unit IV

Coordination and Control

Two chapters in this unit describe the nervous system and some of its many parts and complex functions. The organs of special sense and other sensory receptors are described in a separate chapter. The last chapter in this unit discusses hormones and the organs that produce them. Working with the nervous system, these hormones play an important role in coordination and control.

Selected Key Terms

The following terms and other boldface terms in the chapter are defined in the Glossary

acetylcholine
action potential
afferent
autonomic nervous system
axon
dendrite
effector
efferent
epinephrine
ganglion
interneuron
motor
nerve
nerve impulse
neuritis
neuroglia
neurotransmitter
parasympathetic nervous system
plexus
receptor
reflex
sensory
somatic nervous system
sympathetic nervous system
synapse
tract

Learning Outcomes

After careful study of this chapter, you should be able to:

1. Describe the organization of the nervous system according to structure and function
2. Describe the structure of a neuron
3. Describe how neuron fibers are built into a nerve
4. Explain the purpose of neuroglia
5. Diagram and describe the steps in an action potential
6. Briefly describe the transmission of a nerve impulse
7. Explain the role of myelin in nerve conduction
8. Briefly describe transmission at a synapse
9. Define *neurotransmitter* and give several examples of neurotransmitters
10. Describe the distribution of gray and white matter in the spinal cord
11. List the components of a reflex arc
12. Define a simple reflex and give several examples of reflexes
13. Describe and name the spinal nerves and three of their main plexuses
14. Compare the location and functions of the sympathetic and parasympathetic nervous systems
15. Describe several disorders of the spinal cord and of the spinal nerves
16. Show how word parts are used to build words related to the nervous system (see Word Anatomy at the end of the chapter)

chapter 9

The Nervous System: The Spinal Cord and Spinal Nerves

Role of the Nervous System

None of the body systems is capable of functioning alone. All are interdependent and work together as one unit to maintain normal conditions, termed *homeostasis*. The nervous system serves as the chief coordinating agency for all systems. Conditions both within and outside the body are constantly changing. The nervous system must detect and respond to these changes (known as *stimuli*) so that the body can adapt itself to new conditions. The nervous system has been compared with a telephone exchange, in that the brain and the spinal cord act as switching centers and the nerves act as cables for carrying messages to and from these centers.

Although all parts of the nervous system work in coordination, portions may be grouped together on the basis of either structure or function.

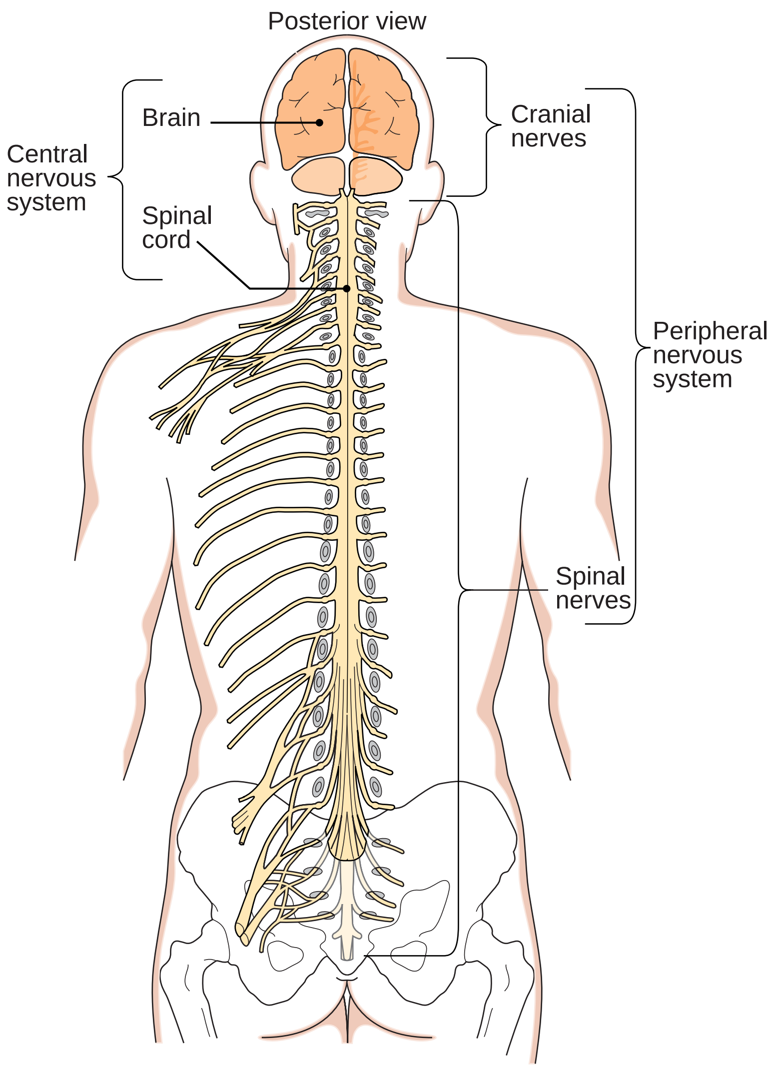

Figure 9-1 **Anatomic divisions of the nervous system.**

Structural Divisions

The anatomic, or structural, divisions of the nervous system are as follows (Fig. 9-1):

- The **central nervous system** (CNS) includes the brain and spinal cord.
- The **peripheral** (per-IF-er-al) **nervous system** (PNS) is made up of all the nerves outside the CNS. It includes all the **cranial nerves** that carry impulses to and from the brain and all the **spinal nerves** that carry messages to and from the spinal cord.

The CNS and PNS together include all of the nervous tissue in the body.

Functional Divisions

Functionally, the nervous system is divided according to whether control is voluntary or involuntary and according to what type of tissue is stimulated (Table 9-1). Any tissue or organ that carries out a command from the nervous system is called an **effector**, all of which are muscles or glands.

The **somatic nervous system** is controlled voluntarily (by conscious will), and all its effectors are skeletal muscles (described in Chapter 8). The involuntary division of the nervous system is called the **autonomic nervous system** (ANS), making reference to its automatic activity. It is also called the **visceral nervous system** because it controls smooth muscle, cardiac muscle, and glands, much of which make up the soft body organs, the viscera.

The ANS is further subdivided into a **sympathetic nervous system** and a **parasympathetic nervous system** based on organization and how each affects specific organs. The ANS is described later in this chapter.

Although these divisions are helpful for study purposes, the lines that divide the nervous system according to function are not as distinct as those that classify the system structurally. For example, the diaphragm, a skeletal muscle, typically functions in breathing without conscious thought. In addition, we have certain rapid reflex responses involving skeletal muscles—drawing the hand away from a hot stove, for example—that do not involve the brain. In contrast, people can be trained to consciously control involuntary functions, such as blood pressure, heart rate, and breathing rate, by techniques known as *biofeedback*.

Table 9•1 Functional Divisions of the Nervous System

DIVISION	CHARACTERISTICS CONTROL	EFFECTORS	SUBDIVISIONS
Somatic nervous system	Voluntary	Skeletal muscle	None
Autonomic nervous system	Involuntary	Smooth muscle, cardiac muscle, and glands	Sympathetic and parasympathetic systems

Checkpoint 9-1 What are the two divisions of the nervous system based on structure?

Checkpoint 9-2 The nervous system can be divided functionally into two divisions based on type of control and effectors. What division is voluntary and controls skeletal muscle, and what division is involuntary and controls involuntary muscles and glands?

Neurons and Their Functions

The functional cells of the nervous system are highly specialized cells called **neurons** (Fig. 9-2). These cells have a unique structure related to their function.

Structure of a Neuron

The main portion of each neuron, the cell body, contains the nucleus and other organelles typically found in cells. A distinguishing feature of the neurons, however, are the long, threadlike fibers that extend out from the cell body and carry impulses across the cell (Fig. 9-3). There are two kinds of fibers: dendrites and axons.

- **Dendrites** are neuron fibers that conduct impulses *to* the cell body. Most dendrites have a highly branched, treelike appearance (see Fig. 9-2). In fact, the name comes from a Greek word meaning "tree." Dendrites function as **receptors** in the nervous system. That is, they receive the stimulus that begins a neural pathway. In Chapter 11, we describe how the dendrites of the sensory system may be modified to respond to a specific type of stimulus.
- **Axons** (AK-sons) are neuron fibers that conduct impulses *away from* the cell body (see Fig. 9-2). These impulses may be delivered to another neuron, to a muscle, or to a gland. An axon is a single fiber, which may be quite long and which branches at its end.

The Myelin Sheath Some axons are covered with a fatty material called **myelin** that insulates and protects the fiber (see Fig. 9-2). In the PNS, this covering is produced by special connective tissue cells called **Schwann** (shvahn) **cells** that wrap around the axon like a jelly roll, depositing layers of myelin (Fig. 9-4). When the sheath is complete, small spaces remain between the individual cells. These tiny gaps, called **nodes** (originally, nodes of Ranvier), are important in speeding the conduction of nerve impulses.

The outermost membranes of the Schwann cells form a thin coating known as the **neurilemma** (nu-rih-LEM-mah). This covering is a part of the mechanism by which some peripheral nerves repair themselves when injured. Under some circumstances, damaged nerve cell fibers may regenerate by growing into the sleeve formed by the neurilemma. Cells of the brain and the spinal cord are myelinated, not by Schwann cells, but by

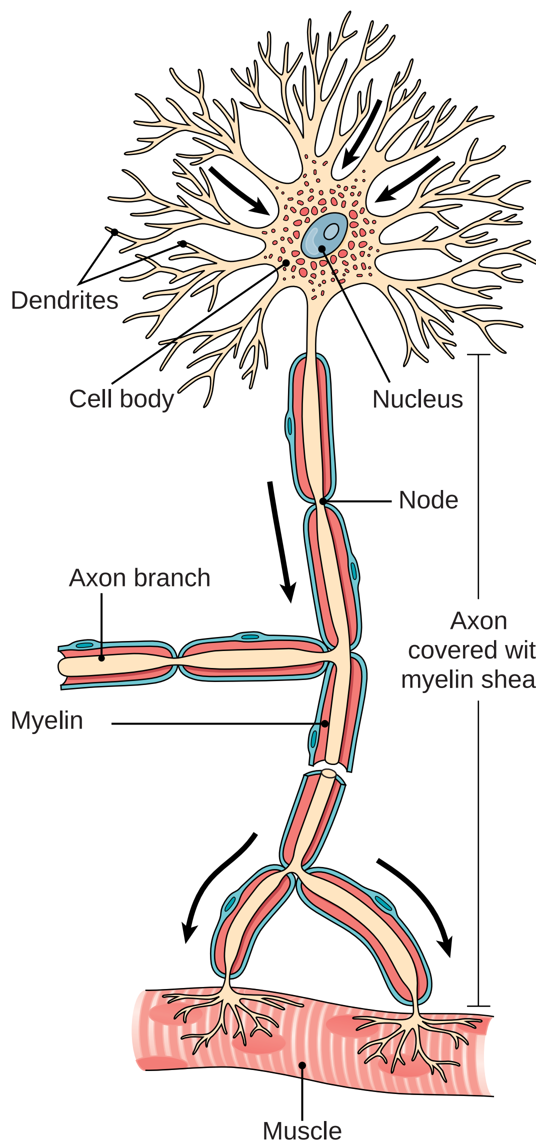

Figure 9-2 Diagram of a motor neuron. The break in the axon denotes length. The arrows show the direction of the nerve impulse. *ZOOMING IN ✦ Is the neuron shown here a sensory or a motor neuron?*

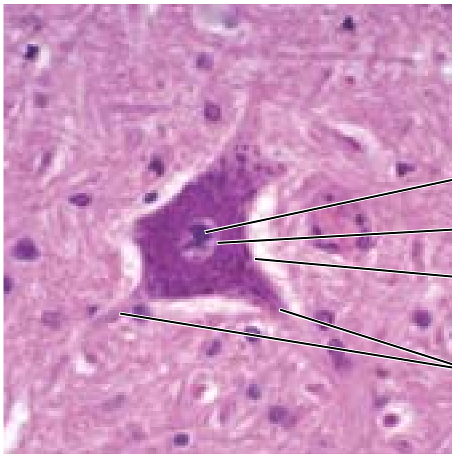

Figure 9-3 **A typical neuron as seen under the microscope.** The nucleus, nucleolus, and multiple fibers of the neuron are visible. (Reprinted with permission from Cormack DH. Essential Histology. 2nd ed. Philadelphia: Lippincott Williams & Wilkins, 2001.)

