To understand the nervous system, start by thinking of your body as a biological machine that runs on electricity. In fact, this is true; your body does run on electricity! Your brain is the control center of your biological machine and sends and receives electrical impulses, or signals, throughout your body. The sophisticated communication system that delivers these electrical signals to and from the brain is your nervous system.

With all this electrical activity going on, why don’t our bodies light up? The answer is that the electrical charges within our bodies are very tiny. In the eighteenth century, Italian scientist Luigi Galvani discovered that muscle produces a detectable electric current, or voltage, when developing tension. But it was not until the twentieth century that technology became sophisticated enough to detect and record the extremely small electrical charges that move through the nervous system.

The activities performed by the nervous system are crucial. What enables the nervous system to perform these various functions so efficiently? In this chapter, we will take a look at the different anatomical structures and the functions of the nervous system. We will also discuss some of the common injuries and disorders of the nervous system, along with their symptoms and treatments.
Lesson 6.1
Overview of the Nervous System

Before You Read
Try to answer the following questions before you read this lesson.
Why are some body functions under involuntary control?
Why is the myelin sheath around nerve axons so important?

Lesson Objectives
1. Differentiate between the central nervous system and peripheral nervous system, and explain the function of each.
2. Explain the differences between afferent and efferent nerves.
3. Describe the functions of the somatic and autonomic branches of the nervous system.
4. Identify the general role of the glial cells.
5. Describe the anatomical structure of a typical neuron.

Key Terms
afferent nerves, autonomic nervous system, cell body, central nervous system (CNS), dendrites, efferent nerves, myelin sheath, neurilemma, neuroglia, nodes of Ranvier, peripheral nervous system (PNS), somatic nervous system, synapse

Our nervous system is amazing in its ability to simultaneously direct a whole host of different functions. The nervous system not only controls voluntary movement by activating skeletal muscle, but it also directs the involuntary functions of smooth muscle in internal organs and cardiac muscle in the heart. By automatically controlling the functions of smooth muscle and cardiac muscle, the nervous system ensures that these life functions are able to occur without conscious thought.

At the same time that your heart is beating and your last meal is making its way through your digestive tract, you may be talking to a friend, walking to a class, or even reading this book. Our senses—the ability to see, hear, smell, taste, feel pressure, and feel pain—are all dependent on sensory electrical input from specialized receptors.

For the purpose of discussion, the nervous system is organized into structural and functional subdivisions. This organization makes it easier to learn about the activities directed by the various parts of the nervous system, and how these parts interact.

Organization of the Nervous System

There are two major divisions of the human body’s nervous system: the central nervous system and the peripheral nervous system. There are further subdivisions of the peripheral nervous system. Figure 6.1 illustrates these major divisions and subdivisions.

First, let’s look at the organization of the nervous system. We will examine the structure and function of the two major divisions of the nervous system in greater detail later in the chapter.

Figure 6.1 This diagram represents the organization of the nervous system and summarizes the relationships among the subdivisions. If you were asked to put the word voluntary into one of the six boxes above and involuntary into another one of the boxes, where would you put each word?

Two Major Divisions

The central nervous system (CNS) includes the brain and spinal cord. The CNS directs the activity of the entire nervous system. Injuries to either the brain or the spinal cord have serious consequences and can be life threatening. Fortunately, these delicate structures are well protected inside the skull and vertebral column.

The parts of the nervous system other than the brain and spinal cord make up what is called the peripheral nervous system (PNS). For example, the PNS includes spinal nerves that transmit information to and from the spinal cord and cranial nerves that transmit information to and from the brain. The PNS also includes specialized nerve endings called sensory receptors, which respond to stimuli such as pressure, pain, or temperature.

Nerves that transmit impulses from the sensory receptors in the skin, muscles, and joints to the CNS are known as afferent (sensory) nerves. Those that carry impulses from the CNS out to the muscles and glands are efferent (motor) nerves.

Memory Tip
Afferent nerves tell the body how it is being affected by stimuli such as light, heat, and pressure. Efferent nerves stimulate muscles to produce effort.

The Efferent Nerves

There are two functional subdivisions of the efferent, or motor, nerves. The somatic (voluntary) nervous system stimulates our skeletal muscles, causing them to develop tension. The autonomic (involuntary) nervous system controls the cardiac muscle of the heart and the smooth muscles of the internal organs. The autonomic nervous system prompts the heart to beat faster when we exercise and causes the smooth muscle activities that move food through the digestive system.

Thanks to our autonomic nervous system, we do not have to think about everyday body functions that sustain life. And under certain
circumstances, such as when we inadvertently touch a hot surface, the efferent neurons can trigger involuntary action of the skeletal muscles through a reflex arc. The autonomic nervous system includes sympathetic and parasympathetic branches, which you will learn about in Lesson 6.4.

Becoming aware of these various subdivisions of the nervous system will help you learn and understand the different functional capabilities of the nervous system. Keep in mind, however, that the nervous system as a whole is a single, remarkably coordinated, functioning unit.

Check Your Understanding

1. Which structures make up the central nervous system (CNS)?
2. Which structures make up the peripheral nervous system (PNS)?
3. Which function is the somatic nervous system responsible for?
4. Which functions is the autonomic nervous system responsible for?

Nervous Tissues

Two categories of tissues exist within the nervous system. These include specialized supporting cells called neuroglia and neurons.

Neuroglia

The neuroglia (ner-ROHG-lee-a), also known as glial (GLIGH-al) cells, are a category of specialized cells that perform support functions (Figure 6.2). Within the CNS are four types of glial cells:

- Astrocytes (AS-troh-sights) are positioned between neurons and capillaries. Astrocytes link the nutrient-supplying capillaries to neurons and control the chemical environment to protect the neurons from any harmful substances in the blood. The astrocytes are so numerous that they account for nearly half of all neural tissue.
- Microglia (migh-KROHG-lee-a) absorb and dispose of dead cells and bacteria.
- Ependymal (eh-PEHN-di-mal) cells form a protective covering around the spinal cord and central cavities within the brain.
- Oligodendrocytes (AHL-i-goh-DEHN-droh-sights) wrap around nerve fibers and produce a fatty insulating material called myelin.

