trigeminal nerves (V)	
(6) abducens nerves (VI)	D. heart, various smooth muscles and glands in the thorax and abdomen
(7) facial nerves (VII)	
(8) vestibulocochlear nerves (VIII)	E. taste, facial expressions, secretion of tears and saliva
(9) glossopharyngeal nerves (IX)	F. sense of smell
(10) vagus nerves (X)	G. tongue movements and swallowing
(11) accessory nerves (XI)	H. face and scalp
(12) hypoglossal nerves (XII)	I. eye movements

56. Explain how the spinal nerves are classified and numbered. (p. 261)

57. Describe the structure of a spinal nerve. (p. 262)
58. Define *plexus,* and locate the major plexuses of the spinal nerves. (p. 262)

9.16 Autonomic Nervous System

59. Describe the general functions of the autonomic nervous system. (p. 262)
60. Distinguish between the sympathetic and parasympathetic divisions of the autonomic nervous system. (p. 262)
61. Distinguish between preganglionic and postganglionic neurons. (p. 263)
62. The effects of the sympathetic and parasympathetic autonomic divisions differ because _____ . (pp. 263–265)
63. List two ways in which the CNS controls autonomic activities. (p. 266)

INTEGRATIVE ASSESSMENTS/CRITICAL THINKING

OUTCOMES 3.4, 9.3, 9.4

1. State two reasons why rapidly growing brain cancers are composed of neuroglia rather than neurons.

OUTCOMES 9.3, 9.4, 9.7, 9.13, 9.14

2. In multiple sclerosis, nerve fibers in the CNS lose their myelin. Explain why this loss affects skeletal muscle function.

OUTCOMES 9.4, 9.5, 9.11, 9.13, 9.14

3. List four skills encountered in everyday life that depend on nervous system function, and list the part of the nervous system responsible for each.

OUTCOMES 9.11, 9.13

4. The biceps-jerk reflex is carried out by motor neurons that exit the spinal cord in the fifth spinal nerve (C5). The triceps-jerk reflex uses motor neurons in the seventh spinal nerve (C7). Describe how these reflexes might be tested to help pinpoint damage in a patient with a neck injury.

OUTCOMES 9.11, 9.14

5. Describe the roles of the cerebrum and cerebellum in athletics.

OUTCOMES 9.13, 9.14

6. Describe expected functional losses in a patient who has suffered injury to the right occipital lobe of the cerebral cortex compared to injury in the right temporal lobe of the cerebral cortex.

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