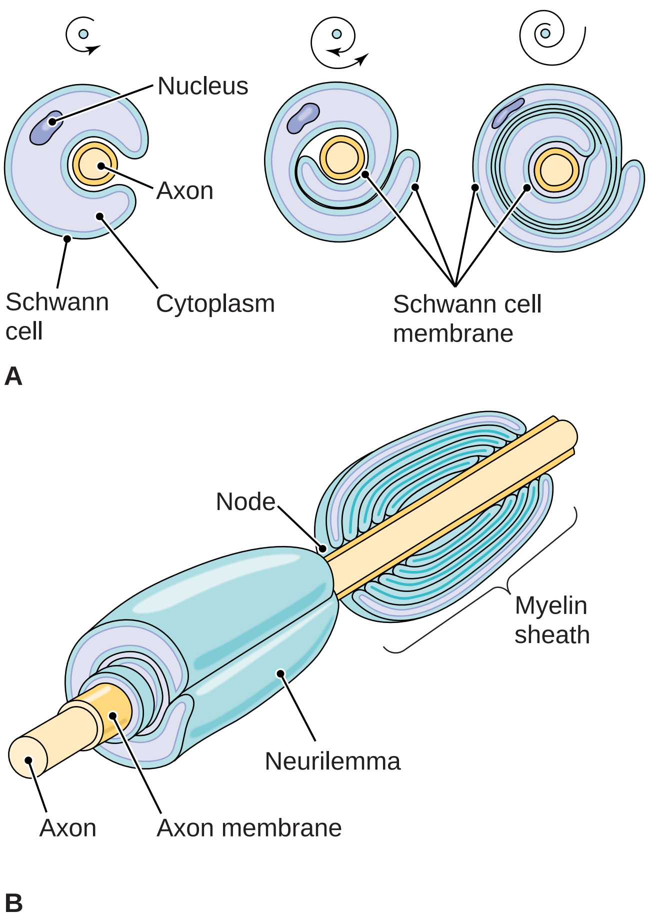

Figure 9-4 **Formation of a myelin sheath. (A)** Schwann cells wrap around the axon, creating a myelin coating. **(B)** The outermost layer of the Schwann cell forms the neurilemma. Spaces between the cells are the nodes (of Ranvier).

other types of connective tissue cells. As a result, they have no neurilemma. If they are injured, the damage is permanent. Even in the peripheral nerves, however, repair is a slow and uncertain process.

Myelinated axons, because of myelin's color, are called **white fibers** and are found in the **white matter** of the brain and spinal cord as well as in the nerve trunks in all parts of the body. The fibers and cell bodies of the **gray matter** are not covered with myelin.

> **Checkpoint 9-3** The neuron, the functional unit of the nervous system, has long fibers extending from the cell body. What is the name of the fiber that carries impulses toward the cell body, and what is the name of the fiber that carries impulses away from the cell body?

> **Checkpoint 9-4** Myelin is a substance that covers and protects some axons. What color describes myelinated fibers, and what color describes unmyelinated tissue of the nervous system?

Types of Neurons

The job of neurons in the PNS is to relay information constantly either to or from the CNS. Neurons that conduct impulses *to* the spinal cord and brain are described as **sensory neurons,** also called **afferent neurons.** Those cells that carry impulses *from* the CNS out to muscles and glands are **motor neurons,** also called **efferent neurons.** Neurons that relay information within the CNS are **interneurons,** also called *central* or *association neurons.*

Nerves and Tracts

Everywhere in the nervous system, neuron fibers are collected into bundles of varying size (Fig. 9-5). A bundle of fibers located within the PNS is a **nerve.** A similar grouping, but located within the CNS, is a **tract.** Tracts are located both in the brain and in the spinal cord, where they conduct impulses to and from the brain.

A nerve or tract can be compared with an electric cable made up of many wires. The "wires," the nerve cell fibers, in a nerve or tract are bound together with connective tissue, just like muscle fibers in a muscle. As in muscles, the individual fibers are organized into subdivisions called *fascicles*. The names of the connective tissue layers are similar to their names in muscles, but the root *neur/o*, meaning "nerve" is substituted for the muscle root *my/o*, as follows:

- Endoneurium is around an individual fiber
- Perineurium is around a fascicle
- Epineurium is around the whole nerve

A nerve may contain all sensory fibers, all motor fibers, or a combination of both types of fibers. A few of the cranial nerves contain only sensory fibers conducting impulses toward the brain. These are described as **sensory (afferent) nerves.** A few of the cranial nerves contain only motor fibers conducting impulses away from the brain, and

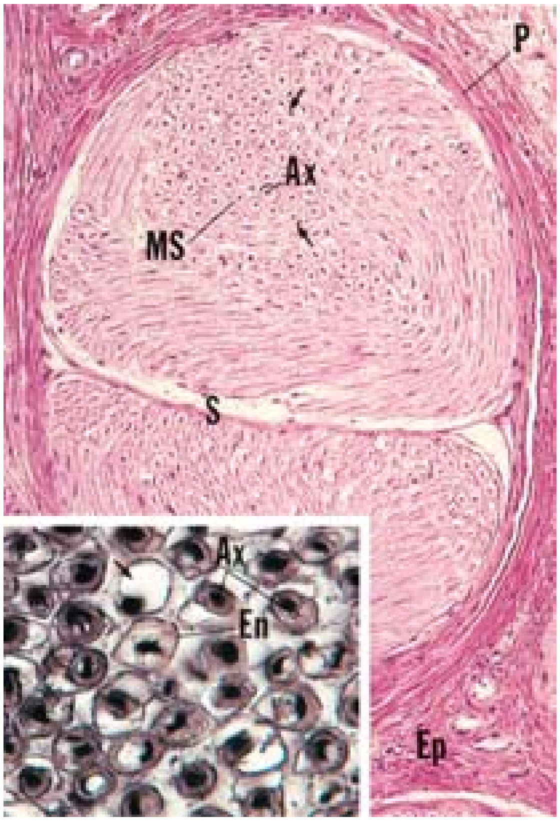

Figure 9-5 Cross section of a nerve as seen under the microscope (×132). Two fascicles (subdivisions) are shown. Perineurium (P) surrounds each fascicle. Epineurium (Ep) is around the entire nerve. Individual axons (Ax) are covered with a myelin sheath (MS), around which is the endoneurium (En) (inset). (Reprinted with permission from Gartner LP, Hiatt JL. Color Atlas of Histology. 3rd ed. Philadelphia: Lippincott Williams & Wilkins, 2000.)

these are classified as **motor (efferent) nerves.** However, most of the cranial nerves and *all* of the spinal nerves contain both sensory *and* motor fibers and are referred to as **mixed nerves.** Note that in a mixed nerve, impulses may be traveling in two directions (toward or away from the CNS), but each individual fiber in the nerve is carrying impulses in one direction only. Think of the nerve as a large highway. Traffic may be going north and south, for example, but each car is going forward in only one direction.

> **Checkpoint 9-5** Nerves are bundles of neuron fibers in the PNS. These nerves may be carrying impulses either toward or away from the CNS. What name is given to nerves that convey impulses toward the CNS, and what name is given to nerves that transport away from the CNS?

Neuroglia

In addition to conducting tissue, the nervous system contains cells that serve for support and protection. Collectively, these cells are called **neuroglia** (nu-ROG-le-ah) or **glial** (GLI-al) **cells**, from a Greek word meaning "glue." There are different types of neuroglia, each with specialized functions, some of which are the following:

- Protect nervous tissue
- Support nervous tissue and bind it to other structures
- Aid in repair of cells
- Act as phagocytes to remove pathogens and impurities
- Regulate the composition of fluids around and between cells

Neuroglia appear throughout the central and peripheral nervous systems. The Schwann cells that produce the myelin sheath in the peripheral nervous system are one type of neuroglia. Another example is shown in Figure 9-6.

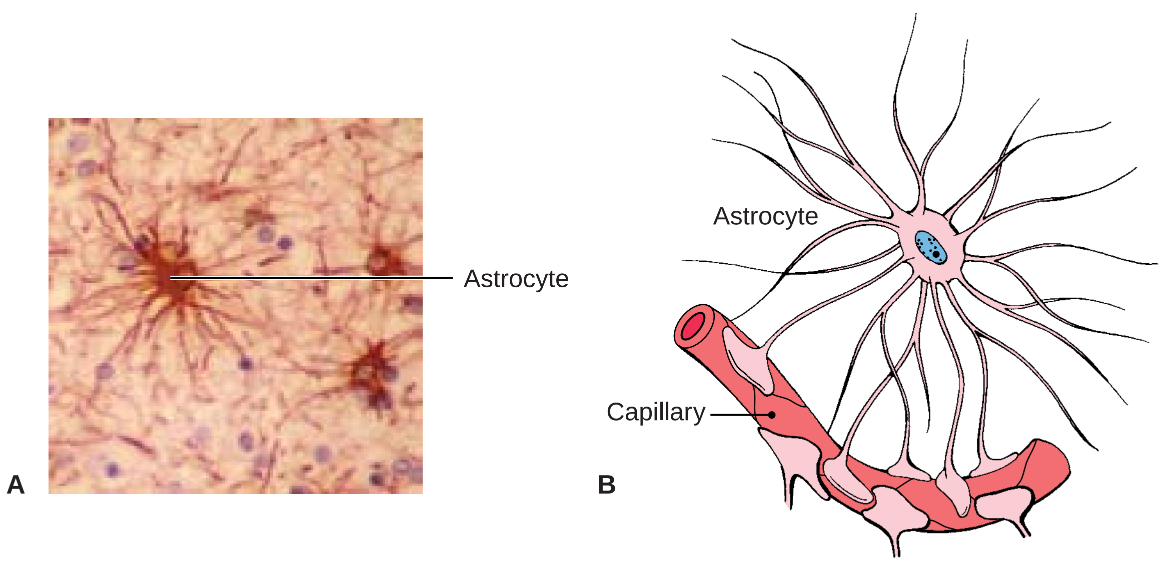

Figure 9-6 Examples of neuroglia. (A) Astrocytes in the white matter of the brain. **(B)** Astrocytes attach to capillaries and help to protect the brain from harmful substances. (Reprinted with permission from Ross MH, Kaye GI, Pawlina W. Histology. 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2003.)