The PNS includes two forms of glial cells:

- Schwann (shwahn) cells form the fatty myelin sheaths around nerve fibers in the PNS.
- Satellite cells serve as cushioning support cells.

Neurons

The glial cells provide support and protection for the nervous system, but it is the neurons that transmit information in the form of nerve impulses throughout the body. A typical neuron, or nerve cell, consists of a cell body surrounded by branching dendrites. The typical neuron also has a long, tail-like projection called an axon (Figure 6.3).

The cell body includes a nucleus and mitochondria, like all cell bodies, as described in chapter 2. The dendrites (DEHN-drights) collect stimuli and transport them to the cell body. Axons (AK-sahns) transmit impulses away from the cell body.

Within the PNS, the Schwann cells wrap around the axon, covering most of it with a fatty myelin (MIGH-eh-lin) sheath. The myelin sheaths serve an important purpose: insulating the axon fibers, which increases the rate of neural impulse transmission.

The external covering of the Schwann cell, outside the myelin sheath, is called the neurilemma (NOO-ri-LEHM-a). The uninsulated gaps, where the axon is exposed between the Schwann cells, are known as the nodes of Ranvier (rahn-vee-AY). The myelin sheaths are white, giving rise to the term white matter to describe tracts of myelinated fibers within the CNS. Gray matter is the term for unmyelinated nerve fibers.

At the terminal end of each axon, there can be up to thousands of axon terminals that connect with other neurons or muscles (Figure 6.3). The axon terminals are filled with tiny sacs, or vesicles, that contain chemical messengers called neurotransmitters (Figure 6.6). Axon terminals do not actually touch the other neuron or muscle, but are separated by a microscopic gap called the synaptic cleft. This intersection, including the synaptic cleft, is known as the synapse (SYN-ap). A synapse between an axon terminal and a muscle fiber is called the neuromuscular junction, as you learned in chapter 5.
When classified by their function, there are three types of neurons:

- **Sensory (afferent) neurons** carry impulses from the skin and organs to the spinal cord and brain, providing information about the external and internal environments.
- **Motor (efferent) neurons** transmit impulses from the brain and spinal cord to the muscles and glands, directing body actions.
- **Neurons that form bridges to transmit impulses between other neurons are interneurons (inter-NOO-rhnuhs), or association neurons.**

As shown in Figure 6.4, there are also three different neuron structures:

- **Bipolar neurons** have one axon and one dendrite. These are sensory processing cells found in the eyes and nose.
- **Unipolar neurons** have a single axon with dendrites on the peripheral end and axon terminals on the central end. The peripheral process carries impulses to the cell body, while the central process carries impulses to the central nervous system. Some of the sensory neurons in the PNS are unipolar.
- **Multipolar neurons** have one axon and multiple dendrites. All motor neurons and interneurons are multipolar.

### MINI GLOSSARY

- **afferent nerves**—sensory transmitters that send impulses from receptors in the skin, muscles, and joints to the central nervous system
- **autonomic nervous system**—branch of the nervous system that controls involuntary body functions
- **cell body**—part of an axon that contains a nucleus
- **central nervous system (CNS)**—the brain and spinal cord
- **dendrites**—branches of a neuron that collect stimuli and transport them to the cell body
- **efferent nerves**—motor transmitters that carry impulses from the central nervous system out to the muscles and glands
- **myelin sheath**—the fatty bands of insulation surrounding axon fibers
- **neuromuscular junction**—the point at which axon fibers of sensory neurons make contact with fibers of the muscle and gland
- **nodes of Ranvier**—the uninsulated gaps in the myelin sheath of a nerve fiber where the axon is exposed
- **peripheral nervous system (PNS)**—all parts of the nervous system external to the brain and spinal cord
- **somatic nervous system**—branch of the nervous system that stimulates the skeletal muscles
- **synapse**—the intersection between a neuron and another neuron, a muscle, a gland, or a sensory receptor

### LESSON 6.1 REVIEW AND ASSESSMENT

#### Mini Glossary

- **Know and Understand**
  1. Explain how the nervous system is organized, including subdivisions of each component.
  2. What is a sensory receptor?
  3. Which nerves—the afferent nerves or efferent nerves—are also referred to as motor nerves? Why are they called motor nerves?
  4. List the three parts of a typical neuron and state the function of each part.
  5. What do the tiny sacs inside axon terminals contain?
  6. What are the two ways of classifying neurons?
  7. Explain the difference between bipolar, unipolar, and multipolar neurons.

- **Analyze and Apply**
  8. Describe a synapse. In your description use at least three terms that you learned in this lesson.
  9. Explain the negative effects on a neuron when the myelin sheath is damaged or destroyed by a demyelinating disorder.

- **In the Lab**
  10. Using clay, or a substitute material, create a model of a typical neuron as described in the lesson. Include all of the different parts mentioned. Label the parts and list the functions of those parts.
Neurons have one behavioral property in common with muscle: irritability (the ability to respond to a stimulus). Neurons, however, have an aspect of irritability that muscles do not have: the ability to convert a stimulus into a nerve impulse. **Conductivity**, the other behavioral property of neurons, is the ability to transmit nerve impulses.

What, exactly, is a nerve impulse? It is a tiny electrical charge that transmits information between neurons. In this lesson we will explore the processes by which nerve impulses are created and spread throughout the nervous system.

### Action Potentials

When a neuron is inactive or at rest, there are potassium (K⁺) ions inside the cell and sodium (Na⁺) ions outside the cell membrane. The overall distribution of ions is such that the inside of the membrane is more negatively charged than the outside. Because of this difference in electrical charge, the cell membrane is said to be **polarized**.

