EIGHT

8

CHAPTER

# Nervous System

## Chapter Preview & Learning Objectives

### Divisions of the Nervous System
- Name the anatomical and functional divisions of the nervous system and indicate their components.

### Nerve Tissue
- Describe the structure of a neuron.
- Compare the three types of neurons.
- Compare the five types of neuroglial cells.

### Neuron Physiology
- Describe the formation and conduction of a nerve impulse.
- Describe how impulses are transmitted across a synapse.

### Protection for the Central Nervous System
- Describe how the brain and spinal cord are protected from injury.

### Brain
- Compare the major parts of the brain as to structure, location, and function.
- Describe the formation, circulation, absorption, and function of the cerebrospinal fluid.

### Spinal Cord
- Describe the structure and function of the spinal cord.

### Peripheral Nervous System (PNS)
- List the 12 cranial nerves and indicate their functions.
- Describe a spinal reflex and indicate the functions of the components involved.

### Autonomic Nervous System (ANS)
- Compare the structure and function of the sympathetic and parasympathetic divisions.

### Disorders of the Nervous System
- Describe the common disorders of the nervous system.

**Chapter Summary**
**Building Your Vocabulary**
**Check Your Understanding**
**Critical Thinking**

## SELECTED KEY TERMS

**Autonomic nervous system** (auto = self; nom = distribute) The involuntary portion of the nervous system that is involved in maintaining homeostasis.
**Axon** (ax = axis, central) A neuron process that carries impulses away from the cell body.
**Central nervous system** The portion of the nervous system composed of the brain and spinal cord.
**Dendrite** (dendr = tree) A neuron process that carries impulses toward the cell body.
**Effector** A muscle or gland.
**Ganglion** (gangli = a swelling) A group of neuron cell bodies.
**Impulse** A wave of depolarization passing over a neuron or muscle fiber.
**Myelin sheath** (myel = marrow) The fatty insulating substance around many axons.
**Nerve** A bundle of neuron processes.
**Neurilemma** (neur = nerve; lemma = rind) The outer membrane covering the myelin sheath.
**Neuroglial cells** Supportive and protective cells within the nervous system.
**Neuron** A nerve cell.
**Neurotransmitter** A chemical secreted by an axon that triggers the formation of an impulse in the postsynaptic neuron.
**Peripheral nervous system** (peri = around) Portion of the nervous system composed of cranial and spinal nerves.
**Receptor** Portion of the peripheral nervous system that responds to certain stimuli by forming impulses.
**Reflex** An involuntary response to a stimulus.
**Somatic nervous system** The voluntary portion of the nervous system that is involved in conscious activities.
**Synapse** (syn = together) The junction between a neuron and another cell.

The nervous system is the primary coordinating and controlling system of the body. It monitors internal and external changes, analyzes the information, makes conscious or unconscious decisions, and then takes appropriate action. All of these activities occur almost instantaneously because communication within the nervous system is by electrochemical **impulses** that flow rapidly over neurons and from neuron to neuron. Most of the activities of the nervous system occur below the conscious level and serve to maintain homeostasis.

The general functions of the nervous system may be summarized as

1. detection of internal and external changes;
2. analysis of the information received;
3. organization of the information for immediate and future use;
4. initiation of the appropriate actions.

# Divisions of the Nervous System

Although the nervous system functions as a coordinated whole, it is divided into anatomical and functional divisions as an aid in understanding this complex organ system.

## Anatomical Divisions

The nervous system has two anatomical divisions. The **central nervous system (CNS)** consists of the brain and spinal cord. The CNS is the body's neural control center. It receives incoming information (impulses), analyzes and organizes it, and initiates appropriate action. The **peripheral nervous system (PNS)** is located outside of the CNS and consists of nerves and sensory receptors. The PNS carries impulses formed by **receptors,** such as pain and sound receptors, to the CNS, and it carries impulses from the CNS to **effectors,** glands and muscles, that carry out actions directed by the CNS.

## Functional Divisions

Similarly, the nervous system is divided into two functional divisions. The **sensory division** carries impulses from sensory receptors to the CNS. The **motor division** carries impulses from the CNS to effectors, muscles, and glands, which perform an action. The motor division is further divided into two subdivisions. The **somatic nervous system (SNS)** is involved in the *voluntary* (conscious) control of the skeletal muscles. The **autonomic nervous system (ANS)** provides *involuntary* (subconscious) control of cardiac muscle, smooth muscle, and glands.

# Nerve Tissue

The nervous system consists of organs composed primarily of nerve tissue supported and protected by connective tissues. There are two types of cells that compose nerve tissue: neurons and neuroglial cells.

## Neurons

**Neurons** (nū′-rahns) are delicate cells that are specialized to transmit neural impulses. They are the structural and functional units of the nervous system. Neurons may vary in size and shape, but they have many common features.

As shown in figures 8.1 and 8.2, the **cell body** is the portion of a neuron that contains the large, spherical nucleus. The cell body also contains the

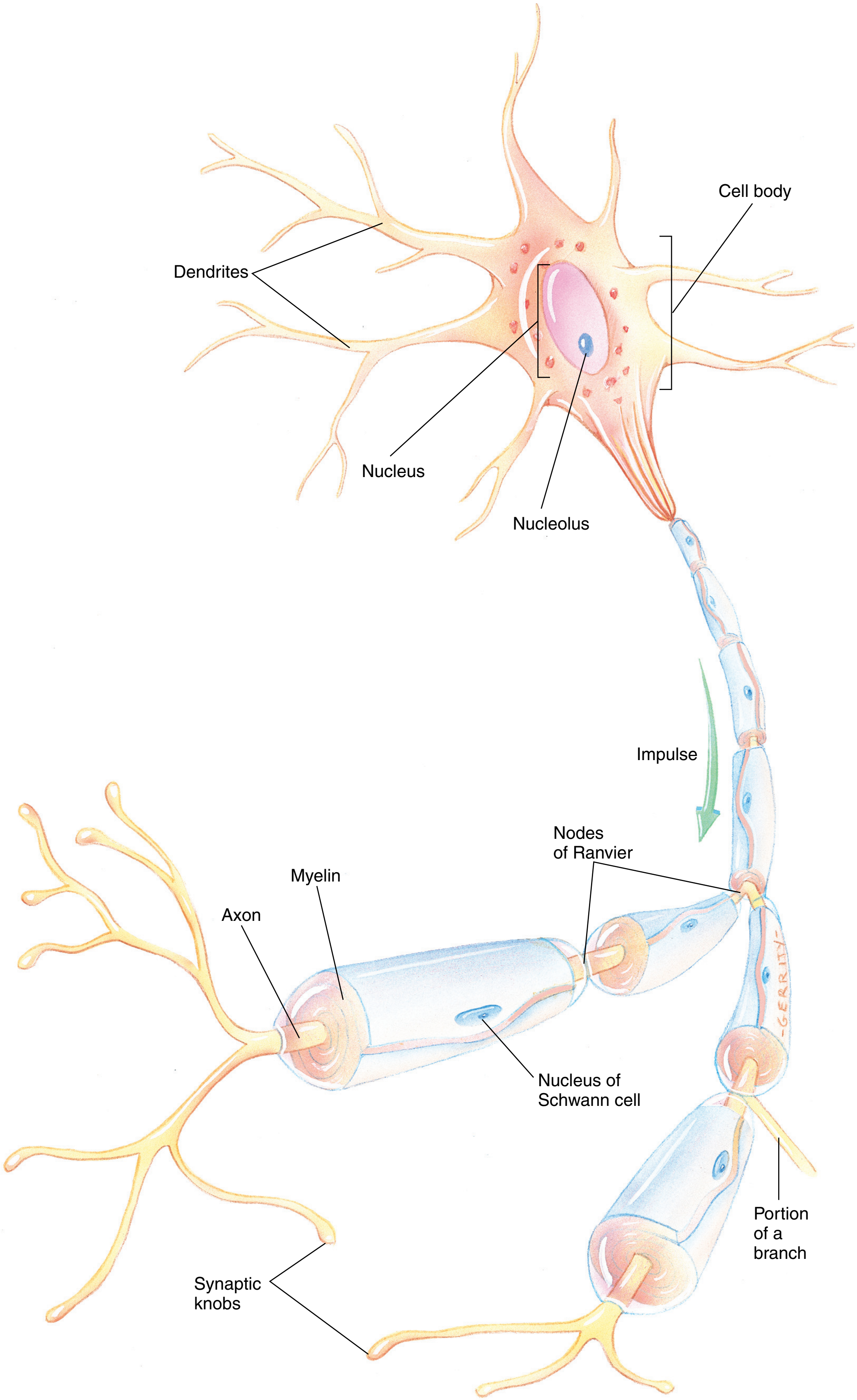


**Figure 8.1** A common neuron.

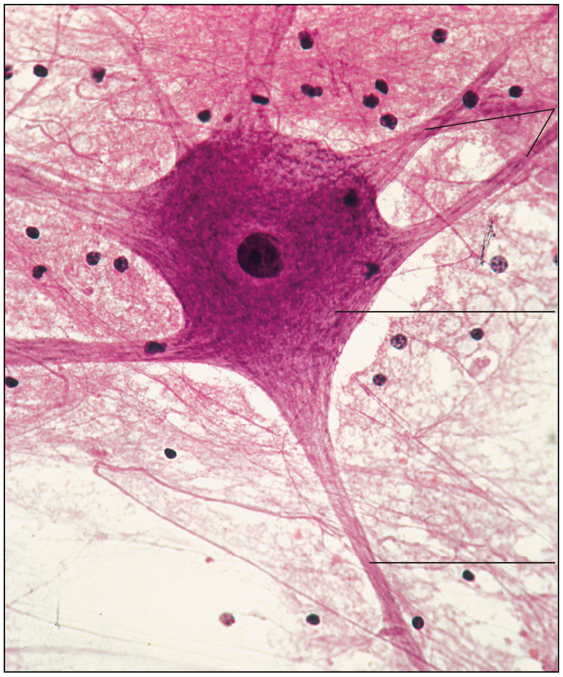


**Figure 8.2** Neurons are the structural and functional units of the nervous system (50×). The dark spots in the area surrounding the neuron are nuclei of neuroglial cells. Note the location of nerve fibers (dendrites and a single axon).

usual cytoplasmic organelles. Two types of neuron processes extend from the cell body: dendrites and axons. A neuron may have many dendrites, but it has only one axon.

**Dendrites** (den′-drits) are numerous, short, and highly branched processes extending from the neuron cell body. They are the primary sites for receiving impulses from other neurons and sensory receptors. Dendrites carry impulses toward the cell body and axon.

An **axon** (ak′-sahn), or *nerve fiber,* is a long, thin process of a neuron. It may have one or more side branches, and it forms a number of short, fine branches, the *axon terminals,* at its tip. The slightly enlarged tips of the axon terminals are the *synaptic knobs,* which form junctions (synapses) with other neurons, muscles, or glands. An axon carries impulses away from the cell body or dendrites.

Axons are enclosed in an insulating **myelin sheath** formed by special neuroglial cells. Such nerve fibers are said to be *myelinated.* The myelin sheath increases the speed of impulse transmission. The tiny spaces between adjacent myelin-forming cells, where the axon is exposed, are known as **nodes of Ranvier.**

## Types of Neurons

There are three types of neurons, based on their functional differences: sensory neurons, interneurons, and motor neurons.

**Sensory neurons** carry impulses from the peripheral parts of the body to the CNS. Their dendrites are associated with sensory receptors or are specialized to detect homeostatic changes directly. Impulses are carried over an axon within cranial or spinal nerves to the CNS. Cell bodies of sensory neurons are located outside the CNS in clusters called **ganglia.**

**Interneurons** are located entirely within the CNS and synapse with other neurons. They are responsible for the processing and interpretation of impulses by the CNS. Interneurons receive impulses from sensory neurons and transmit them from place to place within the CNS, and they activate motor neurons to produce actions by muscles or glands.

**Motor neurons** carry impulses from the CNS to effectors, muscles, and glands, to produce an action. Their cell bodies and dendrites are located within the CNS, and their axons are located in cranial and spinal nerves.

## Neuroglia

The **neuroglia** (nū-rog′-lē-ah), or **neuroglial cells,** provide support and protection for neurons. Only one type of neuroglial cell—Schwann cells—occurs in the PNS. Four types of neuroglial cells occur in the CNS, where they are even more numerous than neurons (figures 8.3 and 8.4).

**Schwann cells** occur only in the peripheral nervous system, where they form the myelin sheath around axons. They wrap tightly around an axon many times so the nucleus and most of the cytoplasm is squeezed into the outermost layer. The inner layers, formed of plasma membranes, form the myelin sheath. The outermost layer form the **neurilemma,**which is essential for regeneration of the axon if it is injured.

**Oligodendrocytes** (ōl-i-gō-den′-drō-sītz) form the myelin sheath of myelinated neurons within the CNS, but they do not form a neurilemma. Destruction of neuron processes in the brain and spinal cord is permanent, because neuron processes cannot regenerate without a neurilemma.

**Astrocytes** (as′-trō-sītz) bind neurons to blood vessels and help regulate the exchange of materials between the blood and neurons. They also provide structural support, stimulate the growth of neurons, and influence synaptic transmission.

**Microglial cells** are scattered throughout the CNS, where they keep the tissues clean by engulfing and digesting cellular debris and bacteria.

**Ependymal** (e-pen-dī′-mal) **cells** form an epithelial-like lining of cavities in the brain and spinal cord.

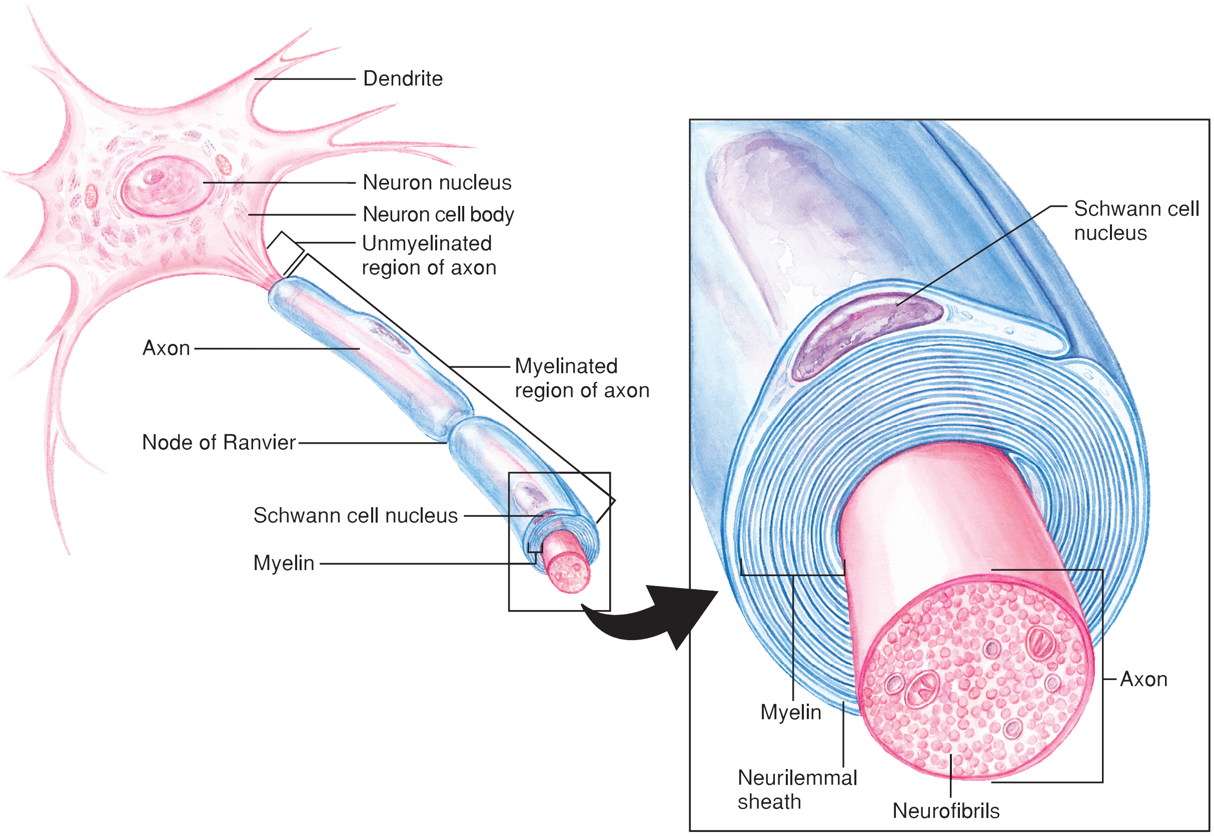


**Figure 8.3** The portion of a Schwann cell that winds tightly around an axon forms a myelin sheath, and the cytoplasm and nucleus of the Schwann cell remaining outside form a neurilemmal sheath.