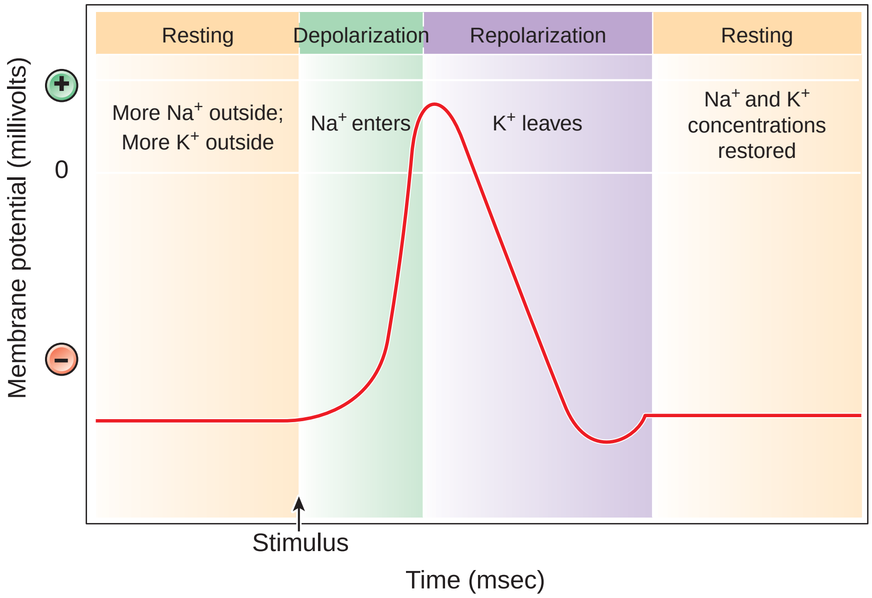

Figure 9-7 **The action potential.** In depolarization, Na^+ membrane channels open and Na^+ enters the cell. In repolarization, K^+ membrane channels open and K^+ leaves the cell. During and after repolarization, the Na^+/K^+ pump returns ion concentrations to their original concentrations so the membrane can be stimulated again.

These cells are astrocytes, named for their starlike appearance. In the brain they attach to capillaries (small blood vessels) and help protect the brain from harmful substances.

Unlike neurons, neuroglia continue to multiply throughout life. Because of their capacity to reproduce, most tumors of the nervous system are tumors of neuroglial tissue and not of nervous tissue itself.

Checkpoint 9-6 The nonconducting cells of the nervous system serve in protection and support. What are these cells called?

The Nervous System at Work

The nervous system works by means of electrical impulses sent along neuron fibers and transmitted from cell to cell at highly specialized junctions.

The Nerve Impulse

The mechanics of nerve impulse conduction are complex but can be compared with the spread of an electric current along a wire. What follows is a brief description of the electrical changes that occur as a resting neuron is stimulated and transmits a nerve impulse.

The plasma membrane of an unstimulated (resting) neuron carries an electrical charge, or **potential**. This resting potential is maintained by ions (charged particles) concentrated on either side of the membrane. At rest, the inside of the membrane is negative as compared with the outside. In this state, the membrane is said to be *polarized*. As in a battery, the separation of charges on either side of the membrane creates a possibility (potential) for generating energy. If there is a way for the charges to move toward each other, electricity will be generated.

A **nerve impulse** starts with a local reversal in the membrane potential caused by changes in the ion concentrations on either side. This sudden electrical change at the membrane is called an **action potential**, as described in Chapter 8 on the muscles. A simple description of the events in an action potential is as follows (Fig. 9-7):

- The resting state. In addition to an electrical difference on the two sides of the plasma membrane at rest, there is also a slight difference in the concentration of ions on either side. At rest, sodium ions (Na^+) are a little more concentrated at the outside of the membrane. At the same time, potassium ions (K^+) are a little more concentrated at the inside of the membrane.
- Depolarization. A stimulus of adequate force, such as electrical, chem-

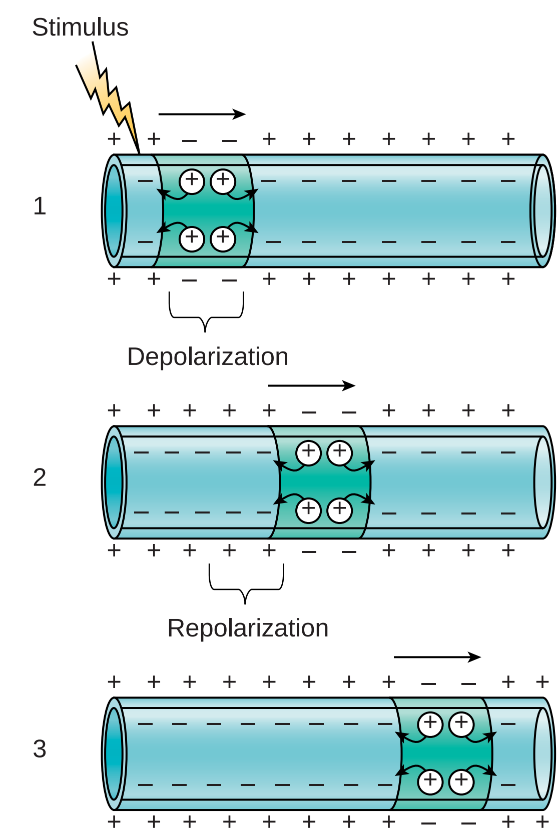

Figure 9-8 **A nerve impulse.** From a point of stimulation, a wave of depolarization followed by repolarization travels along the membrane of a neuron. This spreading action potential is a nerve impulse.

ical, or mechanical energy, causes specific channels in the membrane to open and allow Na^+ ions to flow into the cell. (Remember that substances flow by diffusion from an area where they are in higher concentration to an area where they are in lower concentration.) As these positive ions enter, they raise the charge on the inside of the membrane, a change known as **depolarization** (see Fig. 9-7).

- Repolarization. In the next step of the action potential, K^+ channels open to allow K^+ to leave the cell. As the electrical charge returns to its resting value, the membrane is undergoing **repolarization**. At the same time that the membrane is repolarizing, the cell uses active transport to move Na^+ and K^+ back to their original concentrations on either side of the membrane so that the membrane can be stimulated again. This activity is described as the **Na^+/K^+ pump**.

The action potential occurs rapidly—in less than 1/1000 of a second, and is followed by a rapid return to the resting state (Fig. 9-8). However, this local electrical change in the membrane stimulates an action potential at an adjacent point along the membrane. In scientific terms, the channels in the membrane are "voltage dependent," that is, they respond to an electrical stimulus. And so, the action potential spreads along the membrane as a wave of electrical current. The spreading action potential is the nerve impulse, and in fact, the term *action potential* is used to mean the nerve impulse. A stimulus is any force that can start an action potential by opening membrane channels and allowing Na^+ to enter the cell.

The Role of Myelin in Conduction As previously noted, some axons are coated with the fatty material myelin. If a fiber is not myelinated, the action potential spreads continuously along the membrane of the cell (see Fig. 9-8). When myelin is present on an axon, however, it insulates the fiber against the spread of current. This would appear to slow or stop conduction along these fibers, but in fact, the myelin sheath speeds conduction. The reason is that the action potential must "jump" like a spark from node (space) to node along the sheath (see Fig. 9-4), and this type of conduction is actually faster than continuous conduction.

Checkpoint 9-7 An action potential occurs in two stages. In the first stage, the charge on the membrane reverses, and in the second stage, it returns to the resting state. What are the names of these two stages?

Checkpoint 9-8 What ions are involved in generating an action potential?

The Synapse

Neurons do not work alone; impulses must be transferred between neurons to convey information within the nervous system. The point of junction for transmitting the nerve impulse is the **synapse** (SIN-aps), a term that comes from a Greek word meaning "to clasp" (Fig. 9-9).

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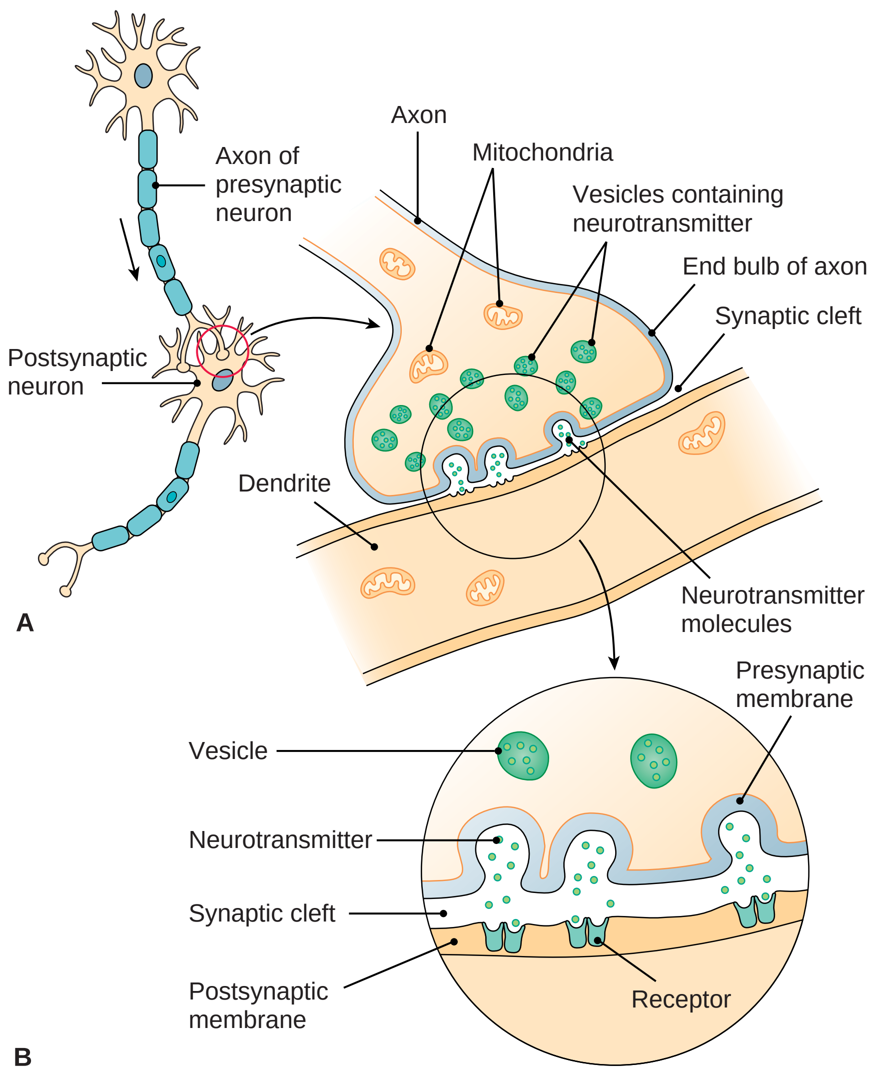

Figure 9-9 **A synapse. (A)** The end-bulb of the presynaptic (transmitting) axon has vesicles containing neurotransmitter, which is released into the synaptic cleft to the membrane of the postsynaptic (receiving) cell. **(B)** Close-up of a synapse showing receptors for neurotransmitter in the postsynaptic cell membrane.

At a synapse, transmission of an impulse usually occurs from the axon of one cell, the **presynaptic cell**, to the dendrite of another cell, the **postsynaptic cell**.

As described in Chapter 8, information must be passed from one cell to another at the synapse across a tiny gap between the cells, the **synaptic cleft**. Information usually crosses this gap in the form of a chemical known as a **neurotransmitter**. While the cells at a synapse are at rest, the neurotransmitter is stored in many small vesicles (bubbles) within the enlarged endings of the axons, usually called *end-bulbs* or *terminal knobs*, but known by several other names as well.

When a nerve impulse traveling along a neuron membrane reaches the end of the presynaptic axon, some of these vesicles fuse with the membrane and release their neurotransmitter into the synaptic cleft (an example of exocytosis, as described in Chapter 3). The neurotransmitter then acts as a chemical signal to the postsynaptic cell.

On the postsynaptic receiving membrane, usually that of a dendrite, but sometimes another part of the cell, there are special sites, or **receptors**, ready to pick up and respond to specific neurotransmitters. Receptors in the postsynaptic cell membrane influence how or if that cell will respond to a given neurotransmitter.