Many different stimuli can activate a neuron. A bright light in the eyes, a bitter taste on the tongue, or the perception of neurotransmitter chemicals from another neuron are possible stimuli. In all cases, if the stimulus exceeds a critical voltage, hundreds of gated sodium channels in the cell membrane briefly open. This allows the sodium ions outside the cell to rapidly diffuse into the neuron. As a result, the electrical charge inside the membrane becomes more positive and the neuron membrane is depolarized.

The depolarization of the neuron membrane opens more gated ion channels along the membrane, generating a wave of depolarization through the neuron. This electrical charge is known as a **nerve impulse**, or **action potential**, and it executes in an all-or-none fashion. This means that the electrical charge of the action potential is always the same size, and once initiated, it always travels the full length of the axon.

Following the discharge of the action potential, the membrane becomes permeable to (or accepting of) potassium ions, which rapidly diffuse out of the cell. This begins the process of restoring the membrane to its original, polarized resting state, a process called **repolarization**. Until the cell membrane is repolarized, it cannot respond to another stimulus. The time between the completion of the action potential and repolarization is called the **refractory** (ree-FRAK-toh-ree) **period.** During the refractory period the neuron is temporarily “fatigued.”

### Impulse Transmission

Two factors—the presence or absence of a myelin sheath and the diameter of the axon—have a major impact on the speed at which a nerve impulse travels. Because the fatty myelin sheath is an electrical insulator, action potentials in a myelinated axon “jump over” the myelinated regions of the axon. Depolarization occurs only at the nodes of Ranvier, where the axon is exposed (Figure 6.3). This process, known as **saltatory** (SAWL-ta-TOH-ree) **conduction**, results in significantly faster impulse transmission than is possible in nonmyelinated axons.

Impulse conduction is much faster in nonmyelinated axons with larger diameters than in those with smaller diameters. The larger the axon, the greater the number of ions there will be to conduct current. This is somewhat like a large-diameter pipe versus a small-diameter pipe when transferring water from one place to another. The water moves through the large-diameter pipe faster than it does through the pipe with a small diameter.

A third factor influencing conduction speed is body temperature. Warmer temperatures increase ion diffusion rates, whereas local cooling, which occurs when holding an ice cube, for example, decreases ion diffusion rates.

So how fast do nerve impulses travel? As is clear from our recent discussion, the type and size of the nerve axon have much to do with this. Impulses that signal limb position to the brain travel extremely fast—up to 119 m/s (meters per second). Information or impulses from the objects that we touch travel more slowly, at around 76 m/s (Figure 6.5). By contrast, the sensation of pain moves more slowly, at less than 1 m/s. Thought signals, which are happening right now as you are reading, transmit at 20–30 m/s. For a nerve to transmit impulses at speeds greater than 1 m/s, it must have a myelinated axon.

### Transmission of Nerve Impulses

Communication between some cells occurs through direct transfer of electrical charges at **electrical synapses** within specialized sites called **gap junctions**. The intercalated discs between cardiac muscle fibers, for example, serve as gap junctions.

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**Check Your Understanding**

1. What is meant when a cell membrane is said to be polarized?
2. Do action potentials occur when neuron cell membranes are polarized or depolarized?
3. What two factors influence the speed at which a nerve impulse travels?
Communication between neurons, however, occurs at the synapse. Because the action potential is electrical, and what occurs at the synapse is chemical, transmission of nerve impulses is an electrochemical event.

When an action potential reaches an axon terminal, the terminal depolarizes, calcium gates open, and calcium (Ca++) ions flow into the terminal. The axon terminal is filled with tiny vesicles containing neurotransmitter (NOO-roh-TRANS-mit-er) chemicals (Figure 6.6). The influx of calcium causes these vesicles to join to the cell membrane adjacent to the synaptic cleft. Pores then form in the membrane, allowing the neurotransmitter to diffuse across the synapse to receptor sites on the membrane of the joining neuron or muscle fiber.

Neurotransmitters can have an excitatory effect or an inhibitory effect on the receiving cell. An example of an excitatory neurotransmitter is acetylcholine (a-SEE-tl-KOH-leen), the chemical that activates muscle fibers. Endorphins are neurotransmitters released to inhibit nerve cells from discharging more pain signals.

The final step in communication between nerves at a synapse is the removal of the neurotransmitter, usually by an enzyme, to prevent ongoing stimulation of the receptor cell. Acetylcholine, for example, is deactivated by the enzyme acetylcholinesterase (a-SEE-tl-KOH-leen-EHS-ter-a). The recording electrode is then placed at a distance up the limb.

How are the results of a clinical NCV test interpreted? An NCV that is significantly slower than normal suggests that damage to the myelin sheath is likely. Alternatively, if NCV is slowed but close to the normal range, damage to the axons of the involved neurons is suspected. Evaluation of the overall pattern of responses can serve as a diagnostic tool in helping a clinician determine the likely pathology involved in an abnormal NCV.

**Microneurography**

Scientists have used a similar but more sophisticated procedure called microneurography (MIGH-kroh-noo-RAHG-ra-fee) to record electrical activity from single sensory fibers. Figure 6.8 shows that the technique involves the direct insertion of fine-tipped needle electrodes into the nerve being studied.

Through the use of microneurography we have developed new and more sophisticated understanding of the sympathetic nervous system. Topics studied include various reflexes, interactions within the sympathetic nervous system, metabolism, hormones, and the effects of drugs or anesthesia during operative procedures. Microneurographic recordings have also been used to study the effects of performance at high altitudes, as well as in space.

Taking It Further

1. Working with a partner, research nerve damage further. Develop a report for the class on the more common causes.
2. Investigate and report to the class on technologies, in addition to NCV tests, that are used for diagnostic and therapeutic purposes to treat nerve disorders.
Lesson 6.3

Functional Anatomy of the Central Nervous System

The central nervous system includes numerous anatomical structures with specialized functions. Using sophisticated imaging techniques, scientists have been able to identify which structures control or contribute to physiological processes and actions.