***What are the general functions of the nervous system?***
***What is the structure and function of neurons?***
***What are the roles of the five types of neuroglial cells?***

# Neuron Physiology

Neurons have two unique functional characteristics: irritability and conductivity. **Irritability** is the ability to respond to a stimulus by forming an impulse. **Conductivity** is the ability to transmit an impulse along a neuron to other neurons, muscles, or glands. These characteristics enable the functioning of the nervous system.

## Resting Potential

An inactive or resting neuron actively pumps sodium ions ($Na^+$) out of the cell and potassium ions ($K^+$) into the cell. However, the plasma membrane is more permeable to $K^+$ irons that $NA^+$ so some $K^+$ diffuse out of the neuron. Large negatively charged proteins and ions, such as phosphate ($PO_4^{-3}$ and sulfate ($SO_4^{-2}$), cannot diffuse out of the neuron. This results in an excess of positively charged ions outside the neuron membrane and an excess of negatively charged ions inside the neuron. This unequal distribution of electrical charges on each side of the plasma membrane makes the membrane polarized, and this condition is known as the *resting potential* (figure 8.5*a*). A "potential" is the difference in electrical charge between two sites. The polarization of the neuron membrane does not change as long as the neuron is inactive.

## Impulse Formation

When stimulated, neurons exhibit an all-or-none response. They either form an impulse, or they do not respond. The weakest stimulus that will activate a neuron is called a *threshold stimulus.* There are no strong or weak impulses. All impulses are alike.

When a neuron is activated by a stimulus, its plasma membrane instantly becomes permeable to $Na^+$, so these ions quickly diffuse into the neuron. The inward

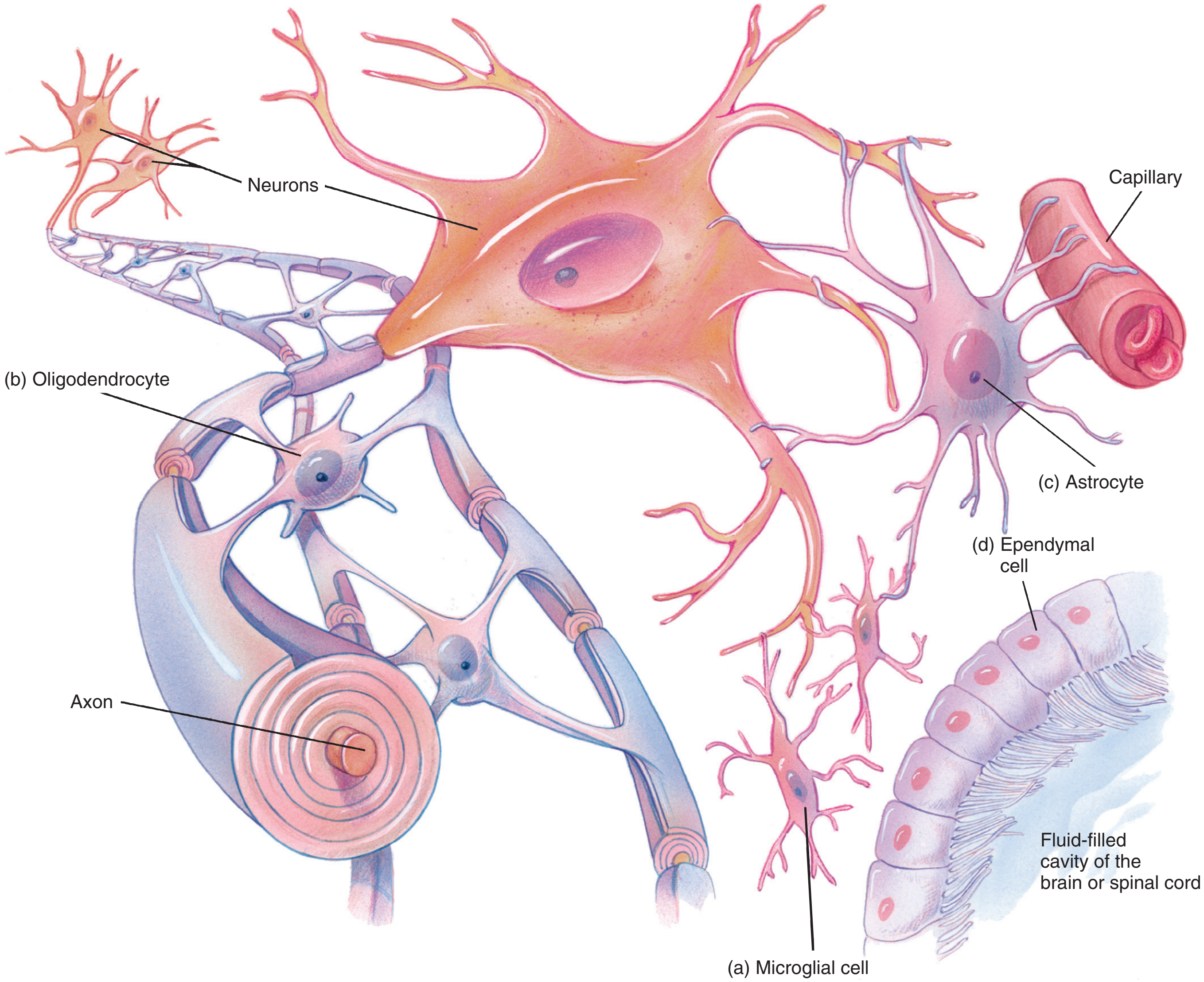


**Figure 8.4** Types of neuroglial cells in the central nervous system include (*a*) microglial cell, (*b*) oligodendrocyte, (*c*) astrocyte, and (*d*) ependymal cell.

flow of $NA^+$ causes positive and negative ions to be equally abundant on each side of the plasma membrane. Thus, there is no net electrical charge on either side of the membrane. The plasma membrane is now *depolarized.* This sudden depolarization *is* the **nerve impulse,** or *action potential* (figure 8.5*b*). The wave of depolarization then flows along the neuron. You will see how this happens momentarily.

## Repolarization

Immediately after depolarization, $K^+$ diffuses outward to reestablish the resting potential of the membrane, with an excess of positive charges outside and an excess of negative charges inside. In this way, the neuron membrane is repolarized. Then, $Na^+$ is pumped out and $K^+$ is pumped into the neuron to reestablish the resting-state distribution of ions. When this is accomplished, the neuron is ready to respond to another stimulus. Depolarization and repolarization are accomplished in about 1/1,000 of a second (figure 8.5*c*).

## Impulse Conduction

When an impulse is formed at one point in a neuron, it triggers the depolarization of adjacent portions of the plasma membrane, which, in turn, depolarizes still other regions of the membrane. The result is a wave of depolarization, the conduction of a nerve

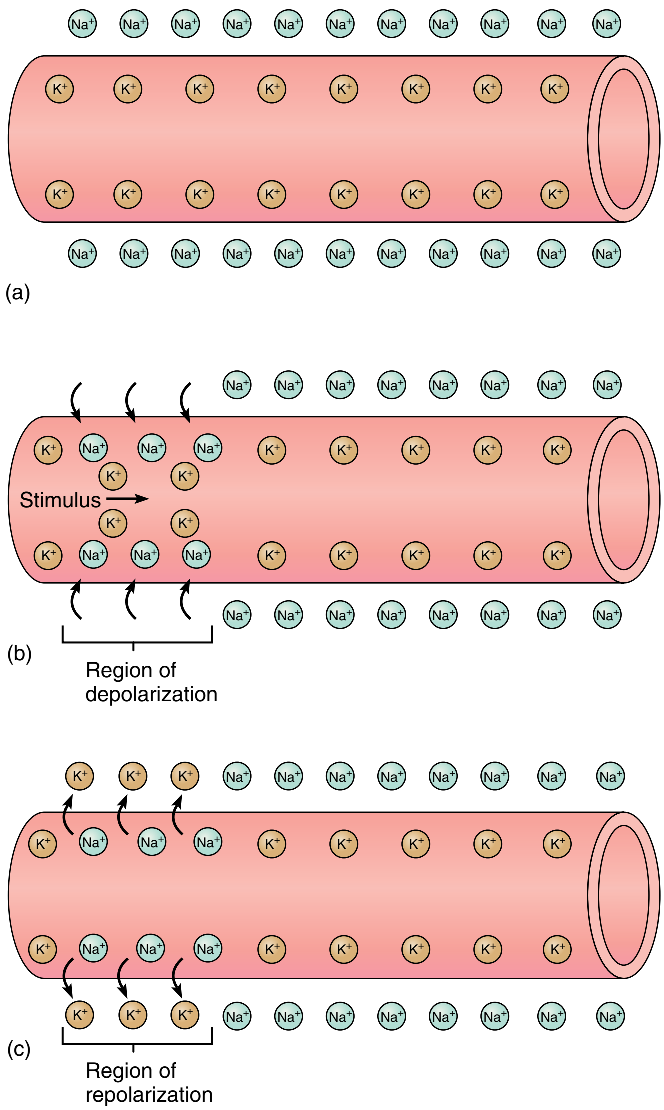


**Figure 8.5** Distribution of $Na^+$ and $K^+$ (*a*) in a resting (polarized) neuron, (*b*) during depolarization, and (*c*) during repolarization. For simplicity, negative ions are not shown.

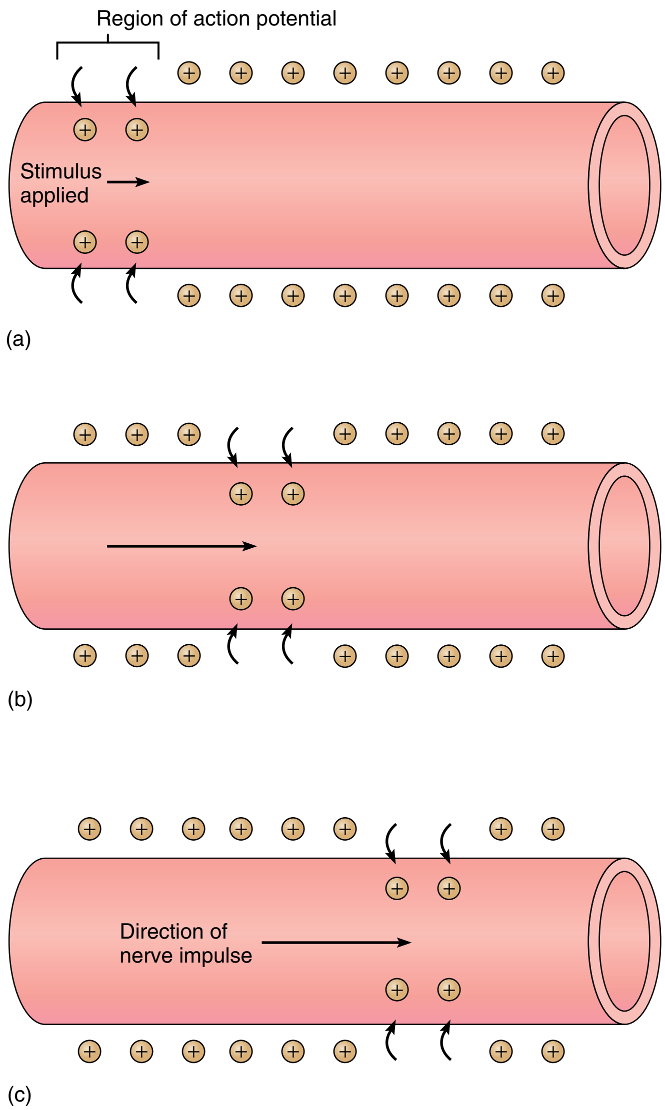


**Figure 8.6** Distribution of excess positive charges during (*a*) impulse formation (depolarization), and (*b*) and(*c*) impulse conduction. Note that repolarization immediately follows depolarization.

impulse, that sweeps along the neuron (figure 8.6). Repolarization immediately follows an impulse.

Conduction of nerve impulses is more rapid in myelinated neuron processes than in unmyelinated processes. Recall that a myelinated neuron process is exposed only at nodes of Ranvier. Because of this, an impulse jumps from node to node and does not have to depolarize the intervening segments of the neuron process.

## Synaptic Transmission

A **synapse** (sin′-aps) is a junction of an axon with either another neuron or an effector cell, such as a gland or muscle. At a synapse, the *synaptic knob* (axon tip) of the presynaptic neuron fits into a small depression on the postsynaptic neuron's dendrite or cell body. There is a tiny space, the *synaptic cleft,* between the neurons, so they are not in physical contact (figure 8.7).

In neuron-to-neuron synaptic transmission, when an impulse reaches the synaptic knob of the presynaptic neuron it causes the knob to secrete a neurotransmitter into the synaptic cleft. Then, the neurotransmitter binds to receptors on the postsynaptic neuron's plasma membrane, which triggers a response in the postsynaptic neuron. Some neurotransmitters stimulate formation of an impulse in the postsynaptic neuron but others inhibit impulse formation. If an impulse is formed in the postsynaptic neuron, it is carried along the neuron's axon to the next synapse where synaptic transmission takes place again.

Because only synaptic knobs can release neurotransmitters, impulses can only pass in one direction across a synapse—from the presynaptic neuron to the postsynaptic neuron. Thus, impulses always pass in the "correct" direction, which maintains order in the nervous system.

Some neurotransmitters are reabsorbed into the synaptic knob for reuse. Others are decomposed by enzymes released into the synaptic cleft. The decomposition products are then reabsorbed for reuse. Quick removal of a neurotransmitter prevents continuous stimulation or inhibition of the postsynaptic neuron (or cell) and prepares the synapse for another transmission. From start to finish, synaptic transmission takes only a fraction of a second.

## Neurotransmitters

Neurotransmitters enable neurons to communicate with each other. More than forty neurotransmitters have been identified, but they may be categorized as two basic types: excitatory and inhibitory. **Excitatory neurotransmitters** cause the formation of an impulse in postsynaptic neurons and activate other target cells. They include acetylcholine (as-e-til-ko′-lēn), which stimulates contraction of skeletal muscles, and norepinephrine (nor-ep-e-nef′-rin), which produces a sense of well-being and is an important neurotransmitter in the autonomic nervous system. **Inhibitory neurotransmitters** inhibit the formation of an impulse in postsynaptic neurons and inhibit the function of other target cells. They include dopamine (do′-pah-mēn), which creates a sense of well-being, and endorphins (in-dor′-fins), which reduce pain. Each neuron releases only one or two neurotransmitters.