Neurotransmitters Although there are many known neurotransmitters, the main ones are **epinephrine** (ep-ih-NEF-rin), also called **adrenaline**; a related compound, **norepinephrine** (nor-ep-ih-NEF-rin), or **noradrenaline**; and **acetylcholine** (as-e-til-KO-lene). Acetylcholine (ACh) is the neurotransmitter released at the neuromuscular junction, the synapse between a neuron and a muscle cell. All three of the above neurotransmitters function in the ANS. It is common to think of neurotransmitters as stimulating the cells they reach; in fact, they have been described as such in this discussion. Note, however, that some of these chemicals inhibit the postsynaptic cell and keep it from reacting, as will be demonstrated later in discussions of the autonomic nervous system.

The connections between neurons can be quite complex. One cell can branch to stimulate many receiving cells, or a single cell may be stimulated by a number of different axons (Fig. 9-10). The cell's response is based on the total effects of all the neurotransmitters it receives at any one time.

After its release into the synaptic cleft, the neurotransmitter may be removed by several methods:

- It may slowly diffuse away from the synapse.
- It may be destroyed rapidly by enzymes in the synaptic cleft.
- It may be taken back into the presynaptic cell to be used again, a process known as *Reuptake*.

The method of removal helps determine how long a neurotransmitter will act.

Checkpoint 9-9 Chemicals are needed to carry information across the synaptic cleft at a synapse. As a group, what are all these chemicals called?

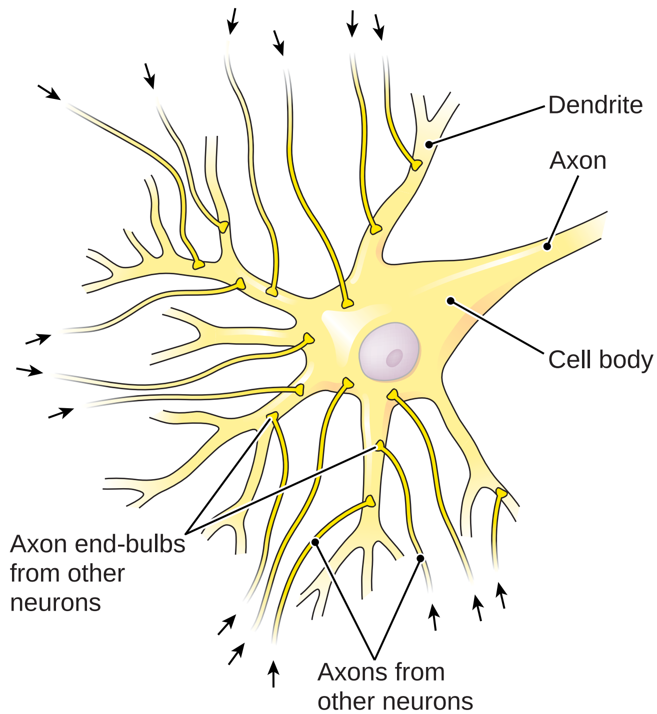

Figure 9-10 The effects of neurotransmitters on a neuron. A single neuron is stimulated by axons of many other neurons. The cell responds according to the total of all the excitatory and inhibitory neurotransmitters it receives.

Electrical Synapses Not all synapses are chemically controlled. In smooth muscle, cardiac muscle, and also in the CNS there is a type of synapse in which electrical energy travels directly from one cell to another. The membranes of the presynaptic and postsynaptic cells are close together and an electrical charge can spread directly between them. These electrical synapses allow more rapid and more coordinated communication. In the heart, for example, it is important that large groups of cells contract together for effective pumping action.

The Spinal Cord

The spinal cord is the link between the peripheral nervous system and the brain. It also helps to coordinate impulses within the CNS. The spinal cord is contained in and protected by the vertebrae, which fit together to form a continuous tube extending from the occipital bone to the coccyx (Fig. 9-11). In the embryo, the spinal cord occupies the entire spinal canal, extending down into the tail portion of the vertebral column. The column of bone grows much more rapidly than the nerve tissue of the cord, however, and eventually, the end of the spinal cord no longer reaches the lower part of the spinal canal. This disparity in growth continues to increase, so that in adults, the spinal cord ends in the region just below the area to which the last rib attaches (between the first and second lumbar vertebrae).

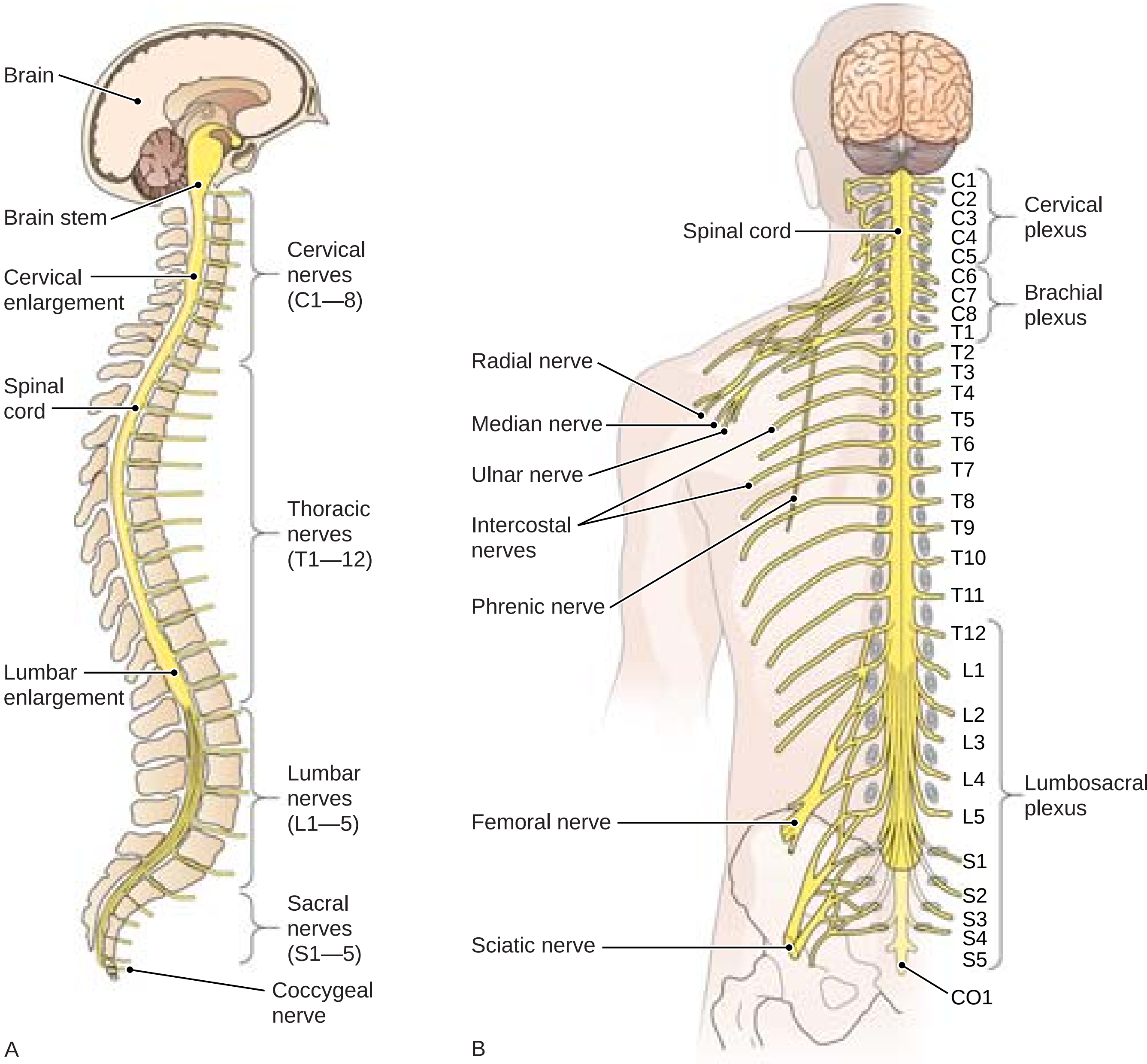

Figure 9-11 Spinal cord and spinal nerves. Nerve plexuses (networks) are shown. **(A)** Lateral view. **(B)** Posterior view. *ZOOMING IN ✦ Is the spinal cord the same length as the spinal column? How does the number of cervical vertebrae compare with the number of cervical spinal nerves?*

Structure of the Spinal Cord

The spinal cord has a small, irregularly shaped internal section of gray matter (unmyelinated tissue) surrounded by a larger area of white matter (myelinated axons) (Fig. 9-12). The internal gray matter is arranged so that a column of gray matter extends up and down dorsally, one on each side; another column is found in the ventral region on each side. These two pairs of columns, called the **dorsal horns** and **ventral horns**, give the gray matter an H-shaped appearance in cross-section. The bridge of gray matter that connects the right and left horns is the **gray commissure** (KOM-ih-shure). In the center of the gray commissure is a small channel, the **central canal**, that contains cerebrospinal fluid, the liquid that circulates around the brain and spinal cord. A narrow groove, the **posterior median sulcus** (SUL-kus), divides the right and left portions of the posterior white matter. A deeper groove, the **anterior median fissure** (FISH-ure), separates the right and left portions of the anterior white matter.

Ascending and Descending Tracts The spinal cord is the pathway for sensory and motor impulses trav-

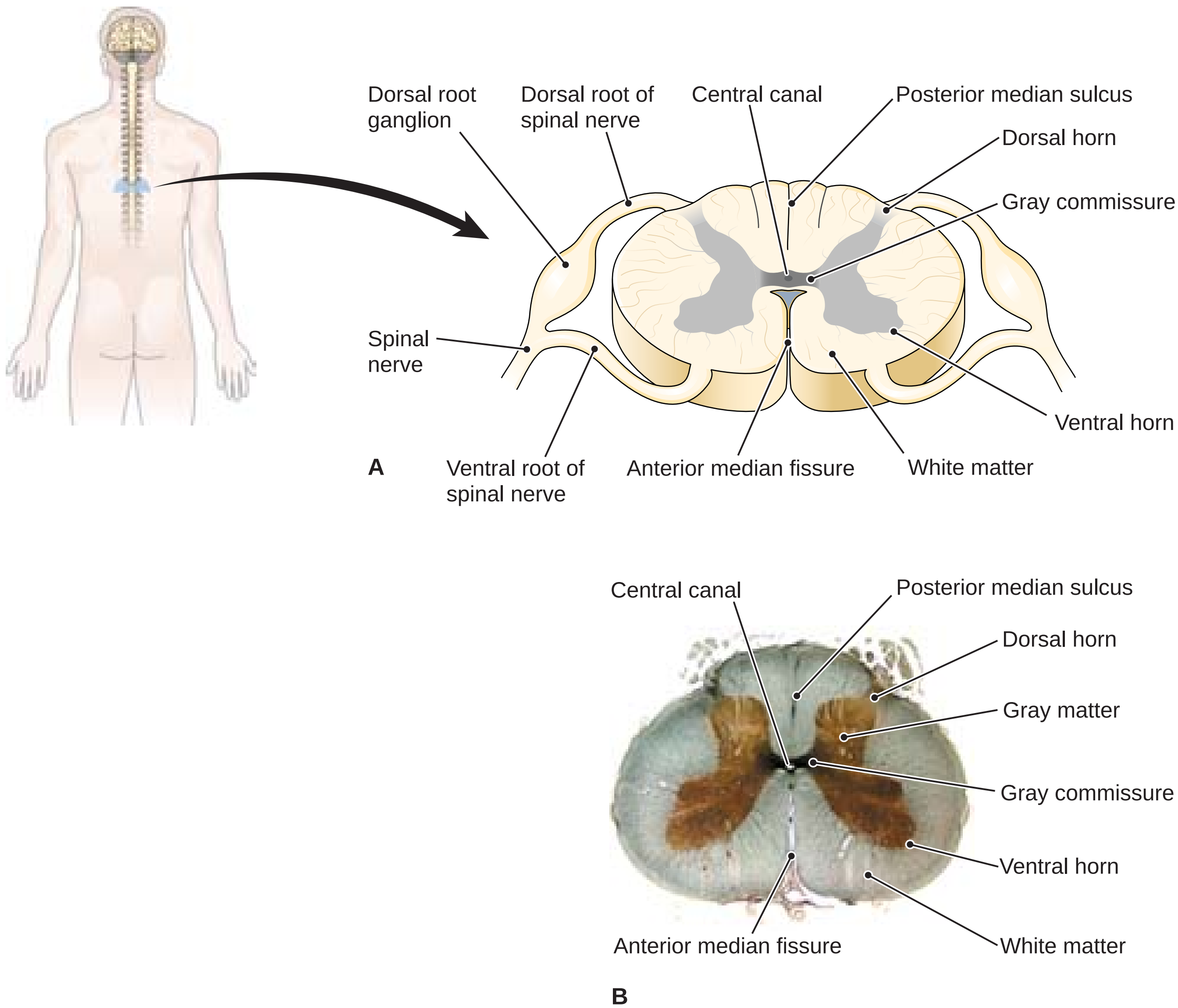

Figure 9-12 **The spinal cord.** **(A)** Cross-section of the spinal cord showing the organization of the gray and white matter. The roots of the spinal nerves are also shown. **(B)** Microscopic view of the spinal cord in cross-section (×5). (B, Reprinted with permission from Ross MH, Kaye GI, Pawlina W. Histology. 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2003.)