The Brain

As you might expect, given its all-important role in directing the activity of the entire nervous system, the brain is structurally and functionally complex. The adult human brain weighs between 2¼ and 3¼ pounds and contains approximately 100 billion neurons and even more glial cells. Recent research indicates that the size of a person’s brain does have some relationship to intelligence; about 67% of individual variation in intelligence is attributed to brain size. The four major anatomical regions of the brain are the cerebrum, diencephalon, brain stem, and cerebellum.

Cerebrum

The left and right cerebral (seh-REE-bral) hemispheres are collectively referred to as the cerebrum (seh-REE-brum), which makes up the largest portion of the brain. The outer surface of the cerebrum, the cerebral cortex, is composed of nonmyelinated gray matter. The internal tissue is myelinated white matter, with small, interspersed regions of gray matter called basal nuclei.

As you can see in Figure 6.9 on the next page, the surface of the brain is not smooth; instead, it is convoluted. Each of the curved, raised areas is called a gyrus (HIGH-rihs), and each of the grooves between the gyri is called a sulcus (SUL-kus). Together, these structures are referred to as the cerebral convolutions.
to as convolutions. No two brains look exactly alike in their pattern of convolutions. However, the major sulci are arranged in the same pattern in all human brains.

The sulci divide the brain into four regions called lobes. The four lobes of the brain are the frontal, parietal, occipital, and temporal.

Like the sulci, fissures are uniformly positioned, deep grooves in the brain. The longitudinal fissure runs the length of the brain and divides it into left and right hemispheres. As a result, the lobes are paired on the left and right sides of the body. Neural communications to and from the right side of the body are controlled by the left brain, and communications with the left side of the body are controlled by the right brain.

The frontal lobes, located behind the forehead in the most anterior portion of the brain, are sectioned off from the rest of the brain by the central sulcus (Figure 6.9B). Just anterior to the central sulcus is the primary motor cortex, which sends neural impulses to the skeletal muscles to initiate and control the development of muscle tension and movement of our body parts. As Figure 6.10 shows, scientists have mapped the primary motor cortex so that we know which body parts are controlled in each region of the cortex. Notice that relatively small regions of the cortex control major body segments, such as the trunk, pelvis, thigh, and arm. Much larger regions of the cortex are allocated for control of smaller body segments, such as the hands, lips, and tongue.

Why is this the case? If you think about it, the body parts associated with larger areas of the motor cortex are the ones capable of the more fine-tuned movements. Such movements require the activation of more nerves.

**Figure 6.9 A**—The hemispheres of the cerebrum. B—The four lobes of the cerebrum (shown in contrasting colors) are separated by indentations called sulci.

**Figure 6.10** The primary motor and somatic sensory cortices, with mapped regions of motor output and sensory input depicted. Why do smaller areas of the body, such as the fingers or lips, require more nerves than larger areas, such as the shoulder or trunk?
brain function involves positron emission tomography (PET). This technology creates images of changes in blood flow to activated brain structures. This is made possible by the slightly different magnetic properties of oxygenated and deoxygenated blood. The images show how brain structures are activated and the amount of time they are activated during performance of different tasks. The individual undergoing the brain scan is presented with certain tasks that can cause activation (increased blood flow) to the regions of the brain responsible for perception, thought, and a stimulated motor action, such as raising an arm or smiling (Figure 6.11).

Increasingly, physicians are using fMRI to diagnose disorders and diseases of the brain. With a fine sensitivity to changes in blood flow, fMRI is particularly useful for evaluating patients who may have suffered a stroke. Early diagnosis of stroke is important because treatment can be significantly more effective the earlier it is given.

**PET Scans**
Another approach for studying brain function involves positron emission tomography (PET). This procedure tracks the locations of radioactively labeled chemicals in the bloodstream. PET scans can show blood flow, oxygen absorption, and glucose absorption in the active brain, indicating where the brain is active and inactive. Although fMRI has largely replaced PET for the study of brain activation patterns, PET scans still provide the advantage of showing where particular neurotransmitters are concentrated in the brain. PET scans are also still widely used in diagnosing various forms of brain disease because they can be analyzed and interpreted more quickly than fMRI scans.

**Taking It Further**
1. How is an MRI used to help diagnose disease and disorders?
2. Why is the blood-flow pattern to the brain a revealing factor in the diagnosis of a particular brain disease or disorder?
3. In what situations might a doctor prefer to use an MRI or PET scan?

### Check Your Understanding
1. List the four major anatomic regions of the brain.
2. Describe the relationship between gyri and sulci.
3. List the four lobes of the brain and state their locations.
4. List the function(s) of each lobe.

### Diencephalon
The **diencephalon** (DIGH-ehn-SEHF-ah-lahn), also known as the interbrain, is located deep inside the brain, enclosed by the cerebral hemispheres (Figure 6.12). It includes several important structures—the thalamus, hypothalamus, and epithalamus.

- The **thalamus** (THAL-oh-mus) serves as a relay station for communicating both sensory and motor information between the body and the cerebral cortex. It also plays a major role in regulating the body’s states of arousal, including sleep, wakefulness, and high-alert consciousness.
- Only about the size of a pearl, the **hypothalamus** (HIGH-poh-THAL-oh-mus) is a key part of the autonomic nervous system, regulating such functions as metabolism, heart rate, blood pressure, thirst, hunger, energy level, and body temperature. The centers for sex, pain, and pleasure also lie within the hypothalamus.
- The **epithalamus** (EHF-ohs-THAL-oh-mus) includes the pineal gland and regulates the sleep-cycle hormones that it secretes.

### Brain Stem
Approximately the size of a thumb, the brain stem is shaped somewhat like a stem and includes three structures: the midbrain, pons, and medulla oblongata (Figure 6.12).