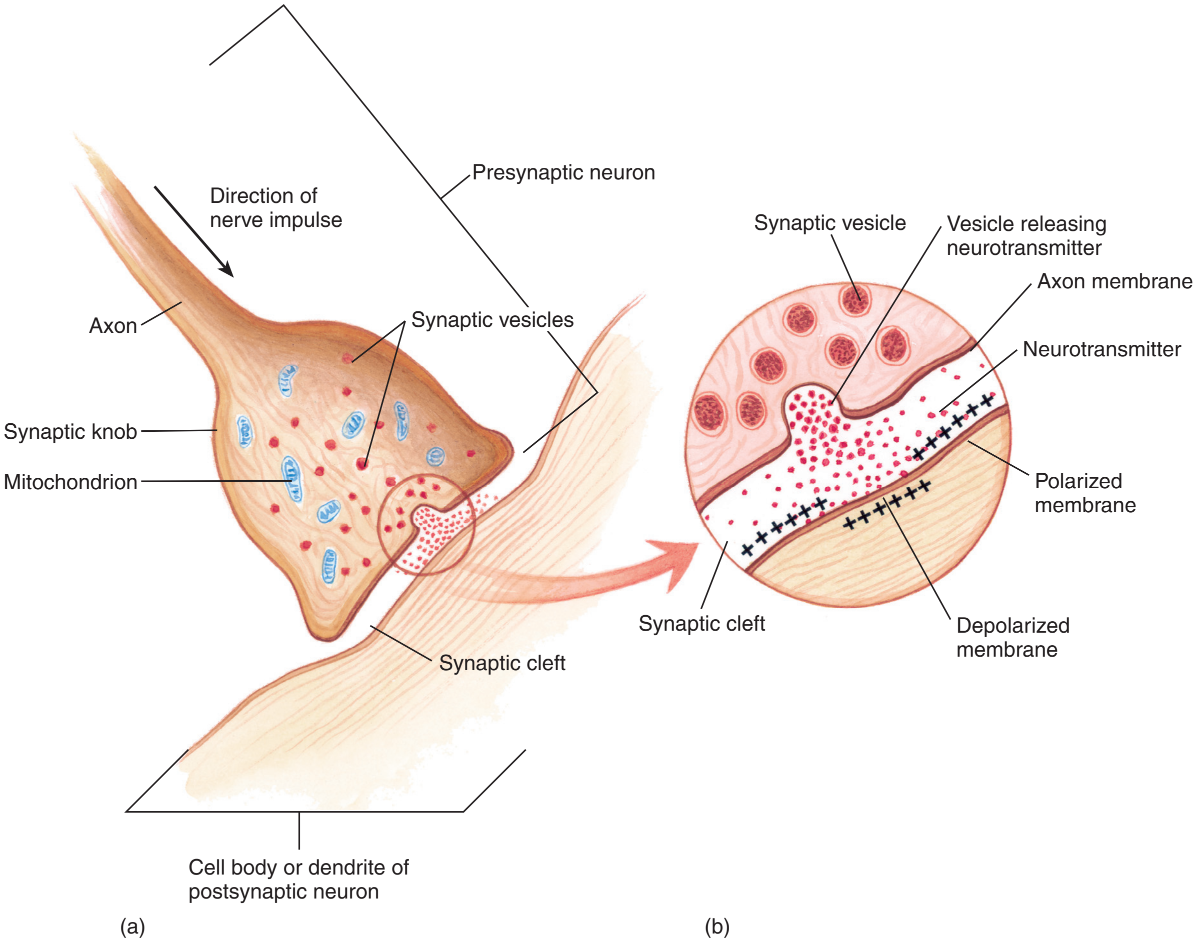


**Figure 8.7** Synaptic transmission from neuron to neuron. (*a*) A synaptic knob of the presynaptic neuron fits into a depression on a dendrite or the cell body of the postsynaptic neuron. When an impulse reaches the synaptic knob, a neurotransmitter is released into the synaptic cleft. (*b*) The neurotransmitter binds with receptors on the membrane of the postsynaptic neuron, causing depolarization of the membrane.

Each postsynaptic neuron has synaptic knobs of hundreds of presynaptic neurons attached to its dendrites and cell body. Some presynaptic neurons secrete excitatory neurotransmitters, and others secrete inhibitory neurotransmitters. Whether or not an impulse is formed in the postsynaptic neuron depends on which type of neurotransmitter is predominant at any instant.

***How are nerve impulses formed and conducted?***
***What is the mechanism of synaptic transmission?***

# Protection for the Central Nervous System

Both the brain and spinal cord are soft, delicate organs that would be easily damaged without adequate protection. Surrounding bones and fibrous membranes provide both protection and support. The brain occupies the cranial cavity formed by the cranial bones, and the spinal cord lies within the vertebral canal formed by the vertebrae. Three membranes are located between the central nervous system and the surrounding bones. These membranes are collectively called the meninges.

## Meninges

The **meninges** (me-nin′-jēs) consist of three membranes arranged in layers. From innermost to outermost, they are the pia mater, arachnoid mater, and dura mater (figures 8.8 and 8.9).

The *pia mater* is the very thin, innermost membrane. It tightly envelops both the brain and spinal cord and penetrates into each groove and depression. It contains many blood vessels that nourish the underlying brain and spinal cord.

The *arachnoid* (ah-rak′-noyd) *mater* is the middle membrane. It is a thin, weblike membrane without blood vessels, and it does not penetrate into the small depressions as does the pia mater. Between the pia mater and arachnoid mater is the *subarachnoid space,* which contains *cerebrospinal fluid.* This clear, watery liquid serves as a shock absorber around the brain and spinal cord.

The *dura* (du′-rah) *mater* is the tough, fibrous outermost layer. In the cranial cavity, it is attached to the inner surfaces of the cranial bones and penetrates into fissures between some parts of the brain. In the vertebral canal, the dura mater forms a protective tube that extends to the sacrum. It does not attach to the bony surfaces of the vertebral canal but is separated from the bone by an *epidural space.* Fatty connective tissues fill the epidural space and serve as an additional protective cushion.

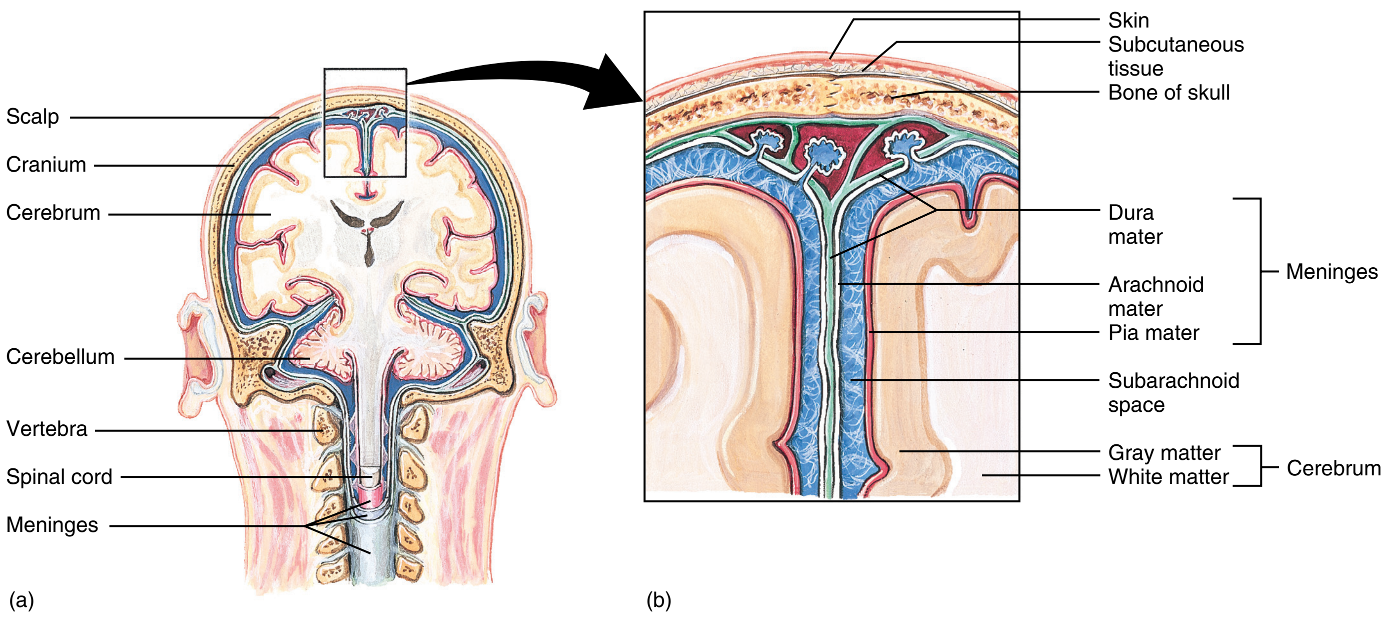


**Figure 8.8** (*a*) Membranes called meninges enclose the brain and spinal cord. (*b*) The meninges include three layers: dura mater, arachnoid mater, and pia mater.

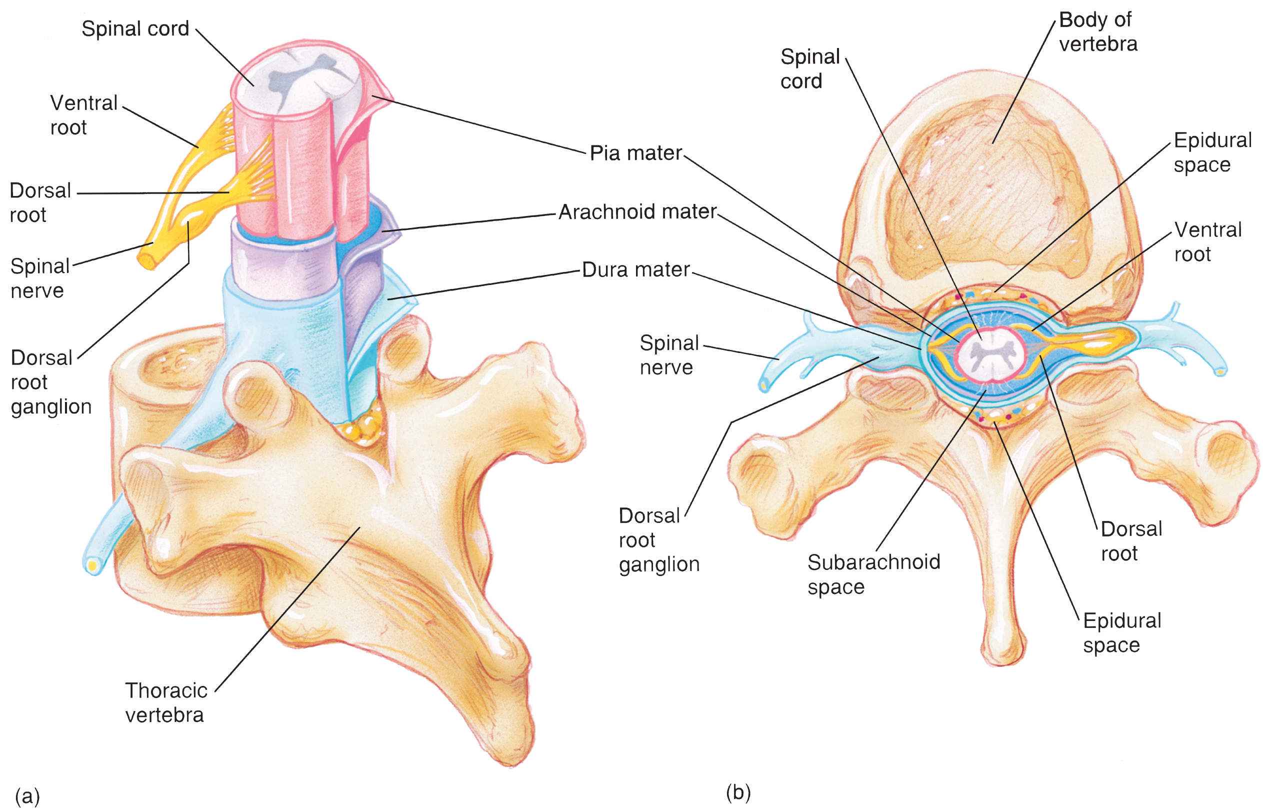


**Figure 8.9** Meninges and spinal cord. (*a*) The meninges support and protect the spinal cord. (*b*) Fatty connective tissue fills the epidural space providing a protective cushion.

> Inhibitory and stimulatory drugs act by affecting synaptic transmission. *Tranquilizers* and *anaesthetics* inhibit synaptic transmission by increasing the threshold of postsynaptic neurons. *Nicotine, caffeine,* and *benzedrine* promote synaptic transmission by decreasing the threshold of postsynaptic neurons.

# Brain

The brain is a large, exceedingly complex organ. It contains about 100 billion neurons and innumerable neuron processes and synapses. The brain consists of four major components: the cerebrum, cerebellum, diencephalon, and brain stem. Locate these structures in figure 8.10.

## Cerebrum

The **cerebrum** is the largest portion of the brain. It performs the higher brain functions involved with sensations, voluntary actions, reasoning, planning, and problem solving.

### *Structure*

The cerebrum consists of the left and right **cerebral hemispheres,** which are joined by a mass of myelinated neuron processes called the **corpus callosum.** The cerebral hemispheres are separated by the **longitudinal fissure,** which lies along the superior midline and extends down to the corpus callosum.

The surface of the cerebrum has numerous folds or ridges, called *gyri* (jī′-rē). The shallow grooves between the gyri are called *sulci* (sul′-sē). The surface layer of the cerebrum is composed of gray matter (neuron cell bodies and unmyelinated fibers) and is called the **cerebral cortex.** White matter, composed of myelinated fibers, lies beneath the cortex and composes most of the cerebrum. Myelinated fibers transmit impulses between the cerebral hemispheres via the corpus callosum and between the cerebral cortex and lower brain centers. Several masses of gray matter are embedded deep within the white matter of each cerebral hemisphere.

Each cerebral hemisphere is divided into four lobes. Each lobe is named for the cranial bone under which it lies. Locate the cerebral lobes in figures 8.10 and 8.11.