eling to and from the brain. These impulses are carried in the thousands of myelinated axons in the white matter of the spinal cord, which are subdivided into tracts (groups of fibers). Sensory (afferent) impulses entering the spinal cord are transmitted toward the brain in **ascending tracts** of the white matter. Motor (efferent) impulses traveling from the brain are carried in **descending tracts** toward the peripheral nervous system.

Checkpoint 9-10 The spinal cord contains both gray and white matter. How is this tissue arranged in the spinal cord?

Checkpoint 9-11 What is the purpose of the tracts in the white matter of the spinal cord?

The Reflex Arc

As the nervous system functions, it receives, interprets, and acts on both external and internal stimuli. The spinal cord is also a relay center for coordinating neural pathways. A complete pathway through the nervous system from stimulus to response is termed a **reflex arc** (Fig. 9-13). This is the basic functional pathway of the nervous system. The basic parts of a reflex arc are the following (Table 9-2):

1. **Receptor**—the end of a dendrite or some specialized receptor cell, as in a special sense organ, that detects a stimulus.
2. **Sensory neuron**, or afferent neuron—a cell that transmits impulses *toward* the CNS. Sensory impulses enter the dorsal horn of the gray matter in the spinal cord.

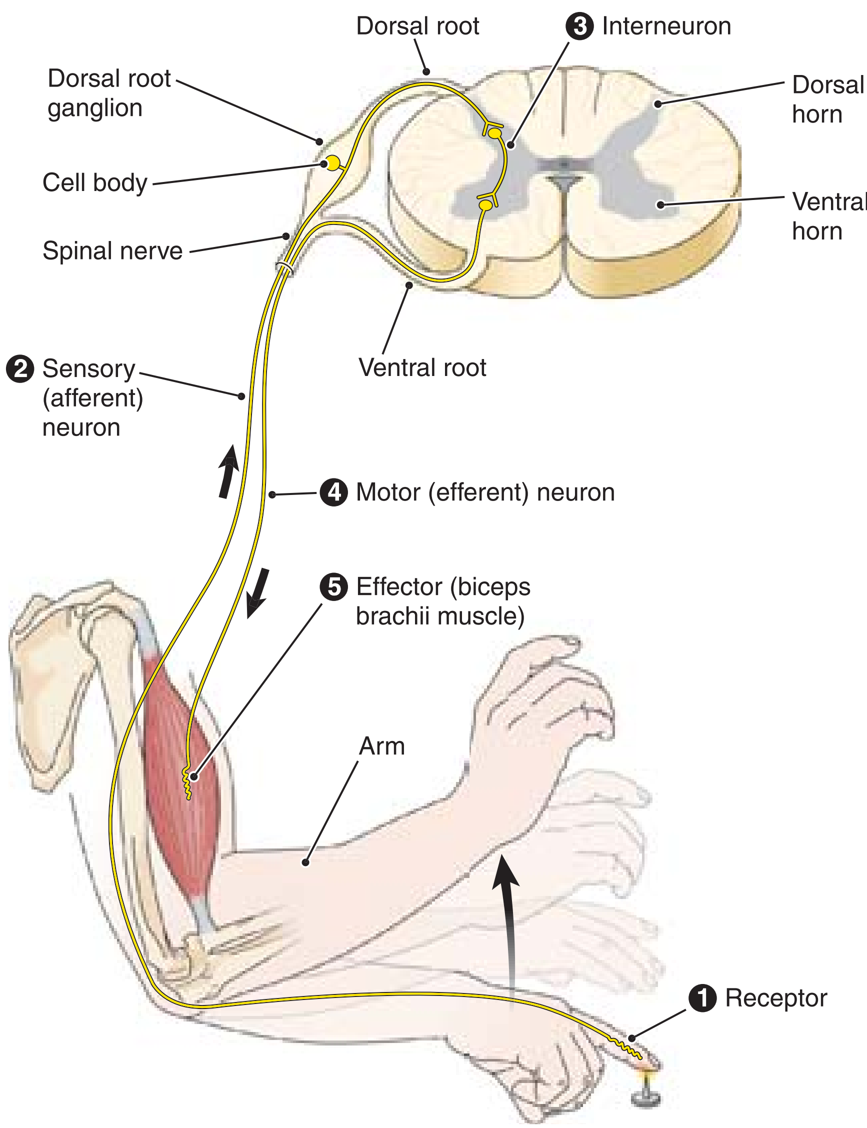

Figure 9-13 **Typical reflex arc.** Numbers show the sequence of impulses through the spinal cord (solid arrows). Contraction of the biceps brachii results in flexion of the arm at the elbow. *ZOOMING IN ✦ Is this a somatic or an autonomic reflex arc? What type of neuron is located between the sensory and motor neuron in the CNS?*

3. **Central nervous system**—where impulses are coordinated and a response is organized. One or more interneurons may carry impulses to and from the brain, may function within the brain, or may distribute impulses to different regions of the spinal cord. Almost every response involves connecting neurons in the CNS.
4. **Motor neuron**, or efferent neuron—a cell that carries impulses *away from* the CNS. Motor impulses leave the cord through the ventral horn of the spinal cord gray matter.
5. **Effector**—a muscle or a gland outside the CNS that carries out a response.

At its simplest, a reflex arc can involve just two neurons, one sensory and one motor, with a synapse in the CNS. Few reflex arcs require only this minimal number of neurons. (The knee-jerk reflex described below is one of the few examples in humans.) Most reflex arcs involve many more, even hundreds, of connecting neurons within the CNS. The many intricate patterns that make the nervous system so responsive and adaptable also make it difficult to study, and investigation of the nervous system is one of the most active areas of research today.

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Checkpoint 9-12 What name is given to a pathway through the nervous system from a stimulus to an effector?

Reflex Activities Although reflex pathways may be quite complex, a **simple reflex** is a rapid, uncomplicated, and automatic response involving very few neurons. Reflexes are specific; a given stimulus always produces the same response. When you fling out an arm or leg to catch your balance, withdraw from a painful stimulus, or blink to avoid an object approaching your eyes, you are experiencing reflex behavior. A simple reflex arc that passes through the spinal cord alone and does not involve the brain is termed a **spinal reflex.**

The **stretch reflex**, in which a muscle is stretched and responds by

Table 9•2 Components of a Reflex Arc

COMPONENT	FUNCTION
Receptor	End of a dendrite or specialized cell that responds to a stimulus
Sensory neuron	Transmits a nerve impulse toward the CNS
Central nervous system	Coordinates sensory impulses and organizes a response; usually requires interneurons
Motor neuron	Carries impulses away from the CNS toward the effector, a muscle, or a gland
Effector	A muscle or gland outside the CNS that carries out a response

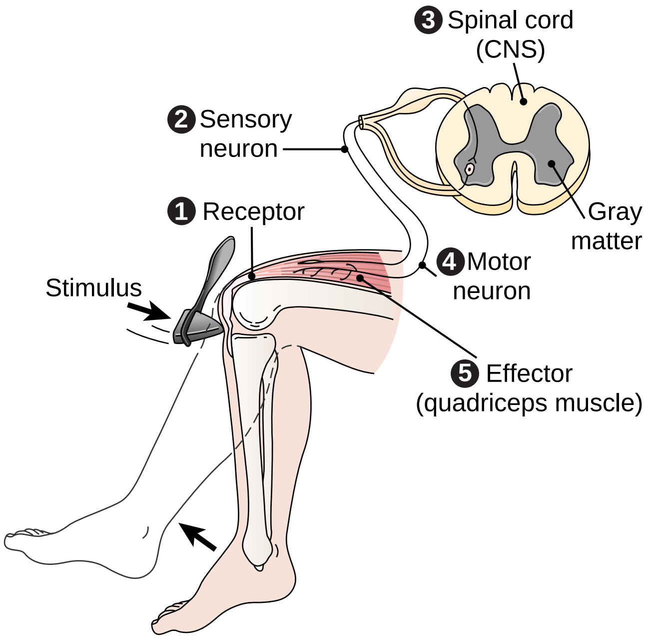

Figure 9-14 The patellar (knee-jerk) reflex. Numbers indicate the sequence of a reflex arc. *ZOOMING IN ❖ How many total neurons are involved in this spinal reflex? What neurotransmitter is released at the synapse shown by number 5?*

contracting, is one example of a spinal reflex. If you tap the tendon below the kneecap (the patellar tendon), the muscle of the anterior thigh (quadriceps femoris) contracts, eliciting the knee-jerk reflex (Fig. 9-14).

Such stretch reflexes may be evoked by appropriate tapping of most large muscles (such as the triceps brachii in the arm and the gastrocnemius in the calf of the leg). Because reflexes are simple and predictable, they are used in physical examinations to test the condition of the nervous system.

Medical Procedures Involving the Spinal Cord

- Lumbar puncture. It is sometimes necessary to remove a small amount of cerebrospinal fluid (CSF) from the nervous system for testing. CSF is the fluid that circulates in and around the brain and spinal cord. This fluid is taken from the space below the spinal cord to avoid damage to nervous tissue. Because the spinal cord is only about 18 inches long and ends above the level of the hip line, a lumbar puncture or spinal tap is usually done between the third and fourth lumbar vertebrae, at about the level of the top of the hipbone. The sample that is removed can then be studied in the laboratory for evidence of disease or injury.
- Administration of drugs. Anesthetics or medications are sometimes injected into the space below the cord. The anesthetic agent temporarily blocks all sensation from the lower part of the body. This method of giving anesthesia has an advantage for certain types of procedures or surgery; the patient is awake but feels nothing in his or her lower body. Injection of anesthetic into the epidural space in the lumbar region of the spine (an "epidural") is often used during labor and childbirth. The spinal route also can be used to administer pain medication.

Diseases and Other Disorders of the Spinal Cord

Multiple sclerosis (MS) is a disease in which the myelin sheath around axons is damaged and the neuron fibers themselves degenerate. This process of demyelination slows the speed of nerve impulse conduction and disrupts nervous system communication. Both the spinal cord and the brain are affected. Although the cause of MS is not completely understood, there is strong evidence that it involves an attack on the myelin sheath by a person's own immune system, a situation described as *autoimmunity*. Genetic makeup, in combination with environmental factors, may trigger MS. Some research suggests that a prior viral or bacterial infection, even one that occurred many years before, may set off the disease.