- The **midbrain** on the superior end of the brain stem serves as a relay station for sensory and motor impulses. Specifically, it relays information concerning vision, hearing, motor activity, sleep and wake cycles, arousal (alertness), and temperature regulation.
- The **pons** (pahnz), located immediately below the midbrain, plays a role in regulating breathing.
- Inferior to the pons, the **medulla oblongata** (meh-DOLL-uh AHB-lawn-gah-tah) regulates heart rate, blood pressure, and breathing, and controls the reflexes for coughing, sneezing, and vomiting.

The **reticular** (reh-TIK-yoo-lahr) formation is a collection of gray matter that extends the length of the brain stem. The reticular formation regulates waking from slumber, as well as heightened states of awareness. Individuals with severe brain injuries can continue to live as long as the brain stem remains functional and they receive sufficient hydration and nutrition.
The cerebellum (SER-eh-BEL-um), found below the occipital lobe, looks similar to the cerebrum with its outer gray cortex, convolutions, and dual hemispheres (Figure 6.9). The cerebellum serves the important role of coordinating body movements, including balance.

The middle membrane, the arachnoid mater, is composed of webleke tissue. Beneath this membrane is the subarachnoid space, filled with cerebrospinal (seh-REE-broh-SPIGH-nal) fluid, which cushions the brain and spinal cord. The innermost layer of the meninges attaches directly to the surface of the brain and spinal cord. This layer is the delicate pia mater (PIGH-ah MAY-ter), meaning “gentle mother.”

Blood-Brain Barrier

A rich network of blood vessels supplies the brain. Like all tissues of the body, the brain depends on a circulating blood supply to provide nutrients and carry away the waste products of cell metabolism. At any given time, roughly 20%–25% of the blood in your body is circulating in the region of the brain.

The capillaries supplying the brain, however, are different from other capillaries in the body. Specifically, they are impermeable to many substances that freely diffuse through the walls of capillaries in other body regions. This property of impermeability has given rise to the term blood-brain barrier.

The blood-brain barrier protects the brain against surges in concentrations of hormones, ions, and some nutrients. Substances allowed to pass through the capillaries include water, glucose, and essential amino acids. Other substances that can penetrate the blood-brain barrier are blood-borne alcohol, nicotine, fats, respiratory gases, and anesthetics.

Spinal Cord

The spinal cord extends from the brain stem down to the beginning of the lumbar region of the spine. It serves as a major pathway for relaying sensory impulses to the brain and motor impulses from the brain. It also provides the

Meninges

Three protective membranes, the meninges (meh-NIN-jeez), surround the brain and spinal cord (Figure 6.14). The outer membrane, the dura mater (DOO-rah MAY-ter), meaning “hard mother,” is a tough, double-layered membrane that lies beneath the skull and surrounds the brain. The inner layer of the dura mater continues down to enclose the spinal cord.

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neural connections involved in reflex arcs. Like the brain, the spine is surrounded and protected by the three meninges and cerebrospinal fluid.

When viewed in cross section, the exterior of the spinal cord is myelinated white matter, with butterfly-shaped gray matter, composed of neuron cell bodies and interneurons (inter-NOO-rahnz), located centrally (Figure 6.15). The regions of the white and gray matter in the spinal cord are named after their locations—ventral (anterior), lateral, or dorsal (posterior). The dorsal columns of white matter carry sensory impulses to the brain, while the lateral and ventral columns transmit both sensory and motor impulses. The dorsal, lateral, and ventral projections of gray matter are called horns.

Figure 6.15 also shows the formations of the spinal nerves. These will be discussed in the next lesson.

Check Your Understanding
1. Name the three structures that make up the diencephalon and state their functions.
2. Name the three structures that make up the brain stem and state the function of each.
3. Where is the cerebellum located and what is its function?
4. What are the three regions of white and gray matter in the spinal cord?

Figure 6.15 Layers and regions of the spinal cord. Which is shaped like a butterfly—the layers and regions of the spinal cord, the gray matter, or the white matter?

Lesson 6.3 Review and Assessment

Mini Glossary

- cerebellum: section of the brain that coordinates body movements, including balance
- cerebrum: the largest part of the brain, consisting of the left and right hemispheres
- diencephalon: area of the brain that includes the thalamus, hypothalamus, and epithalamus; also known as the interbrain
- epithalamus: the uppermost portion of the diencephalon, which includes the pineal gland and regulates sleep-cycle hormones
- fissures: the uniformly positioned, deep grooves in the brain
- frontal lobes: sections of the brain located behind the forehead
- hypothalamus: a portion of the diencephalon, which regulates functions such as metabolism, heart rate, and blood pressure
- central canal: White matter
- meninges: three protective membranes that surround the brain and spinal cord
- midbrain: relay station for sensory and motor impulses; located on the superior end of the brain stem
- occipital lobes: sections of the brain located behind the parietal lobes; integrate sensory information from the skin, internal organs, muscles, and joints
- parietal lobes: sections of the brain located behind the frontal lobes; integrate sensory information from the skin, internal organs, muscles, and joints
- pons: the section of the brain that plays a role in regulating breathing
- primary motor cortex: outer region of the brain in the frontal lobes that sends neural impulses to the skeletal muscles
- primary somatic sensory cortex: outer region of the brain in the parietal lobes that interprets sensory impulses received from the skin, internal organs, muscles, and joints
- spinal cord: a column of nerve tissue that extends from the brain stem to the beginning of the lumbar region of the spine
- temporal lobes: most inferior portions of the brain; responsible for speech, hearing, vision, memory, and emotion
- thalamus: the largest portion of the diencephalon, which communicates sensory and motor information between the body and the cerebral cortex

Know and Understand

1. Is the brain divided into four lobes and two hemispheres or two lobes and four hemispheres?
2. What is the difference between gray matter and white matter in the brain? Where is each found?
3. Explain why someone might say that the brain is convoluted.
4. Are major body segments, such as the trunk and pelvis, controlled by large or small regions of the brain’s primary motor cortex?
5. What area of the brain has probably been damaged if a stroke patient has difficulty speaking?
6. Like the brain, the spinal cord has gray and white matter. Identify the responsibility of both the gray and white matter when found in the spinal cord.

