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)
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.

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.
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

### Table 9-1

Functional Divisions of the Nervous System

<table>
<thead>
<tr>
<th>DIVISION</th>
<th>CONTROL</th>
<th>EFFECTORS</th>
<th>SUBDIVISIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Somatic nervous system</td>
<td>Voluntary</td>
<td>Skeletal muscle</td>
<td>None</td>
</tr>
<tr>
<td>Autonomic nervous system</td>
<td>Involuntary</td>
<td>Smooth muscle, cardiac muscle, and glands</td>
<td>Sympathetic and parasympathetic systems</td>
</tr>
</tbody>
</table>

**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

**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?
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
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**.
CHAPTER NINE

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.

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.

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- Depolarization. A stimulus of adequate force, such as electrical, chem-

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.

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).

先进技术。在下一步，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 **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).
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).
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-
CHAPTER NINE

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.

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.
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.

**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 contracting, is a common example of a spinal reflex. Other examples include the **knee-jerk reflex** and the **foot-level reflex**. These reflexes are mediated by the spinal cord and do not involve higher brain centers.

**Table 9-2** Components of a Reflex Arc

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

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?
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
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 (kwahdrih-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
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.

**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.

**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.

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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 (effferent) 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 (thor-ah-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. Which division of the autonomic nervous system has ganglia closer to the effector organ?
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).

**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).
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.

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.

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

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
            (2) Myelin sheath—spreads conduction
         d. White matter—unmyelinated 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)

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. Receptor—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
   2. Dermatome—region of the skin supplied by a single spinal nerve
   3. 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 tumours are called
      a. motor neurons

   ___ 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 commissure
   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.
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?