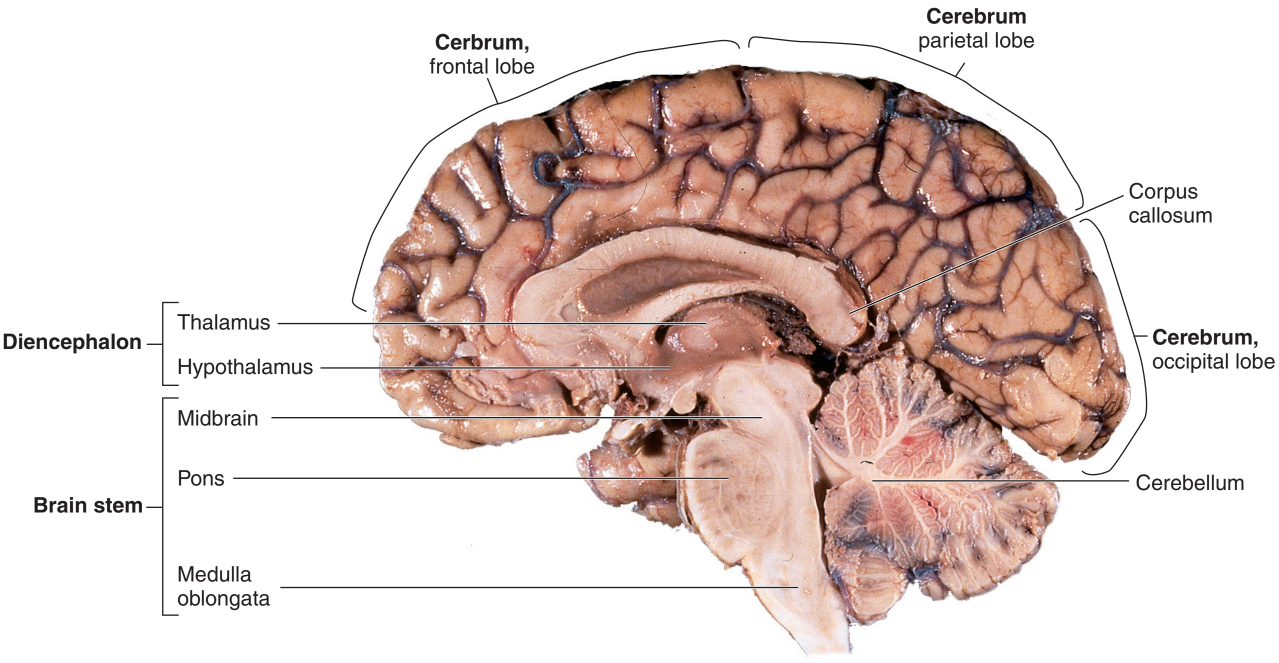


**Figure 8.10** The major components of the brain as show in a midsagittal section. Note the unlabeled gyri and sulci of the cerebrum.

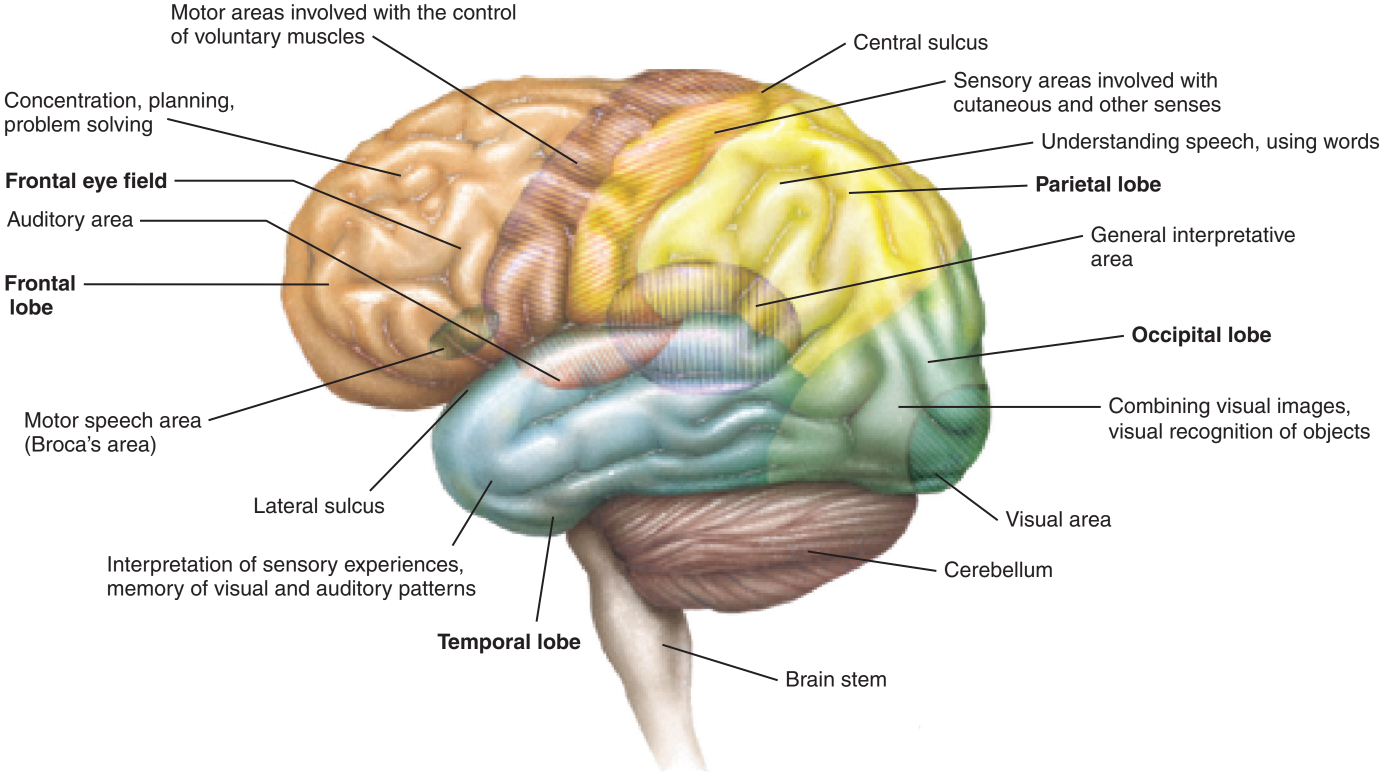


**Figure 8.11** A lateral view of the brain showing the cerebral lobes and their functional areas.

1. The **frontal lobe** lies anterior to the *central sulcus* and superior to the *lateral sulcus.*
2. The **parietal lobe** lies posterior to the central sulcus, superior to the temporal lobe, and anterior to the occipital lobe.
3. The **temporal lobe** lies inferior to the frontal and parietal lobes and anterior to the occipital lobe.
4. The **occipital lobe** lies posterior to the parietal and temporal lobes. The boundaries between the parietal, temporal, and occipital lobes are not distinct.

### *Functions*

The cerebrum is involved in the interpretation of sensory impulses as sensations and in controlling voluntary motor responses, intellectual processes, the will, and many personality traits. The cerebrum has three major types of functional areas: sensory, motor, and association areas (figure 8.11).

**Sensory areas** receive impulses formed by sensory receptors and interpret them as sensations. These areas occur in several cerebral lobes. For example, the sensory areas for vision are in the occipital lobes and those for hearing are found in the temporal lobes. Areas interpreting sensations from skin (cutaneous) stimulation lie along the *postcentral gyri* (gyri just posterior to the central sulci) of the parietal lobes, and sensory areas for taste are located at the lower end of the postcentral gyri. The sensory areas for smell are located in the inferior part of the frontal lobe.

Ascending sensory fibers cross over from one side to the other in the spinal cord or brain stem. Thus, sensory areas in the left cerebral hemisphere receive impulses from the right side of the body, and vice versa.

**Motor areas** are located in the frontal lobe. The primary motor areas that control skeletal muscles lie along the *precentral gyri* of the frontal lobes. The region anterior to the primary motor area is the *premotor area.* It is involved in complex learned activities, such as writing, problem solving, and planning. *Broca's area,* which controls the ability to speak, is located near the inferior end of the primary motor area. It is found in only one hemisphere; the left hemisphere in about 90% of people. Also in the premotor region is the *frontal eye field,* which controls eye movements.

Descending motor fibers cross over from one side to the other in the brain stem. Thus, the left side of the cerebrum controls skeletal muscles on the right side of the body, and vice versa.

**Association areas** occur in each cerebral lobe, where they interrelate sensory inputs and motor outputs. They play critical roles in the interrelationships of sensations, memory, will, and the coordination of motor responses. The *general interpretative area* is a major association area that is located at the junction of the temporal, parietal, and occipital lobes. It is involved with the interpretation of complex sensory experiences and thought processes.

> The transmission of impulses by neurons in the brain produces electrical potentials that can be detected and recorded as brain waves. A recording of brain waves is called an *electroencephalogram (EEG).* The patterns of brain waves are used in the diagnosis of certain brain disorders. The cessation of brain wave production is one criterion of brain death.

### *Hemisphere Specialization*

The two cerebral hemispheres perform different functions in most people, although each performs basic functions of receiving sensory input and initiating voluntary motor output. In about 90% of the population, the left cerebral hemisphere controls analytical and verbal skills, such as mathematics, reading, writing, and speech. In these persons, the right hemisphere controls musical, artistic, and spatial awareness, imagination, and insight. In some persons, this pattern is reversed, and in a few, there seems to be no specialization.

## Diencephalon

The **diencephalon** (di-en-sef′-a-lon) is a small but important part of the brain. It lies between the brain stem and the midbrain of the brain and consists of two major components: the thalamus and the hypothalamus.

### *Thalamus*

The **thalamus** (thal′-ah-mus) consists of two lateral masses of neural tissue that are joined by a narrow isthmus of neural tissue called the *intermediate mass.* Sensory impulses (except those for smell) coming from lower regions of the brain and the spinal cord are first received by the thalamus before being relayed to the cerebral cortex. The thalamus provides a general, but nonspecific, awareness of sensations such as pain, pressure, touch, and temperature. It seems to associate sensations with emotions, but it is the cerebral cortex that interprets the precise sensation. The thalamus also serves as a relay station for motor impulses descending from the cerebral cortex to lower brain regions.

### *Hypothalamus*

The **hypothalamus** (hī-pō-thal′-ah-mus) is located inferior to the thalamus and anterior to the midbrain. It communicates with the thalamus, cerebrum, and other parts of the brain. The hypothalamus is a major control center for the autonomic nervous system. In this role, it controls virtually all internal organs. The hypothalamus also is the connecting link between the brain and the endocrine system, which produces chemicals (hormones) that affect every cell in the body. This link results from hypothalamic control of the hypophysis, or pituitary gland, which is suspended from its inferior surface. Although it is small, the hypothalamus exerts a tremendous impact on body functions.

The primary function of the hypothalamus is the maintenance of homeostasis, and this is accomplished through its regulation of

- body temperature;
- mineral and water balance;
- appetite and digestive processes;
- heart rate and blood pressure;
- sleep and wakefulness;
- emotions of fear and rage;
- secretion of hormones by the pituitary gland.

## Limbic System

The thalamus and hypothalamus are associated with parts of the cerebral cortex and deep nuclei (concentrations of gray matter) of the cerebrum to form a complex known as the **limbic system.** The limbic system is involved in memory and in emotions such as sadness, happiness, anger, and fear. It seems to regulate emotional behavior, especially behavior that enhances survival. Mood disorders, such as depression, are usually a result of malfunctions of the limbic system.

***How is the CNS protected from mechanical injuries?***
***What are the functional areas of the cerebrum?***
***What are the functions of the thalamus and hypothalamus?***

## Brain Stem

The **brain stem** is the stalklike portion of the brain that joins higher brain centers to the spinal cord. It contains several localized masses of *gray matter,* called **nuclei,** that are surrounded by *white matter.* Ascending and descending fibers between higher brain centers and the spinal cord pass through the brain stem. The components of the brain stem include the midbrain, pons, and medulla oblongata.

### *Midbrain*

The **midbrain** is the most superior portion of the brain stem. It is located posterior to the hypothalamus and superior to the pons. It contains reflex centers for head, eye, and body movements in response to visual and auditory stimuli. For example, reflexively turning the head to enable better vision or better hearing is activated by the midbrain.

### *Pons*

The **pons** lies between the midbrain and the medulla oblongata and is recognizable by its bulblike anterior portion. It consists primarily of nerve fibers. Longitudinal fibers connect lower and higher brain centers, and transverse fibers connect with the cerebellum. The pons works with the medulla oblongata to control the rate and depth of breathing.

### *Medulla Oblongata*

The **medulla oblongata** (me-dūl′-ah ob-lon-ga′-ta) is the most inferior portion of the brain, and it is the connecting link with the spinal cord. Ascending and descending fibers extending between the brain and spinal cord cross over to the opposite side of the brain within the medulla. The medulla contains three control centers that are vital for homeostasis:

1. The **respiratory control center** works with the pons to regulate the rate and depth of breathing. It is also involved in associated reflexes such as coughing and sneezing.
2. The **cardiac control center** regulates the rate of heart contractions.
3. The **vasomotor center** regulates blood pressure and blood flow by controlling the diameter of blood vessels.

## Reticular Formation

The **reticular** (re-tik′-ū-lar) **formation** is a network of nerve fibers and small nuclei of gray matter scattered in the brain stem and spinal cord. Its fibers connect centers in the hypothalamus, cerebrum, and cerebellum. This network generates and transmits impulses that arouse the cerebrum to wakefulness. A decrease in activity results in sleep. Damage to the reticular formation may cause unconsciousness or a coma.

## Cerebellum

The **cerebellum** (ser-e-bel′-um) is the second largest portion of the brain. It is located inferior to the occipital and temporal lobes of the cerebrum posterior to the pons and medulla oblongata. It is divided into two lateral hemispheres by a medial constriction, the **vermis** (ver′-mis). Gray matter forms a thin outer layer covering the underlying white matter, which forms most of the cerebellum.

The cerebellum is a reflex center that controls and coordinates the interaction of skeletal muscles. It controls posture, balance, and muscle coordination. Damage to the cerebellum may result in a loss of equilibrium, muscle coordination, and muscle tone.

Table 8.1 summarizes the major brain functions.

***What are the functions of the medulla oblongata? How is the cerebellum involved in skeletal muscle contractions?***

## Ventricles and Cerebrospinal Fluid

There are four interconnecting **ventricles,** or cavities, within the brain. Each ventricle is lined by ependymal cells and is filled with **cerebrospinal fluid.** The largest ventricles are the two *lateral ventricles* (first and second ventricles), which are located within the cerebral hemispheres. The *third ventricle* is a narrow space that lies on the midline between the lateral masses of the thalamus and hypothalamus. The *fourth ventricle* is located on the midline in the posterior portion of the brain stem just anterior to the cerebellum. It is continuous with the central canal of the spinal cord. Observe the relative positions of the ventricles in figure 8.12.

Each ventricle contains a **choroid** (kō′-royd) **plexus,** a mass of special capillaries that secrete the cerebrospinal fluid, but most of the cerebrospinal fluid is produced in the lateral ventricles. From the lateral ventricles, the cerebrospinal fluid flows into the third ventricle and on into the fourth ventricle. From the fourth ventricle, some of the fluid flows down the central canal of the spinal cord, but most of it passes into the subarachnoid space of the meninges. Within the subarachnoid space, the cerebrospinal fluid flows in two directions. Some flows upward around the brain. The remainder flows down the posterior side of the spinal cord, returns upward along its anterior surface, and continues upward around the brain in the subarachnoid space. Cerebrospinal fluid is reabsorbed into the blood-filled dural sinus that is located along the superior midline within the dura mater (figures 8.8 and 8.13). The secretion and absorption of cerebrospinal fluid normally occurs at equal rates, which results in a rather constant hydrostatic pressure within the ventricles and subarachnoid space.