Analyze and Apply

7. Compare and contrast the three protective membranes surrounding the brain and spinal cord. Discuss their structures and functions.
8. Why are the capillaries in the brain different from the capillaries in other parts of the body?
9. Which general area of the brain—the anterior or posterior region—is associated with more sophisticated functions? Explain.

In the Lab

10. Obtain a model or picture of a human brain. Color-code the different lobes and structures on the model or picture and then list the function(s) and body processes that each area controls.
Lesson 6.4
Functional Anatomy of the Peripheral Nervous System

Before You Read
Try to answer the following questions before you read this lesson.

What is in a nerve besides nerve tissue?
What are the similarities and differences between the sympathetic and parasympathetic nervous systems?
Have you ever experienced the fight-or-flight response?

Lesson Objectives
1. Describe the basic structure of a nerve.
2. Identify the twelve cranial nerves and the purpose of each.
3. Explain the organization of the spinal nerves, the dorsal and ventral rami, and the plexuses.
4. Describe the location, structure, and function of ganglions.
5. Differentiate between the functions of the sympathetic and parasympathetic nervous systems.

Key Terms
- cranial nerves
- craniosacral division
- dorsal ramus
- endoneurium
- epineurium
- ganglion
- norepinephrine
- paravertebral ganglia
- perineurium
- plexuses
- postganglionic neuron
- preganglionic neuron
- spinal nerves
- thoracolumbar division
- ventral ramus

The peripheral nervous system (PNS) transmits information to the CNS and carries instructions from the CNS. It achieves these functions through a network of nerves outside of the CNS.

Nerve Structure
Each nerve consists of a collection of axons (nerve fibers) and nutrient-supplying blood vessels, all bundled in a series of protective sheaths of connective tissue. As shown in Figure 6.16, each axon is covered by a fine endoneurium (EHN-doh-NOO-ree-um). In myelinated axons, the endoneurium surrounds the myelin sheath as well as the nodes of Ranvier.

Groups of these sheathed fibers are bundled into fascicles surrounded by a protective perineurium (PER-i-NOO-ree-um). Finally, groups of fascicles and blood vessels are encased in a tough epineurium (EHP-i-NOO-ree-um). This structural arrangement provides a cordlike strength that helps the nerve resist injury.

Cranial Nerves
Twelve pairs of cranial nerves relay impulses to and from the left and right sides of the brain. These pairs are referred to by both a name and a number (Figure 6.18). The functions of the cranial nerves are summarized in Figure 6.17. The names of these nerves indicate their functions.

Some of these nerves contain only afferent (sensory) fibers, some contain only efferent (motor) fibers, and others—the mixed nerves—carry both kinds of impulses. All but the first two cranial nerves emanate from the brain stem.

Spinal Nerves and Nerve Plexuses
Thirty-one pairs of spinal nerves branch out from the left and right sides of the spinal cord. Each pair is named for the vertebral level from which it originates. As you learned in chapter 4, the vertebral levels include the cervical, thoracic, and lumbar regions, as well as the sacrum. All of the spinal nerves are mixed nerves, carrying both afferent and efferent information.

The spinal nerve cell bodies are located within the gray matter of the spinal cord. The axons of spinal nerve cells extend out of the spinal cord and eventually connect with muscles. As shown earlier in Figure 6.15, dorsal (posterior) and ventral (anterior) spinal nerve roots unite to form the left and right spinal nerves that exit at each spinal level.

The spinal nerves are only about one-half inch long, immediately dividing into a dorsal ramus (DOR-sal RAY-mus) and ventral ramus (VEHN-tral RAY-mus) (Figure 6.19). The dorsal and ventral rami carry nerve impulses to the muscle and skin of the trunk.

<table>
<thead>
<tr>
<th>Nerve</th>
<th>#</th>
<th>System</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olfactory</td>
<td>I</td>
<td>sensory</td>
<td>smell</td>
</tr>
<tr>
<td>Optic</td>
<td>II</td>
<td>sensory</td>
<td>sight</td>
</tr>
<tr>
<td>Oculomotor</td>
<td>III</td>
<td>both</td>
<td>eye movements</td>
</tr>
<tr>
<td>Trochlear</td>
<td>IV</td>
<td>both</td>
<td>eye movements</td>
</tr>
<tr>
<td>Trigeminal</td>
<td>V</td>
<td>both</td>
<td>facial sensation, jaw motion</td>
</tr>
<tr>
<td>Abducens</td>
<td>VI</td>
<td>both</td>
<td>eye movements</td>
</tr>
<tr>
<td>Facial</td>
<td>VII</td>
<td>both</td>
<td>facial movements, taste</td>
</tr>
<tr>
<td>Vestibulocochlear</td>
<td>VIII</td>
<td>sensory</td>
<td>hearing, balance</td>
</tr>
<tr>
<td>Glossopharyngeal</td>
<td>IX</td>
<td>both</td>
<td>throat muscle movements, taste</td>
</tr>
<tr>
<td>Vagus</td>
<td>X</td>
<td>both</td>
<td>autonomic control of heart, lungs, digestion, taste, communica- tion between brain and organs</td>
</tr>
<tr>
<td>Accessory</td>
<td>XI</td>
<td>mostly motor</td>
<td>trapezius movements, sternocleidomastoid movements</td>
</tr>
<tr>
<td>Hypoglossal</td>
<td>XII</td>
<td>both</td>
<td>tongue muscle movements, tongue sensation</td>
</tr>
</tbody>
</table>
All of the rami are mixed nerves, carrying both afferent and efferent signals.