MS is the most common chronic CNS disease of young adults in the United States. The disease affects women about twice as often as men, and it is more common in temperate climates and in people of northern European ancestry. MS progresses at different rates depending on the individual, and it may be marked by episodes of relapse and remission. At this point, no cure has been found for MS, but drugs that stop the autoimmune response and drugs that relieve MS symptoms are currently under study.

Amyotrophic (ah-mi-o-TROF-ik) **lateral sclerosis** is a disorder of the nervous system in which motor neurons are destroyed. The progressive destruction causes muscle atrophy and loss of motor control until finally the affected person is unable to swallow or talk.

Poliomyelitis (po-le-o-mi-eh-LI-tis) ("polio") is a viral disease of the nervous system that occurs most commonly in children. Polio is spread by ingestion of water contaminated with feces containing the virus. Infection of the gastrointestinal tract leads to passage of the virus into the blood, from which it spreads to the CNS. Poliovirus tends to multiply in motor neurons in the spinal cord, leading to paralysis, including paralysis of the breathing muscles.

Polio has been virtually eliminated in many countries through the use of vaccines against the disease—first the injected Salk vaccine developed in 1954, followed by the Sabin oral vaccine. A goal of the World Health Organization (WHO) is the total eradication of polio by worldwide vaccination programs.

Tumors Tumors that affect the spinal cord commonly arise in the support tissue in and around the cord. They are frequently tumors of the nerve sheaths, the meninges, or neuroglia. Symptoms are caused by pressure on the cord and the roots of the spinal nerves. These include

Box 9-1 **Hot Topics**

Spinal Cord Injury: Crossing the Divide

Approximately 11,000 new cases of spinal cord injury occur each year in the United States, the majority involving males ages 16 to 30. Because neurons show little, if any, capacity to repair themselves, spinal cord injuries almost always result in a loss of sensory or motor function (or both), and therapy has focused on injury management rather than cure. However, scientists are investigating four improved treatment approaches:

- *Minimizing spinal cord trauma after injury*. Intravenous injection of the steroid methylprednisolone shortly after injury reduces swelling at the site of injury and improves recovery.
- *Using* ***neurotrophins*** *to induce repair in damaged nerve tissue.* Certain types of neuroglia produce chemicals called neurotrophins (*e.g.,* nerve growth factor) that have promoted nerve regeneration in experiments.
- *Regulation of inhibitory factors that keep neurons from dividing.* "Turning off" these factors (produced by neuroglia) in the damaged nervous system may promote tissue repair. The factor called Nogo is an example.
- *Nervous tissue transplantation*. Successfully transplanted donor tissue may take over the damaged nervous system's functions.

pain, numbness, weakness, and loss of function. Spinal cord tumors are diagnosed by magnetic resonance imaging (MRI) or other imaging techniques, and treatment is by surgery and radiation.

Injuries Injury to the spinal cord may result from wounds, fracture or dislocation of the vertebrae, herniation of intervertebral disks, or tumors. The most common causes of accidental injury to the cord are motor vehicle accidents, falls, sports injuries (especially diving accidents), and job-related injuries. Spinal cord injuries are more common in the young adult age group and many are related to use of alcohol or drugs.

Damage to the cord may cause paralysis or loss of sensation in structures supplied by nerves below the level of injury. Different degrees of loss are named using the root *-plegia*, meaning "paralysis," for example:

- Monoplegia (mon-o-PLE-je-ah)—paralysis of one limb
- Diplegia (di-PLE-je-ah)—paralysis of both upper or both lower limbs
- Paraplegia (par-ah-PLE-je-ah)—paralysis of both lower limbs
- Hemiplegia (hem-e-PLE-je-ah)—paralysis of one side of the body
- Tetraplegia (tet-rah-PLE-je-ah) or quadriplegia (kwah-drih-PLE-je-ah)—paralysis of all four limbs

Box 9-1, Spinal Cord Injury: Crossing the Divide, contains information on treatment of these injuries.

The Spinal Nerves

There are 31 pairs of spinal nerves, each pair numbered according to the level of the spinal cord from which it arises (see Fig. 9-11). Each nerve is attached to the spinal cord by two roots: the **dorsal root** and the **ventral root** (see Fig. 9-12). On each dorsal root is a marked swelling of gray matter called the **dorsal root ganglion**, which contains the cell bodies of the sensory neurons. A **ganglion** (GANG-le-on) is any collection of nerve cell bodies located outside the CNS. Fibers from sensory receptors throughout the body lead to these dorsal root ganglia.

The ventral roots of the spinal nerves are a combination of motor (efferent) fibers that supply muscles and glands (effectors). The cell bodies of these neurons are located in the ventral gray matter (ventral horns) of the cord. Because the dorsal (sensory) and ventral (motor) roots are combined to form the spinal nerve, all spinal nerves are mixed nerves.

Branches of the Spinal Nerves

Each spinal nerve continues only a short distance away from the spinal cord and then branches into small posterior divisions and larger anterior divisions. The larger anterior branches interlace to form networks called **plexuses** (PLEK-sus-eze), which then distribute branches to all parts of the body (see Fig. 9-11). The three main plexuses are described as follows:

- The **cervical plexus** supplies motor impulses to the muscles of the neck and receives sensory impulses from the neck and the back of the head. The phrenic nerve, which activates the diaphragm, arises from this plexus.
- The **brachial** (BRA-ke-al) **plexus** sends numerous branches to the shoulder, arm, forearm, wrist, and hand. The radial nerve emerges from the brachial plexus.
- The **lumbosacral** (lum-bo-SA-kral) **plexus** supplies nerves to the pelvis and legs. The largest branch in this plexus is the **sciatic** (si-AT-ik) **nerve**, which leaves the dorsal part of the pelvis, passes beneath the gluteus maximus muscle, and extends down the back of the thigh. At its beginning, it is nearly 1 inch thick, but it soon branches to the thigh muscles; near the knee, it forms two subdivisions that supply the leg and the foot.

Dermatomes Sensory neurons from all over the skin, except for the skin of the face and scalp, feed information

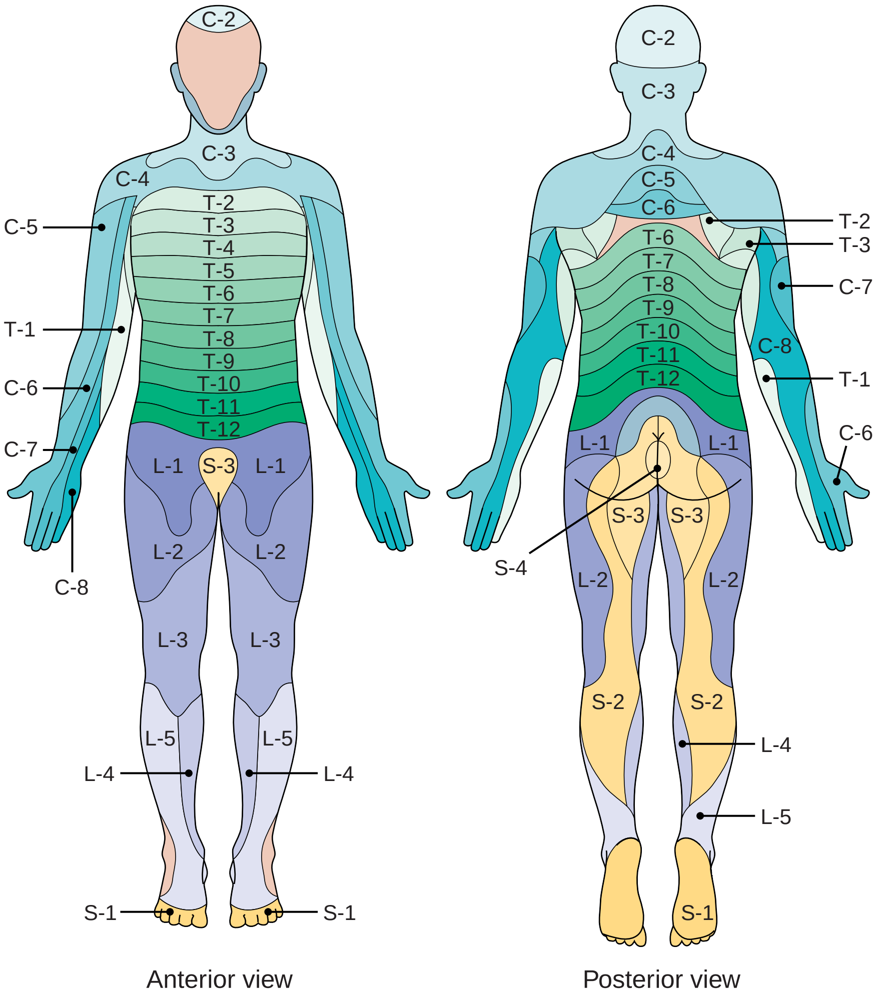

Figure 9-15 Dermatomes. A dermatome is a region of the skin supplied by a single spinal nerve. *ZOOMING IN ✦ Which spinal nerves carry impulses from the skin of the toes? From the anterior hand and fingers?*

into the spinal cord through the spinal nerves. The skin surface can be mapped into distinct regions that are supplied by a single spinal nerve. Each of these regions is called a **dermatome** (DER-mah-tome) (Fig. 9-15).

Sensation from a given dermatome is carried over its corresponding spinal nerve. This information can be used to identify the spinal nerve or spinal segment that is involved in an injury. In some areas, the dermatomes are not absolutely distinct. Some dermatomes may share a nerve supply with neighboring regions. For this reason, it is necessary to numb several adjacent dermatomes to achieve successful anesthesia.

Checkpoint 9-13 How many pairs of spinal nerves are there?

Disorders of the Spinal Nerves

Peripheral neuritis (nu-RI-tis), or peripheral neuropathy, is the degeneration of nerves supplying the distal areas of the extremities. It affects both sensory and motor function, causing symptoms of pain and paralysis. Causes include chronic intoxication (alcohol, lead, drugs), infectious diseases (meningitis), metabolic diseases (diabetes, gout), or nutritional diseases (vitamin deficiency, starvation). Identification and treatment of the underlying disorder is most important. Because peripheral neuritis is a symptom rather than a disease, a complete physical examination may be needed to establish its cause.

Sciatica (si-AT-ih-kah) is a form of peripheral neuritis characterized by severe pain along the sciatic nerve and its branches. The most common causes of this disorder are rupture of a disk between the lower lumbar vertebrae and arthritis of the lower part of the spinal column.

Herpes zoster, commonly known as *shingles,* is characterized by numerous blisters along the course of certain nerves, most commonly the intercostal nerves, which are branches of the thoracic spinal nerves in the waist area. It is caused by a reactivation of a prior infection by the chickenpox virus and involves an attack on the sensory cell bodies inside the spinal ganglia. Initial symptoms include fever and pain, followed in 2 to 4 weeks by the appearance of vesicles (fluid-filled skin lesions). The drainage from these vesicles contains highly contagious liquid. The neuralgic pains may persist for years and can be distressing. This infection may also involve the first branch of the fifth cranial nerve and cause pain in the eyeball and surrounding tissues. Early treatment of a recurrent attack with antiviral drugs may reduce the neuralgia.

Guillain-Barré syndrome (ge-YAN bar-RA) is classified as a polyneuropathy (pol-e-nu-ROP-a-the)—that is, a disorder involving many nerves. There is progressive muscle weakness due to loss of myelin, with numbness and paralysis, which may involve the breathing muscles. Sometimes the autonomic nervous system is involved, resulting in problems with involuntary functions. The cause of Guillain-Barré syndrome is not known, but it often follows an infection, usually a viral infection. It may result from an abnormal immune response to one's own nerve tissue. Most people recover completely from the disease with time, but recovery may take months or even years.