### Table 8.1 Summary of Brain Functions

| Part | Function |
|---|---|
| Cerebrum | Sensory areas interpret impulses as sensations. Motor areas control voluntary muscle actions. Association areas interrelate various sensory and motor areas and are involved in intellectual processes, will, memory, emotions, and personality traits. The limbic system is involved with emotions as they relate to survival behavior. |
| Cerebellum | Controls posture, balance, and the coordination of skeletal muscle contractions. |
| ***Diencephalon*** | |
| Thalamus | Receives and relays sensory impulses (except smell) to the cerebrum and motor impulses to lower brain centers. Provides a general awareness of pain, touch, pressure, and temperature and determines sensations as pleasant or unpleasant. |
| Hypothalamus | Serves as a major control center for the autonomic nervous system. Controls water and mineral balance, heart rate and blood pressure, appetite and digestive activity, body temperature, and sexual response. Is involved in sleep and wakefulness and in emotions of anger and fear. Regulates functions of the pituitary gland. |
| ***Brain Stem*** | |
| Midbrain | Relays sensory impulses from the spinal cord to the thalamus and motor impulses from the cerebrum to the spinal cord. Contains reflex centers that move eyeballs in response to visual stimuli and head and neck in response to auditory stimuli. |
| Pons | Relays impulses between the midbrain and the medulla and between the cerebellar hemispheres. Helps medulla control breathing. |
| Medulla | Relays impulses between the brain and spinal cord. Reflex centers control heart rate, blood vessel diameter, breathing, swallowing, vomiting, coughing, sneezing, and hiccupping. Sensory and motor fibers cross over to the opposite side. Reticular formation (also in midbrain and pons) controls wakefulness. |

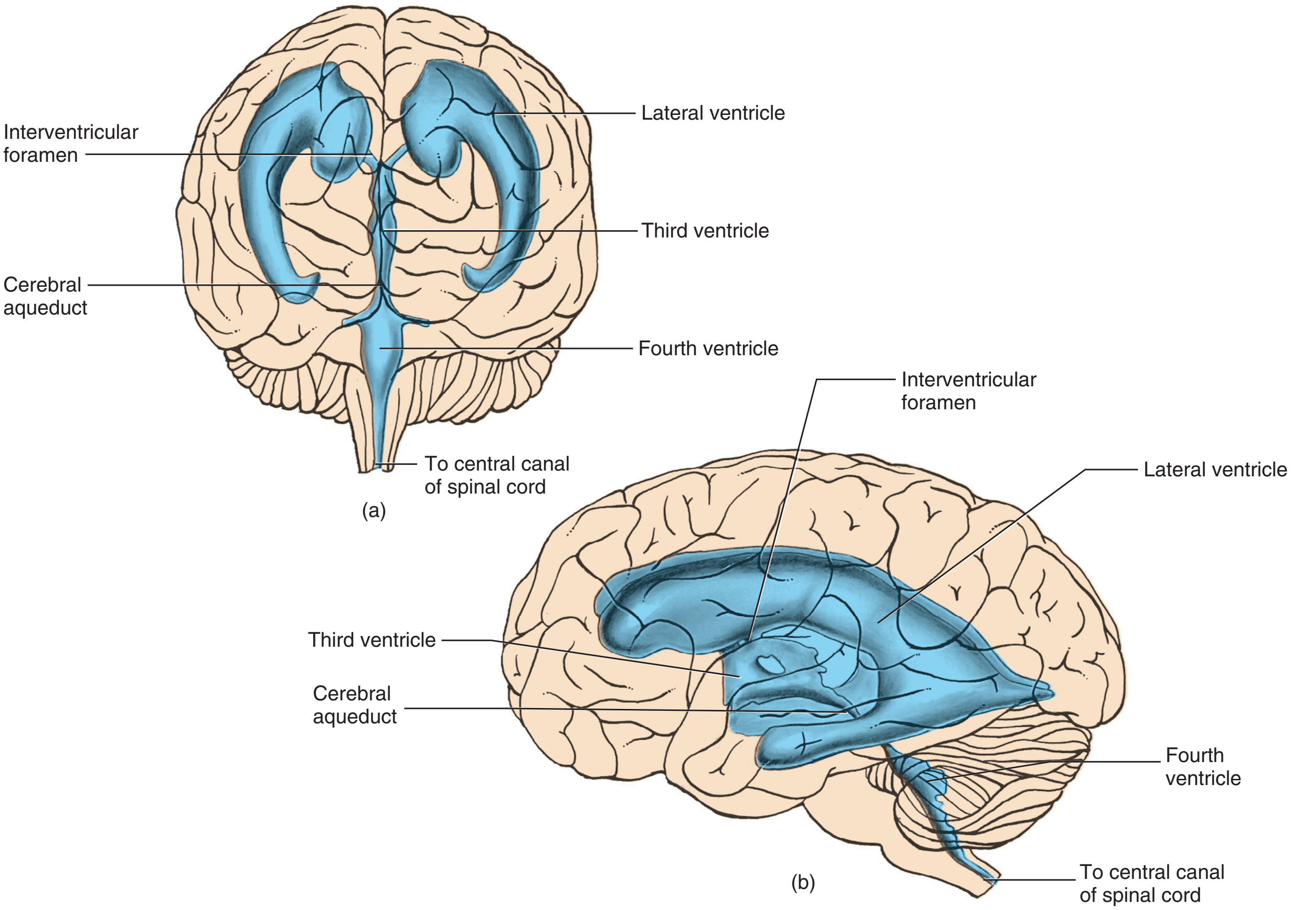


**Figure 8.12** Anterior (*a*) and lateral (*b*) views of the ventricles of the brain. Note how they are interconnected.

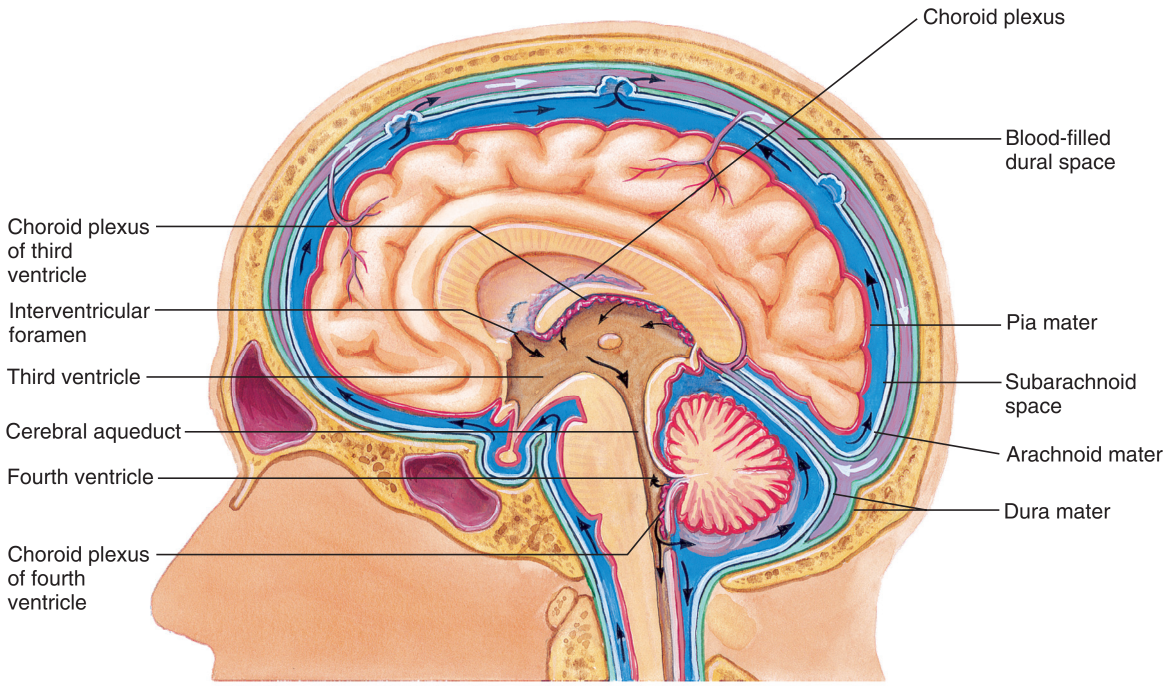


**Figure 8.13** Circulation of cerebrospinal fluid. Choroid plexuses in ventricle walls secrete cerebrospinal fluid. The fluid flows through the ventricles, central canal of the spinal cord, and subarachnoid space. It is reabsorbed into the blood of the dural sinus.

# Spinal Cord

The **spinal cord** is continuous with the brain. It descends from the medulla oblongata through the foramen magnum into the vertebral canal and extends to the second lumbar vertebra. Beyond this point, only the proximal portions of the lower spinal nerves occupy the vertebral canal.

## Structure

The spinal cord is cylindrical in shape. It has two small grooves that extend throughout its length: the wider *anterior median fissure* and the narrower *posterior median sulcus.* These grooves divide the spinal cord into left and right portions. Thirty-one pairs of spinal nerves branch from the spinal cord.

The cross-sectional structure of the spinal cord is shown in figures 8.9 and 8.14. Gray matter, shaped like the outstretched wings of a butterfly, is centrally located and is surrounded by white matter. The *central canal* extends the length of the spinal cord and contains cerebrospinal fluid.

In *hydrocephalus,* a congenital defect restricts the movement of cerebrospinal fluid from the ventricles into the subarachnoid space. In severe cases, the buildup of hydrostatic pressure within an infant's brain causes a marked enlargement of the ventricles and brain and widens the fontanels of the cranium. Without treatment, death usually results within two to three years. Treatment involves surgical insertion of a small tube to drain the excess fluid from a ventricle into a blood vessel in the neck.

The pointed projections of the gray matter, as seen in cross section, are called horns. The *anterior horns* contain the cell bodies of motor neurons whose axons enter spinal nerves and carry impulses to muscles and glands. The *posterior horns* contain interneurons that receive impulses from sensory neurons in the spinal nerves and carry them to sites

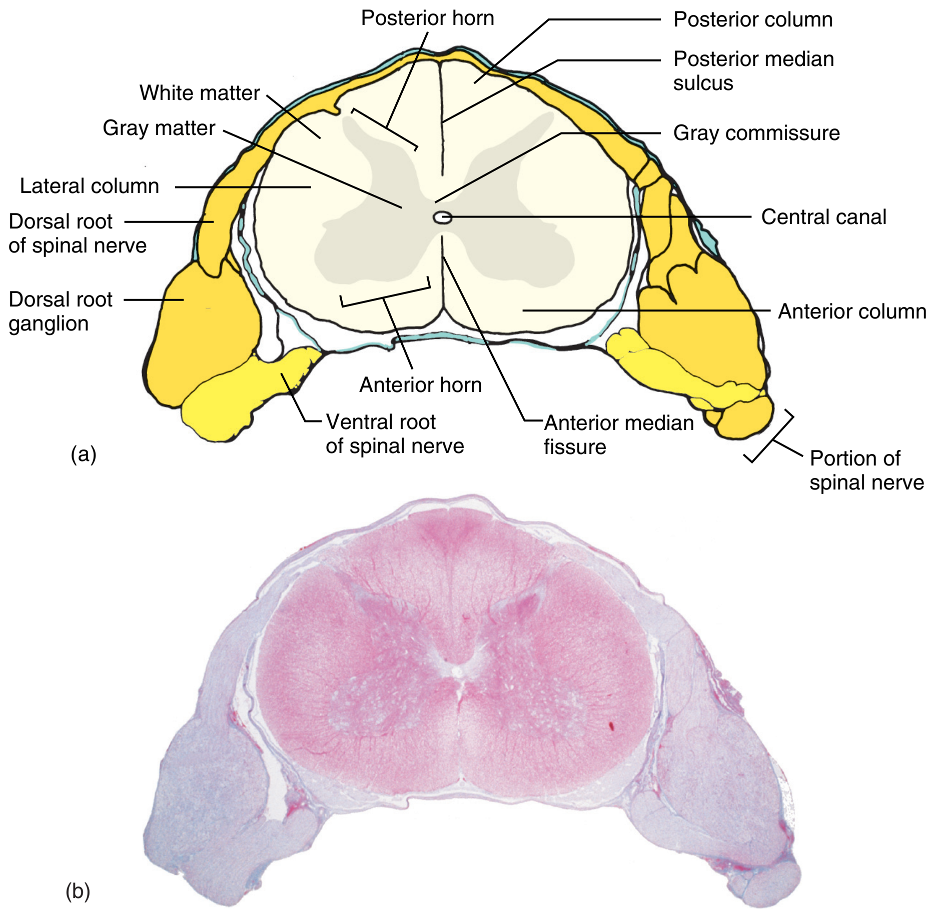


**Figure 8.14** A drawing (*a*) and a photomicrograph (*b*) of the spinal cord in cross section show its basic structure.

cranial nerves arise from the brain stem. Cranial nerves are identified by both Roman numerals and names. The numerals indicate the order in which the nerves arise from the inferior surface of the brain: I is most anterior, XII is most posterior (figure 8.15).

Most cranial nerves are mixed nerves. A few are sensory, and some are mixed but primarily motor nerves.

## Spinal Nerves

Thirty-one pairs of **spinal nerves** arise from the spinal cord. The first pair branches from the spinal cord between the atlas and the occipital bone. The remaining spinal nerves emerge from the spinal cord and pass between adjacent vertebrae through the *intervertebral foramina.* Spinal nerves are mixed nerves.

Spinal nerves are identified by the spinal region from which they branch and are numbered in sequence within each region. There are eight pairs of *cervical nerves* (C1–C8), twelve pairs of *thoracic nerves* (T1–T12), five pairs of *lumbar nerves* (L1–L5), five pairs of *sacral nerves* (S1–S5), and one pair of *coccygeal nerves* (figure 8.16).

As shown in figure 8.16, the spinal cord ends at the second lumbar vertebra. Proximal portions of lumbar, sacral, and coccygeal spinal nerves continue down the vertebral canal to exit between the appropriate vertebrae. The bases of these nerves form the *cauda equina,* or horse's tail, in the inferior portion of the vertebral canal.