- The small dorsal rami transmit motor impulses to the posterior trunk muscles and relay sensory impulses from the skin of the back.
- The ventral rami in the thoracic region of the spine (T1–T12) become the intercostal nerves (running between the ribs). They communicate with the muscles and skin of the anterior and lateral trunk.
- The ventral rami in the cervical and lumbar regions branch out to form complex interconnections of nerves called plexuses. Most of the major efferent nerves in the neck, arms, and legs originate in the plexuses. The four plexuses in the body are summarized in Figure 6.20 on the next page. To see how the major nerves branch out from the lower three plexuses, refer to Figure 6.21.

**Figure 6.21** shows that other large nerves branch out from the plexuses listed in Figure 6.20.

**Autonomic Nervous System**

As described in the first lesson of this chapter, the peripheral nervous system has two divisions—the somatic nervous system and the autonomic, or involuntary, nervous system. The somatic nervous system sends impulses to activate the skeletal muscles, whereas the autonomic nervous system is programmed by the CNS to activate the heart, smooth muscles, and glands.

Within the autonomic system, two nerves connect the CNS to the organs supplied. The cell body of the first nerve originates in the gray matter of the brain or spinal cord.

The autonomic cell bodies that originate in the spinal cord reside in the lateral horn. The axons of these nerves terminate with a synapse to a second neuron in an enlarged junction called a ganglion (GAYNG-glee-abn). The second neuron then courses from the ganglion to the cardiac muscle, smooth muscle, or gland.

As you might suspect, the first neuron in the sequence just described is called the preganglionic (PREE-gayng-glee-AHN-ik) neuron. The second is called the postganglionic (POHST-gayng-glee-AHN-ik) neuron. Now let’s look more closely at the two divisions of the autonomic nervous system. These are the sympathetic and parasympathetic divisions.

**Sympathetic Nerves**

The sympathetic nerves activate the fight-or-flight response by stimulating the adrenal gland to release epinephrine, also known as adrenaline. Supposedly in primitive times, when a person was confronted by a predator, the fight-or-flight response—characterized by increased heart and breathing rates and sweating—prepared the individual either to fight or run. In modern times the sympathetic response is physiologically the same, but it can be triggered by any type of situation that is perceived to be stressful. You will learn more about the fight-or-flight response in Chapter 8, *The Endocrine System*.

The preganglionic neurons in the sympathetic system arise from the spinal segments extending from T1–L2. For this reason, the sympathetic system is also called the thoracolumbar (THOH-rah-koh-LUM-bar) division. These neurons secrete acetylcholine to stimulate the postganglionic neurons in the paravertebral ganglia (pair-a-VER-teh-bral GAYNG-glee-a). The paravertebral ganglia are named after their location; they lie parallel to the spinal cord. The postganglionic neurons release the neurotransmitter norepinephrine (NOR-ehp-i-NEHF-rin).
### Parasympathetic Nerves

In contrast to the sympathetic nervous system, the parasympathetic nervous system controls all of the automatic, day-in-and-day-out functions of the circulatory, respiratory, and digestive systems. For these reasons it is sometimes called the “resting and digesting system.” In addition, after a fight-or-flight situation, the parasympathetic nervous system produces a calming effect that returns the body to a normal state.

Preganglionic parasympathetic neurons originate in one of two separate regions—the brain stem or the sacral (lowermost) region of the spinal cord. For this reason, the parasympathetic system is also known as the craniosacral (KRAY-nee-oh-SAY-kral) division. Activation of both preganglionic and postganglionic nerves in this system triggers the release of the neurotransmitter acetylcholine. Although acetylcholine stimulates skeletal muscle, it also inhibits activity in cardiac and smooth muscle.

### Check Your Understanding

1. How many pairs of cranial nerves does the body have?
2. What kind of impulses do mixed nerves carry?
3. How many pairs of spinal nerves does the body have?
4. List the two divisions of the autonomic nervous system.
5. Which nerves—the sympathetic or the parasympathetic—activate the fight-or-flight response?
Lesson 6.4 Review and Assessment

Know and Understand
1. Explain the function of the peripheral nervous system.
2. What is the major purpose of the endoneurium, perineurium, and epineurium combined?
3. How would you describe cranial nerves in terms of sensory and motor fibers?
4. From where do the majority of cranial nerves emanate?
5. Are spinal nerves efferent, afferent, or mixed?
6. Which nervous system sends impulses to the heart—the somatic or the autonomic system?
7. Why is the parasympathetic nervous system also known as the craniosacral division?
8. Explain the difference between a preganglionic neuron and a postganglionic neuron.

Analyze and Apply
9. Explain how the structure of a nerve decreases the chances of nerve damage.
10. Describe the fight-or-flight response activated by sympathetic nerves and explain how it could be a lifesaver.
11. Neurons meet at junctions called ganglia. Explain the purpose of a ganglion and how these structures help transmit nerve impulses throughout the body.
12. Explain how the function of a cranial nerve might determine whether it is a sensory or motor fiber, or both.

In the Lab
13. Using clay, create a model of a nerve. Use different colors for the different parts of the nerve. Begin with a simpler structure, such as an axon, and continue until you have a more complex structure (complete nerve). Use the illustrations in this lesson to guide you in constructing your model.

Lesson Objectives
1. Describe the symptoms and recovery strategies for someone who has suffered a traumatic brain injury.
2. Explain the causes and range of symptoms for cerebral palsy.
3. Explain the consequences of injuries at different levels of the spinal cord.
4. Describe some of the common diseases and disorders of the nervous system.

Key Terms
- Alzheimer’s disease
- cerebral palsy
- dementia
- epilepsy
- meningitis
- multiple sclerosis
- paraplegia
- Parkinson’s disease
- quadriplegia
- traumatic brain injury

Injuries and Disorders of the Nervous System

Injuries to the Brain and Spinal Cord
The brain and spinal cord are well protected. They are encased, respectively, in the skull and vertebral column, and both are surrounded by the meninges and cerebrospinal fluid. Unfortunately, violent injuries can still cause mild to severe damage to these CNS structures.