Box 9-2, Careers in Occupational Therapy, describes professions related to care of people with nervous system injuries.

Box 9-2 • Health Professions

Careers in Occupational Therapy

Occupational therapy (OT) helps people with physical or mental disability achieve independence at home and at work by teaching them "skills for living." Many people can benefit, including those:

- Recovering from traumas such as fractures, amputations, burns, spinal cord injury, stroke, and heart attack.
- With chronic conditions such as arthritis, multiple sclerosis, Alzheimer disease, and schizophrenia.
- With developmental disabilities such as Down syndrome, cerebral palsy, spina bifida, muscular dystrophy, and autism.

OTs work as part of multidisciplinary teams, which include physicians, nurses, physical therapists, speech pathologists, and social workers. They assess their clients' capabilities and develop individualized treatment programs that help clients recover from injury or compensate for permanent disability. Treatment may include teaching activities ranging from work tasks to dressing, cooking, and eating, and using adaptive equipment such as wheelchairs, computers, and aids for eating and dressing. OT assistants are responsible for implementing the treatment plan and reporting results back to the therapist, who may modify the plan. To perform these duties, OTs and assistants need a thorough understanding of anatomy and physiology. Most OTs in the United States have bachelor's or master's degrees and must pass a national licensing exam. Assistants typically train in a 2-year program and also take a licensing exam.

OTs and their assistants work in hospitals, clinics, and nursing care facilities, and also visit homes and schools. As the population continues to age and the need for rehabilitative therapy increases, job prospects remain good. For more information about OT careers, contact the American Occupational Therapy Association.

9

The Autonomic Nervous System (ANS)

The autonomic (visceral) nervous system regulates the action of the glands, the smooth muscles of hollow organs and vessels, and the heart muscle. These actions are carried on automatically; whenever a change occurs that calls for a regulatory adjustment, it is made without conscious awareness.

Most studies of the ANS concentrate on the motor (efferent) portion of the system. All autonomic pathways contain two motor neurons connecting the spinal cord with the effector organ. The two neurons synapse in ganglia that serve as relay stations along the way. The first neuron, the preganglionic neuron, extends from the spinal cord to the ganglion. The second neuron, the postganglionic neuron, travels from the ganglion to the effector. This differs from the voluntary (somatic) nervous system, in which each motor nerve fiber extends all the way from the spinal cord to the skeletal muscle with no intervening synapse. Some of the autonomic fibers are within the spinal nerves; some are within the cranial nerves (see Chapter 10).

Checkpoint 9-14 How many neurons are there in each motor pathway of the ANS?

Divisions of the Autonomic Nervous System

The motor neurons of the ANS are arranged in a distinct pattern, which has led to their separation for study purposes into **sympathetic** and **parasympathetic** divisions (Fig. 9-16), as described below and summarized in Table 9-3.

Sympathetic Nervous System The sympathetic motor neurons originate in the spinal cord with cell bodies in the thoracic and lumbar regions, the **thoracolumbar** (tho-rah-ko-LUM-bar) area. These preganglionic fibers arise from the spinal cord at the level of the first thoracic spinal nerve down to the level of the second lumbar spinal nerve. From this part of the cord, nerve fibers extend to ganglia where they synapse with postganglionic neurons, the fibers of which extend to the glands and involuntary muscle tissues.

Many of the sympathetic ganglia form the **sympathetic chains,** two cordlike strands of ganglia that extend along either side of the spinal column from the lower neck to the upper abdominal region. (Note that Figure 9-16 shows only one side for each division of the ANS.)

In addition, the nerves that supply the organs of the abdominal and pelvic cavities synapse in three single **collateral ganglia** farther from the spinal cord. These are the:

- Celiac ganglion, which sends fibers mainly to the digestive organs
- Superior mesenteric ganglion, which sends fibers to the large and small intestines
- Inferior mesenteric ganglion, which sends fibers to the distal large intestine and organs of the urinary and reproductive systems

The postganglionic neurons of the sympathetic system, with few exceptions, act on their effectors by releasing the neurotransmitter epinephrine (adrenaline) and the related compound norepinephrine (noradrenaline). This system is therefore described as **adrenergic,** which means "activated by adrenaline."

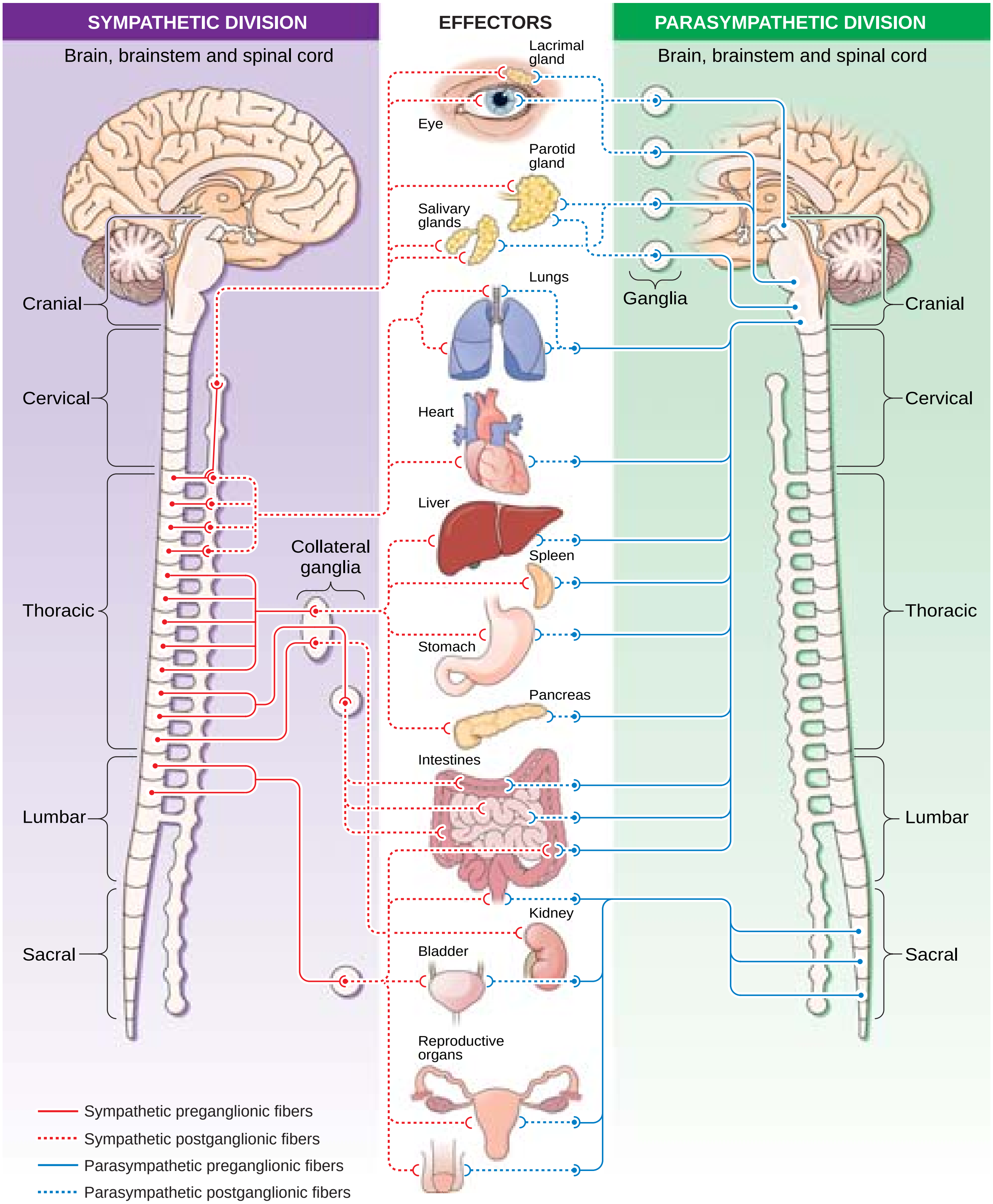

Figure 9-16 Autonomic nervous system. The diagram shows only one side of the body for each division. *ZOOMING IN ✦ Which division of the autonomic nervous system has ganglia closer to the effector organ?*

Table 9•3 Divisions of the Autonomic Nervous System

CHARACTERISTICS	DIVISIONS	
	Sympathetic Nervous System	**Parasympathetic Nervous System**
Origin of fibers	Thoracic and lumbar regions of the spinal cord; thoracolumbar	Brain stem and sacral regions of the spinal cord; craniosacral
Location of ganglia	Sympathetic chains and three single collateral ganglia (celiac, superior mesenteric, inferior mesenteric)	Terminal ganglia in or near the effector organ
Neurotransmitter	Adrenaline and noradrenaline; adrenergic	Acetylcholine; cholinergic
Effects (see Table 9-4)	Response to stress; fight-or-flight response	Reverses fight-or-flight (stress) response; stimulates some activities

Parasympathetic Nervous System The parasympathetic motor pathways begin in the **craniosacral** (kra-ne-o-SAK-ral) areas, with fibers arising from cell bodies in the brainstem (midbrain and medulla) and the lower (sacral) part of the spinal cord. From these centers, the first fibers extend to autonomic ganglia that are usually located near or within the walls of the effector organs and are called **terminal ganglia**. The pathways then continue along postganglionic neurons that stimulate the involuntary tissues.

The neurons of the parasympathetic system release the neurotransmitter acetylcholine, leading to the description of this system as **cholinergic** (activated by acetylcholine).

Functions of the Autonomic Nervous System

Most organs are supplied by both sympathetic and parasympathetic fibers, and the two systems generally have opposite effects. The sympathetic part of the ANS tends to act as an accelerator for those organs needed to meet a stressful situation. It promotes what is called the **fight-or-flight response** because in the most primitive terms, the person must decide to stay and “fight it out” with the enemy or to run away from danger. If you think of what happens to a person who is frightened or angry, you can easily remember the effects of impulses from the sympathetic nervous system:

- Increase in the rate and force of heart contractions.
- Increase in blood pressure due partly to the more effective heartbeat and partly to constriction of small arteries in the skin and the internal organs.
- Dilation of blood vessels to skeletal muscles, bringing more blood to these tissues.
- Dilation of the bronchial tubes to allow more oxygen to enter.
- Stimulation of the central portion of the adrenal gland. This produces hormones, including epinephrine, that prepare the body to meet emergency situations in many ways (see Chapter 12). The sympathetic nerves and hormones from the adrenal gland reinforce each other.
- Increase in basal metabolic rate.
- Dilation of the pupil and decrease in focusing ability (for near objects).

9

Table 9•4 Effects of the Sympathetic and Parasympathetic Systems on Selected Organs

Effector	Sympathetic System	Parasympathetic System
Pupils of eye	Dilation	Constriction
Sweat glands	Stimulation	None
Digestive glands	Inhibition	Stimulation
Heart	Increased rate and strength of beat	Decreased rate of beat
Bronchi of lungs	Dilation	Constriction
Muscles of digestive system	Decreased contraction (peristalsis)	Increased contraction
Kidneys	Decreased activity	None
Urinary bladder	Relaxation	Contraction and emptying
Liver	Increased release of glucose	None
Penis	Ejaculation	Erection
Adrenal medulla	Stimulation	None
Blood vessels to:		
Skeletal muscles	Dilation	Constriction
Skin	Constriction	None
Respiratory system	Dilation	Constriction
Digestive organs	Constriction	Dilation

Box 9-3 A Closer Look

Cell Receptors: Getting the Message

Neurons use neurotransmitters to communicate with other cells at synapses. Just as important, however, are the "docking sites," the receptors on the receiving (postsynaptic) cell membranes. A neurotransmitter fits into its receptor like a key in a lock. Once the neurotransmitter binds, the receptor initiates events that change the postsynaptic cell's activity. Different receptors' responses to the same neurotransmitter may vary, and a cell's response depends on the receptors it contains.