Spinal nerves branch from the spinal cord by two short roots that merge a short distance from the spinal cord to form a spinal nerve. The **anterior root** contains axons of motor neurons whose cell bodies are located within the spinal cord. These neurons carry motor impulses from the spinal cord to effectors. The **posterior root** contains sensory neurons. The swollen region in a posterior root is a

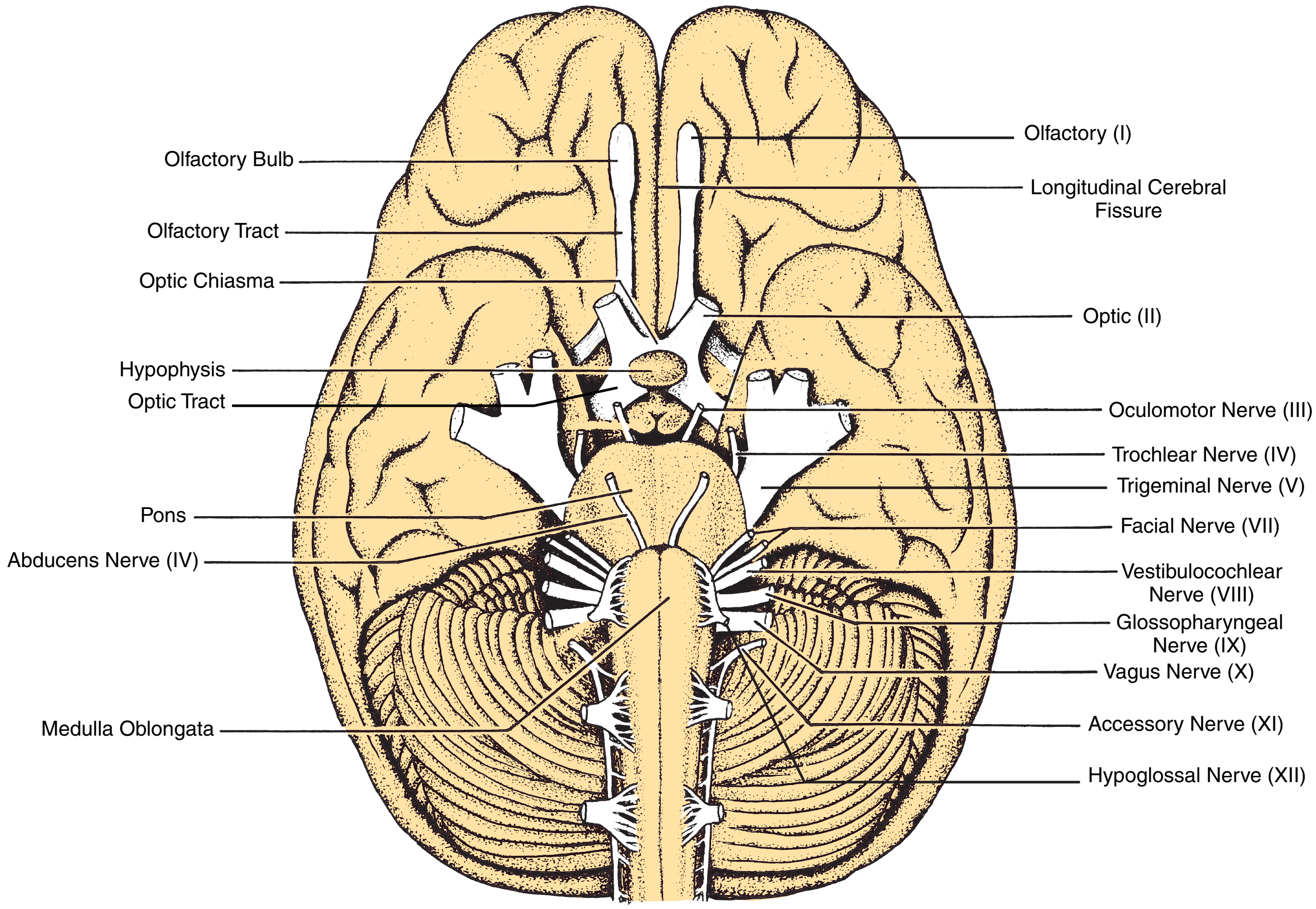


**Figure 8.15** A ventral view of the brain showing the roots of the 12 pairs of cranial nerves. Cranial nerves are identified by both roman numerals and names. Most cranial nerves arise from the brain stem.

**spinal ganglion,** which contains cell bodies of sensory neurons. The long axons of these neurons carry sensory impulses to the spinal cord. Observe these structures and their relationships in figures 8.9, 8.14, and 8.17.

### *Spinal Plexuses*

After a spinal nerve passes through an intervertebral foramen, it divides into two or three major parts: an anterior branch, a posterior branch, and, in thoracic and lumbar spinal nerves only, a visceral branch. The posterior branch continues directly to the innervated structures. The visceral branch passes to the sympathetic chain ganglia and is part of the autonomic system. The anterior branches of many spinal nerves merge to form a **plexus** (plek′-sus), a network of nerves, before continuing to the innervated structures.

In a plexus, the nerve fibers in the anterior branches are sorted and recombined so that fibers going to a specific body part are carried in the same spinal nerve, although they may originate in several different spinal nerves. There are four pair of plexuses: cervical, brachial, lumbar, and sacral plexuses. Because many fibers from the lumbar plexus contribute to the sacral plexus, these two plexuses are sometimes called the *lumbosacral plexuses.* The anterior branches of most thoracic spinal nerves (T2–T11) take a direct route to the skin and muscles of the trunk that they supply (figure 8.16).

**Cervical Plexus** The first four cervical nerves (C1–C4) merge to form a **cervical plexus** on each side of the neck. The nerves from these plexuses supply the muscles and skin of the neck and portions of the head and shoulders. The paired *phrenic* (fren′-ik) *nerves,* which stimulate the diaphragm to contract, producing inspiration, also arise from the cervical plexus.

**Brachial Plexus** The last four cervical nerves (C5–C8) and the first thoracic nerve (T1) join to form a **brachial plexus** on each side of the vertebral column in the shoulder region. Nerves that serve skin and muscles of the arms and shoulders emerge from the brachial plexuses. The *musculocutaneous, axillary, radial, median,* and *ulnar nerves* arise here.

**Lumbar Plexus** The last thoracic nerve (T12) and the first four lumbar nerves (L1–L4) unite to form a **lumbar plexus** on each side of the vertebral column just above the hip bones. Nerves from the lumbar plexus supply the skin and muscles of the lower trunk, genitalia, and part of the thighs. The *femoral* and *obturator nerves* arise here.

**Sacral Plexus** The last two lumbar nerves (L4–L5) and the first four sacral nerves (S1–S4) merge to form a **sacral plexus** on each side of the sacrum within the pelvic girdle. Nerves from the sacral plexuses supply the skin and muscles of the buttocks and legs. The *sciatic nerves,* which emerge from the sacral plexuses, are the largest nerves in the body.

***What composes the peripheral nervous system? What is a spinal plexus?***

## Reflexes

**Reflexes** are rapid, involuntary, and predictable responses to internal and external stimuli. Reflexes maintain homeostasis and enhance chances of survival. A reflex involves either the brain or spinal cord, a receptor, sensory and motor neurons, and an effector.

Most pathways of impulse transmission within the nervous system are complex and involve many neurons. In contrast, reflexes require few neurons in their pathways and therefore produce very rapid responses to stimuli. Reflex pathways are called **reflex arcs.**

Reflexes are divided into two types: autonomic and somatic reflexes. *Autonomic reflexes* act on smooth muscle, cardiac muscle, and glands. They are involved in controlling homeostatic processes such as heart rate, blood pressure, and digestion. Autonomic reflexes maintain homeostasis and normal body functions at the unconscious level, which frees the mind to deal with

Because the spinal cord ends at the level of the second lumbar vertebra, spinal taps and epidural anesthetics are administered inferior to this point. For these procedures, a patient is placed in a fetal position in order to open the spaces between the posterior margins of the vertebrae. A hypodermic needle is inserted through the intervertebral disk either between the third and fourth lumbar vertebrae or between the fourth and fifth lumbar vertebrae. In a *spinal tap* (lumbar puncture), a hypodermic needle is inserted into the subarachnoid space to remove spinal fluid for diagnostic purposes. An *epidural anesthetic* is given by injecting an anesthetic into the epidural space with a hypodermic syringe. The anesthetic prevents sensory impulses from reaching the spinal cord via spinal nerves inferior to the injection. Epidurals are sometimes used to ease pain during childbirth.

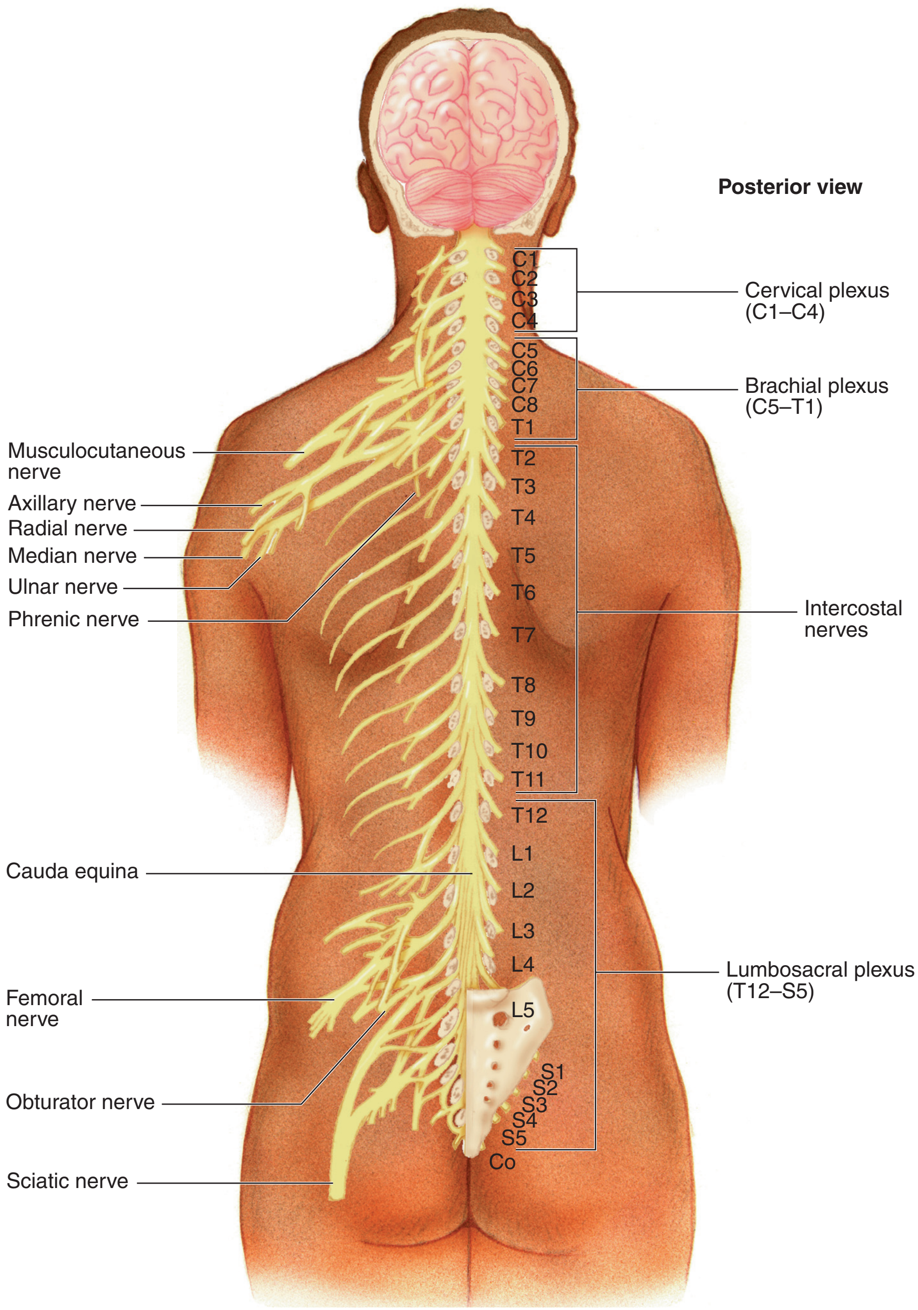


**Figure 8.16** Thirty-one pairs of spinal nerves arise from the spinal cord. Anterior branches of spinal nerves in the thorax form the intercostal nerves. Those in other regions form nerve networks called plexuses before continuing on to their target tissues.

those actions that require conscious decisions. *Somatic reflexes* act on skeletal muscles. They enable quick movements such as moving your hand away from a painful stimulus. A person is usually unaware of autonomic reflexes but is aware of somatic reflexes.

Figure 8.17 illustrates a somatic spinal reflex, which withdraws the hand after sticking a finger with a tack. Three neurons are involved in this reflex. Pain receptors are stimulated by the sharp pin and form impulses that are carried by a sensory neuron to an interneuron in the spinal cord. Impulses pass along the interneuron to a motor neuron, which carries the impulses to a muscle that contracts to move the hand. Although the brain is not involved in this reflex, it does receive sensory impulses that make a person aware of a painful stimulus resulting in the quick withdrawal of the hand.

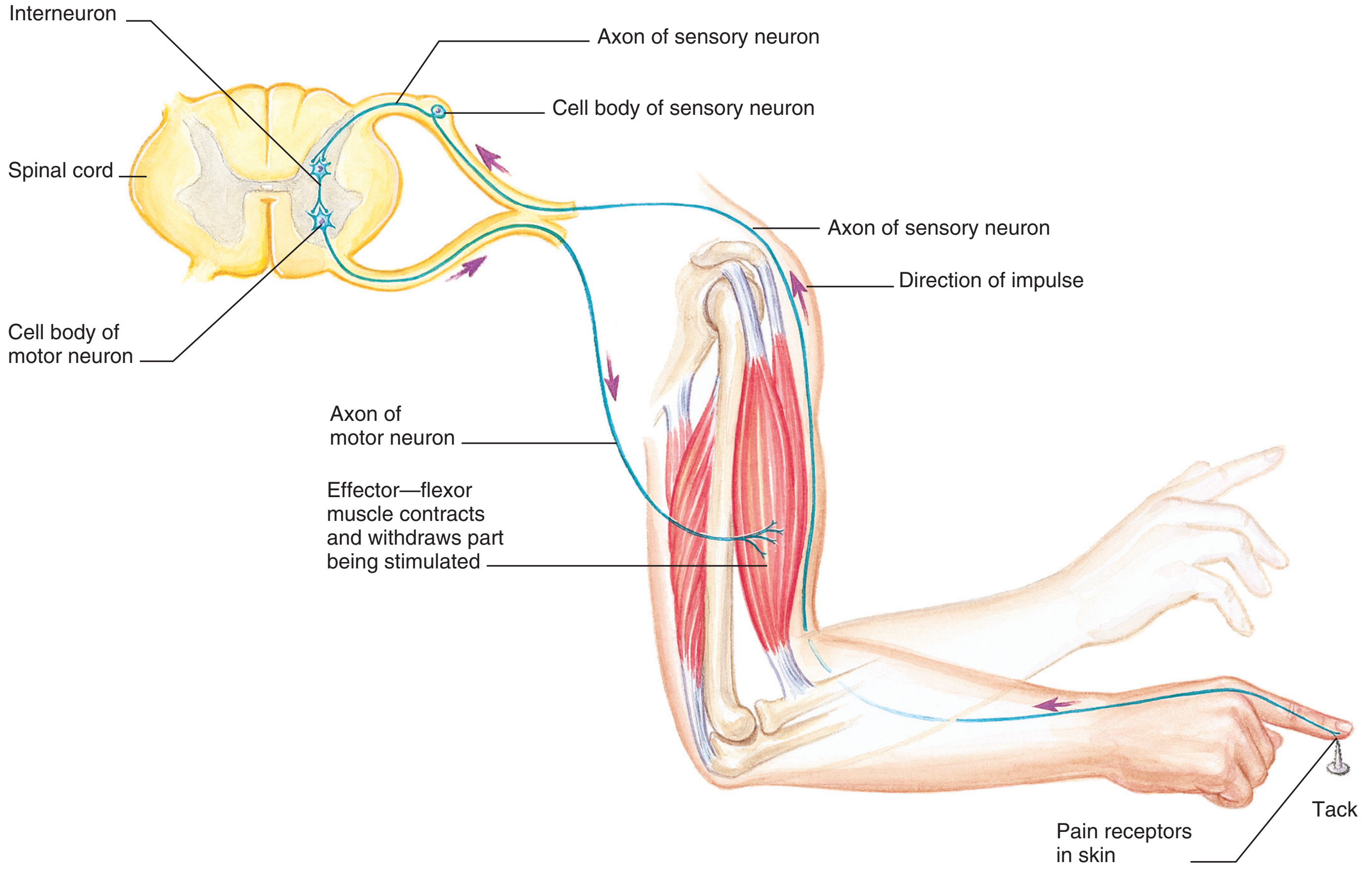


**Figure 8.17** A withdrawal reflex involves a sensory neuron, an interneuron, and a motor neuron.

***What is a reflex?***
***What are the components of a spinal reflex?***

Because the responses of reflexes are predictable, physicians usually test a patient's reflexes in order to determine the health of the nervous system. Exaggerated, diminished, or distorted reflexes may indicate a neurological disorder.

# Autonomic Nervous System (ANS)

The *autonomic* (aw-to-nom′-ik) *nervous system (ANS)* consists of portions of the central and peripheral nervous systems, and it functions involuntarily without conscious control. Its role is to maintain homeostasis in response to changing internal conditions. The effectors under autonomic control are cardiac muscle, smooth muscle, and glands. The ANS functions mostly by involuntary reflexes. Sensory impulses carried to the autonomic reflex centers in the hypothalamus, brain stem, or spinal cord cause motor impulses to be carried to effectors via cranial or spinal nerves. Higher brain centers, such as the limbic system and cerebral cortex, influence the ANS during times of emotional stress.

Table 8.3 compares the somatic and autonomic nervous systems.

## Organization

Autonomic nerve fibers are motor fibers. Unlike the somatic nervous system, in which a single motor neuron extends from the central nervous system to an effector, the ANS uses two motor neurons in sequence to carry

**Table 8.3 Comparison of Somatic and Autonomic Nervous Systems**

| | Somatic | Autonomic |
|---|---|---|
| ***Control*** | Voluntary | Involuntary |
| ***Neural Pathway*** | One motor neuron extends from the CNS to an effector | A preganglionic neuron extends from the CNS to an autonomic ganglion and synapses with a postganglionic neuron that extends to an effector |
| ***Neurotransmitters*** | Acetylcholine | Acetylcholine or norepinephrine |
| ***Effectors*** | Skeletal muscles | Smooth muscle, cardiac muscle, and glands |
| ***Action*** | Excitatory | Excitatory or inhibitory |

motor impulses to an effector. The first neuron, or *preganglionic neuron,* extends from the CNS to an **autonomic ganglion,** a mass of neuron cell bodies. The cell body of the preganglionic neuron is located in the brain or spinal cord. The second neuron, or *postganglionic neuron,* extends from the autonomic ganglion to the visceral effector, and its cell body is located within the autonomic ganglion (figure 8.18).

The autonomic nervous system is subdivided into the **sympathetic division** and the **parasympathetic division.** The origin of their motor neurons and the organs innervated are shown in figure 8.19.

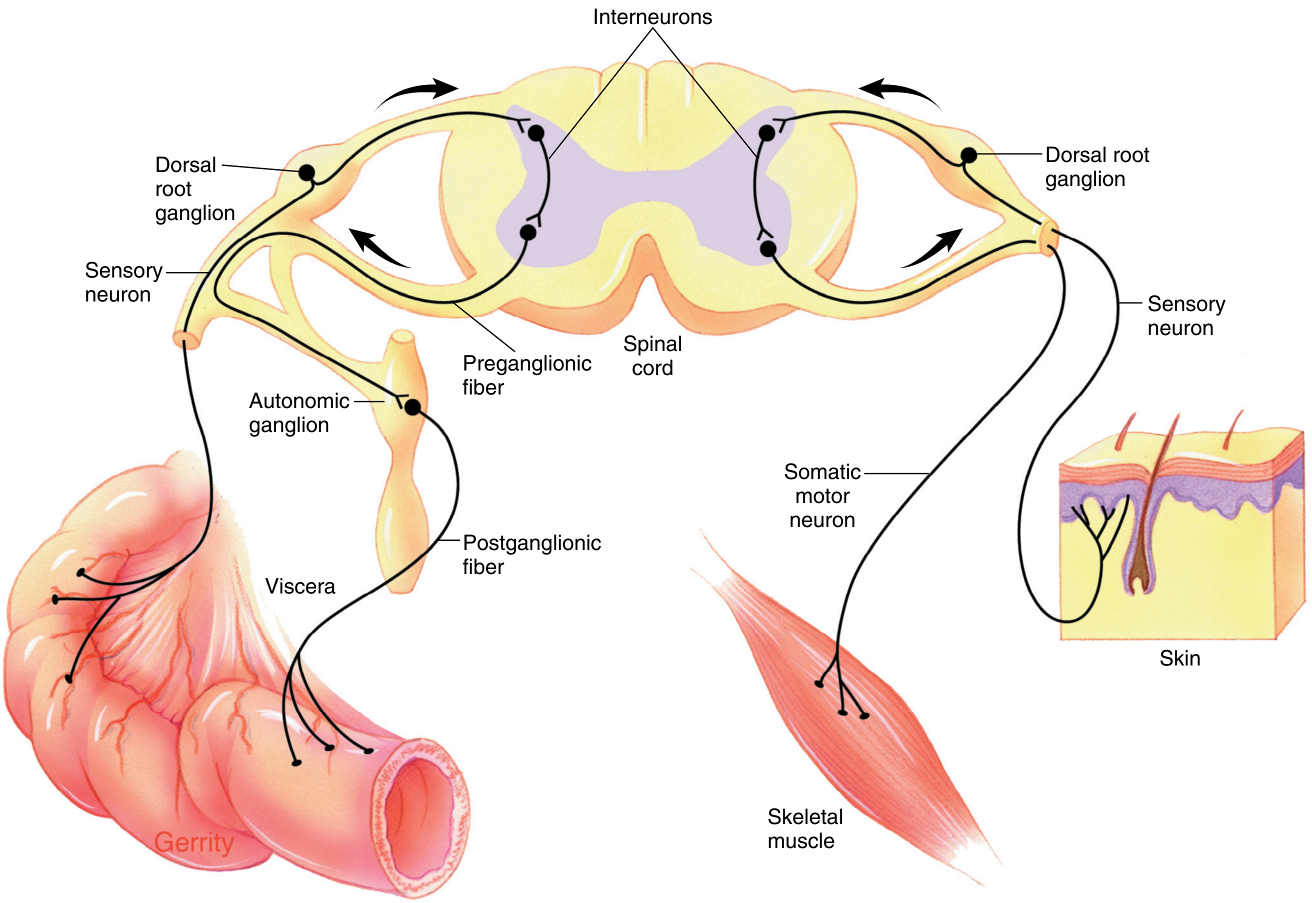


**Figure 8.18** Comparison of autonomic and somatic motor pathways in spinal nerves. (*a*) An autonomic pathway involves a presynaptic neuron and a postsynaptic neuron that synapse at a ganglion outside the spinal cord. (*b*) A somatic pathway involves a single neuron.

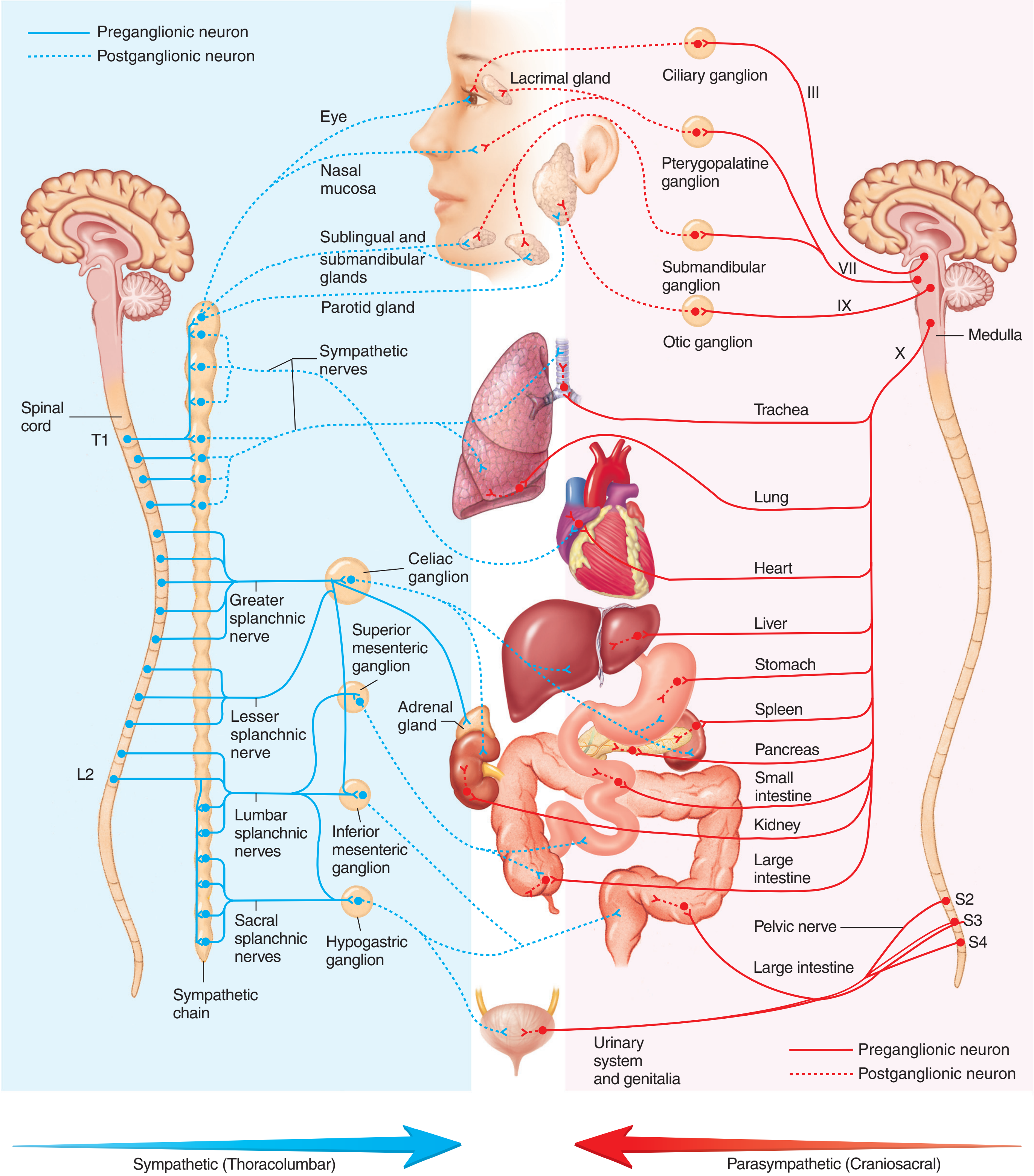


**Figure 8.19** Innervation of internal organs by the autonomic nervous system.

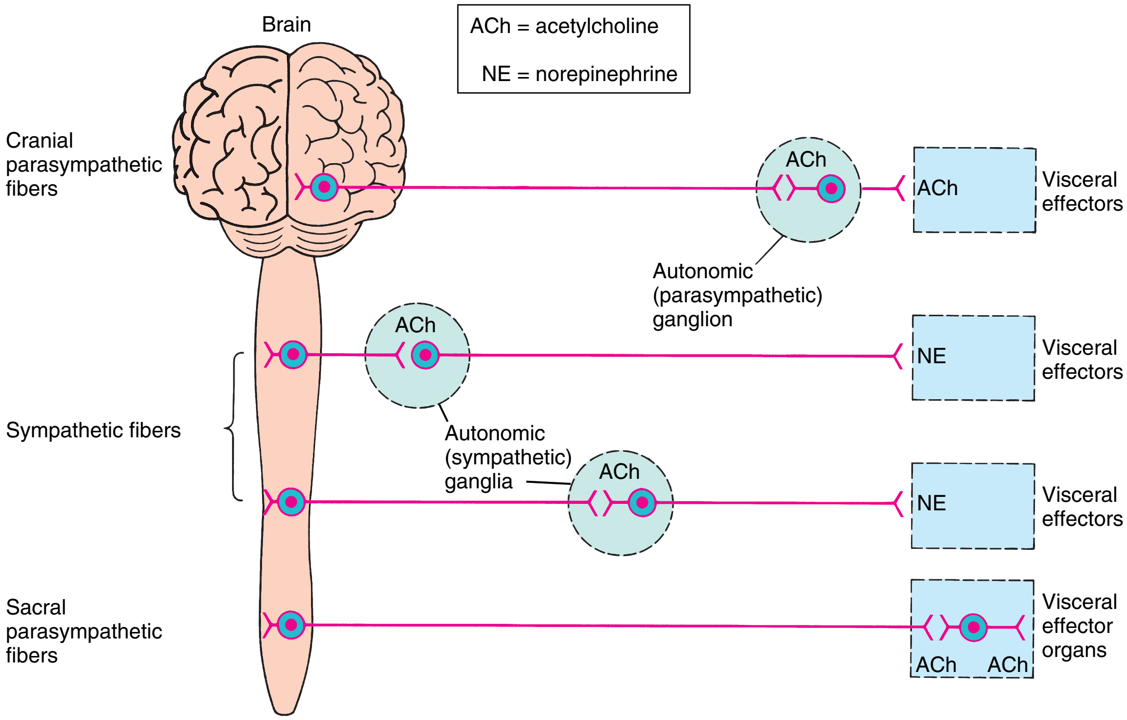


**Figure 8.20** Parasympathetic fibers are cholinergic and secrete acetylcholine at the ends of postganglionic fibers. Most sympathetic fibers are adrenergic and secrete norepinephrine at the ends of postganglionic fibers.

Preganglionic fibers of the sympathetic division arise from the thoracic and lumbar regions of the spinal cord—spinal nerves T1–L2. Some sympathetic fibers branch from the spinal nerves to synapse with postganglionic neurons in autonomic ganglia that are arranged in two chains, one on each side of the vertebral column. These ganglia are called *paravertebral* or *sympathetic chain ganglia.* Other sympathetic preganglionic fibers pass through a paravertebral chain ganglion without synapsing and extend to another type of ganglion, a *collateral ganglion,* before synapsing with a postganglionic neuron. Both pathways are shown in figure 8.19.

Preganglionic fibers of the **parasympathetic division** arise from the brain stem and sacral region (S2–S4) of the spinal cord. They extend through cranial or sacral nerves to synapse with postganglionic neurons within ganglia that are located very near or within visceral organs (figure 8.19).

Most visceral organs receive postganglionic fibers of both the sympathetic and parasympathetic divisions, but a few, such as sweat glands and most blood vessels, receive only sympathetic fibers. Figure 8.20 summarizes the organizational differences between the sympathetic and parasympathetic divisions.

## Autonomic Neurotransmitters

Preganglionic fibers of both the sympathetic and parasympathetic divisions secrete *acetylcholine* to initiate impulses in postganglionic neurons, but their postganglionic fibers secrete different neurotransmitters. Sympathetic postganglionic fibers secrete *norepinephrine,* a substance similar to adrenalin, and they are called *adrenergic fibers.* Parasympathetic postganglionic fibers secrete acetylcholine, and thus are called *cholinergic fibers* (figure 8.20).

## Functions

Both sympathetic and parasympathetic divisions stimulate some visceral organs and inhibit others, but their effects on a given organ are opposite. For example, the sympathetic division increases heart rate while the parasympathetic division slows heart rate. The contrasting effects are due to the different neurotransmitters secreted by postganglionic sympathetic and parasympathetic fibers and the receptors of the receiving organs.