Among the many different classes of identified receptors, two are especially important and well-studied. The first is the cholinergic receptors, which bind acetylcholine (ACh). Cholinergic receptors are further subdivided into two types, each named for drugs that bind to them and mimic ACh's effects:

- Nicotinic receptors (which bind nicotine) are found on skeletal muscle cells and stimulate muscle contraction when ACh is present.
- Muscarinic receptors (which bind muscarine, a poison) are found on effector cells of the parasympathetic nervous system. ACh can either stimulate or inhibit muscarinic receptors depending on the effector organ. For example, ACh stimulates digestive organs but inhibits the heart.

The second class of receptors is the adrenergic receptors, which bind norepinephrine and epinephrine. They are found on effector cells of the sympathetic nervous system. They are further subdivided into alpha (α) and beta (β), each with several subtypes (*e.g*, α_1, α_2, β_1, and β_2). When norepinephrine (or epinephrine) binds to adrenergic receptors, it can either stimulate or inhibit, depending on the organ. For example, norepinephrine stimulates the heart and inhibits the digestive organs. With some exceptions, α_1 and β_1 receptors usually stimulate, whereas α_2 and β_2 receptors inhibit.

Some drugs block specific receptors. For example, "beta-blockers" regulate the heart in cardiac disease by preventing β_1 receptors from binding epinephrine, the neurotransmitter that increases the rate and strength of heart contractions.

The sympathetic system also acts as a brake on those systems not directly involved in the response to stress, such as the urinary and digestive systems. If you try to eat while you are angry, you may note that your saliva is thick and so small in amount that you can swallow only with difficulty. Under these circumstances, when food does reach the stomach, it seems to stay there longer than usual.

The parasympathetic part of the ANS normally acts as a balance for the sympathetic system once a crisis has passed. The parasympathetic system brings about constriction of the pupils, slowing of the heart rate, and constriction of the bronchial tubes. It also stimulates the formation and release of urine and activity of the digestive tract. Saliva, for example, flows more easily and profusely, and its quantity and fluidity increase.

Most organs of the body receive both sympathetic and parasympathetic stimulation, the effects of the two systems on a given organ generally being opposite. Table 9-4 shows some of the actions of these two systems. Box 9-3, Cell Receptors: Getting the Message, stresses the role of receptors in regulating the activities of the sympathetic and parasympathetic systems.

Checkpoint 9-15 Which division of the ANS stimulates a stress response, and which division reverses the stress response?

Word Anatomy

Medical terms are built from standardized word parts (prefixes, roots, and suffixes). Learning the meanings of these parts can help you remember words and interpret unfamiliar terms.

WORD PART	MEANING	EXAMPLE
The Nervous System as a Whole		
soma-	body	The *somatic* nervous system controls skeletal muscles that move the body.
aut/o	self	The *autonomic* nervous system is automatically controlled and is involuntary.
neur/i	nerve, nervous tissue	The *neurilemma* is the outer membrane of the myelin sheath around an axon.
-lemma	sheath	See preceding example.

WORD PART	MEANING	EXAMPLE
The Nervous System at Work		
de-	remove	*Depolarization* removes the charge on the plasma membrane of a cell.
re-	again, back	*Repolarization* restores the charge on the plasma membrane of a cell.
post-	after	The *postsynaptic* cell is located after the synapse and receives neurotransmitter from the presynaptic cell.
The Spinal Cord		
myel/o	spinal cord	*Poliomyelitis* is an infectious disease that involves the spinal cord and other parts of the CNS.
-plegia	paralysis	*Monoplegia* is paralysis of one limb.
para-	beyond	*Paraplegia* is paralysis of both lower limbs.
hemi-	half	*Hemiplegia* is paralysis of one side of the body.
tetra-	four	*Tetraplegia* is paralysis of all four limbs.

Summary

9

I. Role of the nervous system

A. Structural divisions—anatomic
   1. Central nervous system (CNS)—brain and spinal cord
   2. Peripheral nervous system (PNS)—spinal and cranial nerves

B. Functional divisions—physiologic
   1. Somatic nervous system—voluntary; supplies skeletal muscles
   2. Autonomic (visceral) nervous system—involuntary; supplies smooth muscle, cardiac muscle, glands

II. Neurons and their functions

A. Structure of a neuron
   1. Cell body
   2. Cell fibers
      a. Dendrite—carries impulses to cell body
      b. Axon—carries impulses away from cell body
   3. Myelin sheath
      a. Covers and protects some axons
      b. Speeds conduction
      c. Made by Schwann cells in PNS; other cells in CNS
         (1) Neurilemma—outermost layer of Schwann cell; aids axon repair
      d. White matter—myelinated tissue; gray matter—unmyelinated tissue

B. Types of neurons
   1. Sensory (afferent)—carry impulses toward CNS
   2. Motor (efferent)—carry impulses away from CNS
   3. Interneurons—in CNS

C. Nerves and tracts—bundles of neuron fibers
   1. Nerve—in peripheral nervous system
      a. Held together by connective tissue
         (1) Endoneurium—around a single fiber
         (2) Perineurium—around each fascicle
         (3) Epineurium—around whole nerve
      b. Types of nerves
         (1) Sensory (afferent) nerve—contains only fibers that carry impulses toward the CNS (from a receptor)
         (2) Motor (efferent) nerve—contains only fibers that carry impulses away from the CNS (to an effector)
         (3) Mixed nerve—contains both sensory and motor fibers
   2. Tract—in central nervous system

III. Neuroglia

A. Nonconducting cells

B. Protect and support nervous tissue

IV. The nervous system at work

A. Nerve impulse
   1. Potential—electrical charge on the plasma membrane of neuron
   2. Action potential
      a. Depolarization—reversal of charge
      b. Repolarization—return to normal
      c. Involves changes in concentrations of Na^+ and K^+
   3. Nerve impulse—spread of action potential along membrane
   4. Myelin sheath speeds conduction

B. Synapse—junction between neurons
   1. Nerve impulse transmitted from presynaptic neuron to postsynaptic neuron
   2. Neurotransmitter—carries impulse across synapse
   3. Receptors—in postsynaptic membrane; pick up neurotransmitters
   4. Neurotransmitter removed by diffusion, destruction by enzyme, return to presynaptic cell (reuptake)
   5. Electrical synapses—in smooth muscle, cardiac muscle, CNS

V. Spinal cord

A. In vertebral column

B. Ends between first and second lumbar vertebrae

C. Structure of the spinal cord
   1. H-shaped area of gray matter
   2. White matter around gray matter
      a. Ascending tracts—carry impulses toward brain
      b. Descending tracts—carry impulses away from brain

D. Reflex arc—pathway through the nervous system
   1. Components
      a. Receptor—detects stimulus

b. Sensory neuron—receptor to CNS
c. Central neuron—in CNS
d. Motor neuron—CNS to effector
e. Effector—muscle or gland that responds
2. Reflex activities—simple reflex is rapid, automatic response using few neurons
a. Examples—stretch reflex, eye blink, withdrawal reflex
b. Spinal reflex—coordinated in spinal cord
E. Medical procedures involving the spinal cord
a. Lumbar puncture
b. Administration of drugs
F. Diseases and other disorders of the spinal cord
1. Diseases—multiple sclerosis, amyotrophic lateral sclerosis, poliomyelitis
2. Tumors
3. Injuries

VI. Spinal nerves—31 pairs

A. Roots
1. Dorsal (sensory)
2. Ventral (motor)
B. Spinal nerve—combines sensory and motor fibers (mixed nerve)
C. Branches of the spinal nerves
1. Plexuses: networks formed by anterior branches
a. Cervical plexus
b. Brachial plexus
c. Lumbosacral plexus
2. Dermatome—region of the skin supplied by a single spinal nerve
D. Disorders of the spinal nerves—peripheral neuritis, sciatica, herpes zoster (shingles), Guillain-Barré

VII. Autonomic nervous system (visceral nervous system)

A. Involuntary
B. Controls glands, smooth muscle, heart (cardiac) muscle
C. Two motor neurons (preganglionic and postganglionic)
D. Divisions of the autonomic nervous system
1. Sympathetic nervous system
a. Thoracolumbar
b. Adrenergic—uses adrenaline
c. Synapses in sympathetic chains and three collateral ganglia (celiac, superior mesenteric, inferior mesenteric)
2. Parasympathetic system
a. Craniosacral
b. Cholinergic—uses acetylcholine
c. Synapses in terminal ganglia in or near effector organs
E. Functions of the autonomic nervous system
1. Sympathetic—stimulates fight-or-flight (stress) response
2. Parasympathetic—returns body to normal
3. Usually have opposite effects on an organ

Questions for Study and Review

Building Understanding

Fill in the blanks

1. The brain and spinal cord make up the ______ nervous system.
2. Action potentials are conducted away from the neuron cell body by the ______.
3. During an action potential the flow of Na^+ into the cell causes ______.
4. In the spinal cord, sensory information travels in ______ tracts.
5. With few exceptions, the sympathetic nervous system uses the neurotransmitter ______ to act on effector organs.

Matching

Match each numbered item with the most closely related lettered item.

___ 6. Cells that carry impulses from the CNS
___ 7. Cells that carry impulses to the CNS
___ 8. Cells that carry impulses within the CNS
___ 9. Cells that detect a stimulus
___10. Cells that carry out a response to a stimulus

a. receptors
b. effectors
c. sensory neurons
d. motor neurons
e. interneurons

Multiple choice

___ 11. Skeletal muscles are voluntarily controlled by the
a. central nervous system
b. somatic nervous system
c. parasympathetic nervous system
d. sympathetic nervous system

___ 12. The cells involved in most nervous system tumors are called
a. motor neurons
b. sensory neurons
c. interneurons
d. neuroglia

___ 13. The correct order of synaptic transmission is
a. postsynaptic neuron, synapse, and presynaptic neuron
b. presynaptic neuron, synapse, and postsynaptic neuron

c. presynaptic neuron, postsynaptic neuron, and synapse
d. postsynaptic neuron, presynaptic neuron, and synapse

___ 14. Afferent nerve fibers enter the part of the spinal Cord called the
a.. dorsal horn
b. ventral horn
c. gray commisure
d. central canal

___ 15. The "fight-or-flight" response is promoted by the
a. sympathetic nervous system
b. parasympathetic nervous system
c. somatic nervous system
d. reflex arc

Understanding Concepts

16. Differentiate between the terms in each of the following pairs:
    a. neurons and neuroglia
    b. vesicle and receptor
    c. gray matter and white matter
    d. nerve and tract
17. Describe an action potential. How does conduction along a myelinated fiber differ from conduction along an unmyelinated fiber?
18. Discuss the structure and function of the spinal cord.
19. Explain the reflex arc using stepping on a tack as an example.
20. Describe the anatomy of a spinal nerve. How many pairs of spinal nerves are there?
21. Define a *plexus*. Name the three main spinal nerve plexuses.
22. Compare and contrast multiple sclerosis and Guillain-Barré syndrome.
23. Differentiate between the functions of the sympathetic and parasympathetic divisions of the autonomic nervous system.

Conceptual Thinking

24. Clinical depression is associated with abnormal serotonin levels. Medications that block the removal of this neurotransmitter from the synapse can control the disorder. Based on this information, is clinical depression associated with increased or decreased levels of serotonin? Explain your answer.
25. Mr. Hayward visits his dentist for a root canal and is given Novocain, a local anesthetic, at the beginning of the procedure. Novocain reduces membrane permeability to Na^+. What effect does this have on action potential?