The sympathetic division prepares the body for physical action to meet emergencies. Its action has been summarized as preparing the body for *fight or flight.* The parasympathetic division is dominant under the normal, nonstressful conditions of everyday

**Table 8.4 Representative Actions of the Autonomic Nervous System**

| Effector | Sympathetic Stimulation | Parasympathetic Stimulation |
|---|---|---|
| Eye | Dilation of pupil; changes lens shape for far vision | Constriction of pupil; changes lens shape for near vision |
| Heart | Increases rate and strength of contraction | Decreases rate and strength of contraction |
| Arterioles | Constriction increases blood pressure | No known action |
| Blood distribution | Increases supply to skeletal muscles; decreases supply to digestive organs | Decreases supply to skeletal muscles; increases supply to digestive organs |
| Lungs | Dilates bronchioles | Constricts bronchioles |
| Digestive tract | Inhibits motility and secretion by glands | Promotes motility and secretion by glands |
| Liver | Decreases bile production; increases blood glucose | Increases bile production; decreases blood glucose |
| Gallbladder | Relaxation | Contraction |
| Kidneys | Decreases urine production | No known action |
| Pancreas | Decreases secretion of insulin and digestive enzymes | Increases secretion of insulin and digestive enzymes |
| Spleen | Constriction injects stored blood into circulation | No known action |
| Urinary bladder | Contraction of external sphincter; relaxation of bladder wall | Relaxation of external sphincter; contraction of bladder wall |
| Reproductive organs | Vasoconstriction; ejaculation in males; reverse uterine contractions in females; stimulates uterine contractions in childbirth | Vasodilation; erection in males; vaginal secretion in females |

life, and its actions are usually opposite those of the sympathetic division. Table 8.4 compares some of the effects of the sympathetic and parasympathetic divisions on visceral organs.

***How do the somatic and autonomic nervous systems differ?***
***How does the autonomic nervous system maintain homeostasis?***

Cocaine exerts a major effect on the autonomic nervous system. It not only stimulates the sympathetic division but also inhibits the parasympathetic division. In an overdose, this double-barreled action produces an erratic, uncontrollable heartbeat that may result in sudden death.

## Disorders of the Nervous System

The disorders of the nervous system may be categorized as either inflammatory or noninflammatory disorders.

### Inflammatory Disorders

**Meningitis** (men-in-jī′-tis) results from a bacterial, fungal, or viral infection of the meninges. Bacterial meningitis cases are the most serious, with about 20% being fatal. If the brain is also involved, the disease is called *encephalitis.* Some viruses causing encephalitis are transmitted by bites of certain mosquitoes.

**Neuritis** is the inflammation of a nerve or nerves. It may be caused by several factors such as infection, compression, or trauma. Associated pain may be moderate or severe.

**Sciatica** (sī-at′-i-kah) is neuritis involving the sciatic nerve. The pain may be severe and often radiats down the thigh and leg.

**Shingles** is an infection of one or more nerves. It is caused by the reactivation of the chickenpox virus, which, until that time, was dormant in the nerve root. The virus causes painful blisters on the skin at the sensory nerve endings, followed by prolonged pain.

## Noninflammatory Disorders

**Alzheimer's** (alts′-hī-merz) **disease (AD)** is a progressively disabling disease affecting older persons. It is associated with a loss of certain cholinergic neurons in the brain and a reduced ability of neurons to secrete acetylcholine. AD is characterized by a progressive loss of memory, disorientation, and mood swings.

**Cerebral palsy** (ser-ē′-bral pawl-zē) is characterized by partial paralysis and sometimes a degree of mental retardation. It may result from damage to the brain during prenatal development, often from viral infections caused by German measles, or from trauma during delivery.

**Cerebrovascular accidents (CVAs)** are disorders of blood vessels serving the brain. They result from blood clots, aneurysms (an′-ū-rizm), or hemorrhage. Often called strokes, CVAs cause severe damage to the brain. They are a major cause of disability and the third highest cause of death in the United States.

**Comas** are states of unconsciousness in which the patient cannot be aroused even with vigorous stimulation. Illness or trauma to the brain may alter the functioning of the reticular formation, resulting in a coma.

**Concussion** results from a severe jarring of the brain caused by a blow to the head. Unconsciousness, confusion, and amnesia may result in severe cases.

**Dyslexia** (dis-lek′-sē-ah) causes the afflicted person to reverse letters or syllables in words and words within sentences. It results from malfunctioning of the language center of the cerebrum.

**Epilepsy** (ep′-i-lep″-sē) may have a hereditary basis, or it may be triggered by injuries, infections, or tumors. There are two types of epilepsy. *Grand mal epilepsy* is the more serious form and is characterized by convulsive seizures. *Petit mal epilepsy* is the less serious form and is characterized by momentary loss of contact with reality without unconsciousness or convulsions.

**Fainting** is a brief loss of consciousness due to a sudden reduction in blood supply to the brain. It may result from either physical or psychological causes.

**Headaches** may result from several physical or psychological causes, but they often result from a dilation of blood vessels within the meninges of the brain. Migraine headaches have visual or digestive side effects and may result from stress, allergies, or fatigue. Sinus headaches may result from inflammation that causes increased pressure within the sinuses. Some headaches result from tension in muscles of the head and neck.

**Mental illnesses** may be broadly categorized as either neuroses or psychoses. *Neuroses* are mild maladjustments to life situations that may produce anxiety and interfere with normal behavior. *Psychoses* are serious mental disorders that sometimes cause delusions, hallucinations, or withdrawal from reality.

**Multiple sclerosis (MS)** is a progressive degeneration of the myelin sheath around neuron processes in the CNS, accompanied by the formation of plaques of scar tissue called *scleroses.* This destruction results in a short-circuiting of neural pathways and an impairment of motor functions.

**Neuralgia** (nū-ral′-jē-ah) is pain arising from a nerve regardless of the cause of the pain.

**Paralysis** is the permanent loss of motor control of body parts. It most commonly results from accidental injury to the CNS.

**Parkinson's disease** is caused by an insufficient production of *dopamine* by neurons in certain basal nuclei within the cerebrum. It produces tremors and impairs normal skeletal muscle contractions. Parkinson's disease is more common among older persons.

# CHAPTER SUMMARY

## Divisions of the Nervous System

1. Anatomical divisions are the central nervous system (CNS), composed of the brain and spinal cord, and the peripheral nervous system (PNS), composed of cranial and spinal nerves.
2. Functional divisions are the sensory and motor divisions. The motor division is subdivided into the somatic nervous system (SNS), which is involved in voluntary actions, and the autonomic nervous system (ANS), which is involved in involuntary responses.

## Nerve Tissue

1. Nerve tissue consists of neurons and neuroglial cells.
2. A neuron is composed of a cell body, which contains the nucleus, one or more dendrites that conduct impulses toward the cell body, and one axon that conducts impulses away from the cell body.
3. Myelinated neuron processes are covered by a myelin sheath. Schwann cells form the myelin sheath and neurilemma of peripheral myelinated nerve fibers. Oligodendrocytes form the myelin sheath of

myelinated nerve fibers in the CNS; these fibers lack a neurilemma.
4. There are three functional types of neurons. Sensory neurons carry impulses toward the CNS. Interneurons carry impulses within the CNS. Motor neurons carry impulses from the CNS.
5. Schwann cells are the only neuroglial cells in the PNS. Four types of neuroglial cells occur in the CNS: oligodendrocytes, astrocytes, microglial cells, and ependymal cells.

## Neuron Physiology

1. Neurons are specialized to form and conduct impulses.
2. The membrane of a resting neuron is polarized with an excess of positive ions outside the cell and negative ions inside the cell.
3. When a threshold stimulus is applied, the neuron membrane becomes permeable to sodium ions ($Na^+$), which quickly move into the neuron and cause depolarization of the membrane. This depolarization is the formation of a nerve impulse.
4. The depolarized portion of the membrane causes the depolarization of adjacent portions so that a depolarization wave (impulse) flows along the neuron.
5. Depolarization makes the neuron membrane permeable to potassium ions ($K^+$), and they quickly diffuse out of the neuron, which repolarizes the membrane.
6. In synaptic transmission, the synaptic knob of the presynaptic neuron secretes a neurotransmitter into the synaptic cleft. The neurotransmitter reacts with receptors on the postsynaptic neuron, causing either the formation of an impulse or the inhibition of impulse formation. Then, the neurotransmitter is quickly removed by an enzymatic reaction.
7. The most common peripheral neurotransmitters are acetylcholine and norepinephrine. Some neurotransmitters are excitatory, and others are inhibitory.

## Protection for the Central Nervous System

1. The brain is encased by the cranial bones, and the spinal cord is surrounded by vertebrae.
2. Both the brain and spinal cord are covered by the meninges: the pia mater, arachnoid mater, and dura mater.
3. Cerebrospinal fluid in the subarachnoid space serves as a fluid shock absorber.

## Brain

1. The brain consists of the cerebrum, diencephalon, brain stem, and cerebellum.
2. The cerebrum consists of two cerebral hemispheres joined by the corpus callosum. Gyri and sulci increase the surface area of the cerebral cortex. Each hemisphere is subdivided into four lobes: frontal, parietal, temporal, and occipital lobes.
3. The cerebrum interprets sensations, initiates voluntary motor responses, and is involved in will, personality traits, and intellectual processes. The left cerebral hemisphere is dominant in most people.
4. Sensory interpretation areas occur in the parietal, temporal, and occipital lobes. Motor areas occur in the frontal lobe. Association areas occur in all lobes of the cerebrum.
5. The diencephalon consists of the thalamus and the hypothalamus.
6. The thalamus is formed of two lateral masses connected by the intermediate mass. It is a relay station for sensory and motor impulses going to and from the cerebrum and provides an uncritical awareness of sensations.
7. The hypothalamus is located below the thalamus and forms the floor of the third ventricle. It is a major control center for the autonomic nervous system, and it regulates several homeostatic processes such as body temperature, mineral and water balance, appetite, digestive processes, and secretion of pituitary hormones.
8. The limbic system is associated with emotional behavior and memory.
9. The brain stem consists of the midbrain, pons, and medulla oblongata. Ascending and descending fibers between higher brain centers and the spinal cord pass through the brain stem.
10. The midbrain is a small, superior portion of the brain stem. It contains reflex centers for movements associated with visual and auditory stimuli.
11. The pons is the intermediate portion of the brain stem. It works with the medulla oblongata to control breathing.
12. The medulla oblongata is the lowest portion of the brain stem and is continuous with the spinal cord. It contains reflexive control centers that control breathing, heart rate, and blood pressure.
13. The reticular formation consists of nuclei in the brain stem and fibers that extend to the cerebrum. It is involved with wakefulness and sleep.
14. The cerebellum lies posterior to the fourth ventricle. It is composed of two hemispheres separated by the vermis, and it coordinates skeletal muscle contractions.
15. The ventricles of the brain, the central canal of the spinal cord, and the subarachnoid space around the brain and spinal cord are filled with cerebrospinal fluid. Cerebrospinal fluid is secreted by a choroid plexus in each ventricle.
16. Cerebrospinal fluid is absorbed into blood of the sagittal sinus in the dura mater.

## Spinal Cord

1. The spinal cord extends from the medulla oblongata down the vertebral canal to the second lumbar vertebra.
2. Gray matter is located interiorly and is surrounded by white matter. Anterior horns of gray matter contain motor neuron cell bodies; posterior horns contain interneuron cell bodies. White matter contains ascending and descending tracts of myelinated neuron processes.
3. The spinal cord serves as a reflex center and conducting pathway for impulses between the brain and spinal nerves.

## Peripheral Nervous System (PNS)

1. The PNS consists of cranial and spinal nerves. Most nerves are mixed nerves; a few cranial nerves are sensory only. A nerve contains bundles of nerve fibers (neuron processes) supported by connective tissue.
2. The 12 pairs of cranial nerves are identified by Roman numeral and name. The 31 pairs of spinal nerves are divided into 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal nerve.
3. Anterior branches of many spinal nerves form plexuses where nerve fibers are sorted and recombined so that all fibers to a particular organ are carried in the same nerve. The four pairs of plexuses are cervical, brachial, lumbar, and sacral plexuses.

## Autonomic Nervous System (ANS)

1. The ANS involves portions of the central and peripheral nervous systems that are involved in involuntary maintenance of homeostasis.
2. Two ANS neurons are used to activate an effector. The presynaptic neuron arises from the CNS and ends in an autonomic ganglion, where it synapses with a postsynaptic neuron that continues on to the effector.
3. The ANS is divided into two subdivisions that generally have antagonistic effects. Nerves of the sympathetic division arise from the thorax and lumbar regions of the spinal cord and prepare the body to meet emergencies. Nerves of the parasympathetic division arise from the brain and sacral region of the spinal cord and function mainly in nonstressful situations.

## Disorders of the Nervous System

1. Disorders may result from infectious diseases, degeneration from unknown causes, malfunctions, and physical injury.
2. Inflammatory neurological disorders include meningitis, neuritis, sciatica, and shingles.
3. Noninflammatory neurological disorders include Alzheimer's disease, cerebral palsy, CVAs, comas, concussion, dyslexia, epilepsy, fainting, headaches, mental illness, multiple sclerosis, neuralgia, paralysis, and Parkinson's disease.

# BUILDING YOUR VOCABULARY

1. **Selected New Terms**
   acetylcholine, p. 155
   action potential, p. 153
   arachnoid mater, p. 156
   cerebellum, p. 160
   cerebrum, p. 157
   dura mater, p. 156
   gray matter, p. 160
   interneuron, p. 151
   limbic system, p. 160
   medulla oblongata, p. 160
   motor neuron, p. 151
   nerve tracts, p. 164
   norepinephrine, p. 155
   pia mater, p. 156
   resting potential, p. 152
   reticular formation, p. 160
   sensory neuron, p. 151
   spinal plexus, p. 166
   synaptic cleft, p. 154
   synaptic knob, p. 151
   ventricle, p. 161
   white matter, p. 160
2. **Related Clinical Terms**
   analgesic (an″-al-jē′-sik) A pain-relieving drug.
   encephalopathy (en-se-fa-lop′-a-thē) Any disorder or disease of the brain.
   hemiplegia (hem-i-plē′-jē-ah) Paralysis of one side of the body.
   neurology (nū-rol′-ō-jē) Branch of medicine dealing with disorders of the nervous system.
   paraplegia (par″-ah-plē′-jē-ah) Paralysis of both legs.
   psychiatry (si-kī̄′-ah-trē) Branch of medicine that treats mental illness.

## CHECK YOUR UNDERSTANDING

(Answers are located in appendix B.)

1. Impulses are carried away from a neuron cell body by the _____ .
2. Neurons that conduct impulses from place to place within the CNS are _____ .
3. An impulse is formed by the sudden flow of _____ ions through the plasma membrane into a neuron.
4. Synaptic transmission is dependent upon the secretion of a _____ by an axon's synaptic knob.
5. Impulses pass from one cerebral hemisphere to the other over neuron processes composing the _____ .
6. Voluntary muscle contractions are controlled by the _____ lobe of the cerebrum.
7. Intelligence, will, and memory are functions of the _____ .
8. The _____ regulates appetite, water balance, and body temperature.
9. The _____ regulates heart and breathing rates.
10. Coordination of body movements is a function of the _____ .
11. Cerebrospinal fluid fills the ventricles of the brain and the _____ space of the meninges.
12. The _____ is a conducting pathway between the brain and spinal nerves.
13. The _____ roots of spinal nerves consist of axons of motor neurons.
14. The _____ nervous system is involved in involuntary responses that maintain homeostasis.
15. The _____ division prepares the body for physical responses to emergencies.

## CRITICAL THINKING

1. Complete the learning objectives on the first page of this chapter.
2. Distinguish between dendrites, axons, nerve fibers, and nerves.
3. Explain the roles of $Na^+$, $K^+$, negative ions, and plasma membranes in neuron function.
4. If you touch a hot stove, a reflexive withdrawal of your hand is triggered at about the same time that you feel the pain. Describe the roles of the PNS and CNS in your response and sensation.
5. What composes the ANS, and how does the ANS maintain homeostasis?