Traumatic Brain Injury
Traumatic brain injury (TBI) can occur during violent impacts to the head, particularly when the skull is pierced or fractured and bone fragments penetrate the brain. These injuries are classified as mild, moderate, or severe, with increasing levels of damage to the nervous system, particularly the cells and tissues of the brain.

With mild TBI, a person may remain conscious or may lose consciousness for a short time. Symptoms can include any of the following: headache, confusion, dizziness, disturbed vision, ringing in the ears, bad taste in the mouth, fatigue, abnormal sleep patterns, behavioral changes, and trouble with intellectual functions.

Symptoms of moderate to severe TBI include all of those listed above, and can also involve more serious symptoms such as prolonged headache, repeated nausea or vomiting, convulsions or seizures, inability to awaken from sleep, dilatation of one or both pupils of the eyes, slurred speech, weakness or numbness in the extremities, loss
of coordination, confusion, and agitation. Cases of moderate and severe TBI require immediate medical care, with the goal of preventing further brain injury. X-rays and imaging tests may be performed to help with assessment of the nature and extent of the damage. Maintaining proper blood pressure and flow of oxygenated blood to the brain and throughout the body are priorities. Furthermore, about 50% of severe TBI cases require surgical repair.

**Case Study: Phineas Gage.** A miraculous story of survival from a significant TBI is the case of Phineas Gage, a railroad construction foreman who was injured in 1848 at 25 years of age. Gage and his crew were blasting rock to make way for railroad construction outside the town of Cavendish, Vermont, when a ¾ foot iron rod was accidentally blasted through Gage’s skull. The iron entered below the left cheekbone and exited through the top of the skull. The blast was of such force that the iron landed approximately 80 feet away.

Amazingly, within a few minutes Gage was able to speak, walk, and ride upright in a cart back to his home, where he received medical attention. Gage’s recovery was slow, with advances and declines, including time spent in a coma due to brain swelling. Nevertheless, his physical recovery was complete.

Accounts of Gage’s mental recovery vary, but they suggest that his personality was negatively altered. Gage survived for 12 years after the accident. He began to suffer a series of increasingly severe seizures that eventually resulted in his death. The case of Phineas Gage is still discussed in medical and neurology classes.

**Treating and Preventing TBI.** Today, follow-up care for TBI involves individualized rehabilitation programs that may include physical, occupational, and speech language therapies; psychiatry; and social support. The prognosis for those who have suffered from a traumatic brain injury varies greatly, with potential for lingering problems with intellectual functioning, sensation, and behavior. Serious head injuries can result in an unresponsive state or a coma.

Research is being conducted in scientific and clinical settings to achieve a clearer understanding of the biological effects of TBI. One goal of this research is to develop strategies and interventions that limit the brain damage that occurs during the first few days after a head injury. Another goal is to develop more effective therapies for facilitating recovery of function.

**Cerebral Palsy**

Cerebral palsy (CP) is a group of nervous system disorders caused by damage to the brain before or during birth (congenital defect), or in early infancy. Congenital defects that can cause CP include a brain that has an abnormal shape or structure, or damaged nerve cells and brain tissues. Infections such as rubella in the mother during pregnancy can produce CP. During the first two years, while the brain is still developing, several conditions—including brain infections, head injury, and impaired liver function—can cause CP. Sometimes, however, the cause is unknown.

The most common symptoms involve varying degrees of motor function impairment, but can also include hearing, seeing, and cognitive impairment. The degree of impairment may be barely noticeable or very severe (Figure 6.22). One or both sides of the body may be affected and the arms, legs, or both may be involved.

![Figure 6.22 Russian and British athletes with cerebral palsy play a game of soccer in preparation for the Paralympics.](image)

Concussions in Sports

Injuries that produce concussions are of particular concern for participants in American football, boxing, and soccer, although they also occur in other sports. According to the Centers for Disease Control, as many as 3.8 million sports- and recreation-related concussions occur in the United States each year. Concussions also result from car and bicycle accidents, work injuries, and falls.

Because all concussions injure the brain to some extent, it is crucial that these injuries have time to heal. Healing time is particularly important for athletes in contact sports, which involve higher risks of reinjury to the brain. For this reason, researchers are focusing attention on the consequences of repeated concussions.

**Recent Research**

A recent study shows that retired professional football players emphasized that the data in this type of study do not establish a cause-effect relationship. They hypothesized, however, that the players in “speed” positions likely had experienced more high-speed collisions, and possibly repeated concussions, compared to the “non-speed” players.

**NFL Takes Action**

The NFL has implemented several new rules and regulations in an effort to prevent concussions. The most common cause of concussion is a blow to the head. However, concussions can also occur when the head and upper body are violently shaken. In fact, the word concussion comes from the Latin concutere, which means “to shake violently.”

Concussions appear to be at a higher risk of death from diseases of the brain, compared to the general US population. In the study, sponsored by the National Institute for Occupational Safety and Health (NIOSH), researchers examined the medical records of 3,439 former National Football League (NFL) players with an average age of 57. At the time of the analysis, only 10 percent of the participants had died, which is about half the death rate of men that age in the general population. The fact that relatively few had died indicates that the study participants were in better-than-average general health.

The medical records showed, however, that an NFL player’s risk of death from Alzheimer’s disease or amyotrophic lateral sclerosis (ALS), also known as Lou Gehrig’s disease, was almost four times higher than in the general population. Furthermore, those players in “speed” positions—such as wide receiver, running back, and quarterback—accounted for most of the deaths from Alzheimer’s disease and ALS. The researchers
Several different types of cerebral palsy exist, with some individuals having mixed symptoms. The most common form is spastic CP, with symptoms that include:

- Very tight muscles and joints;
- Muscle weakness; and
- Gait (manner of walking) in which the arms are held close to the body with the elbows in flexion, the knees touch or cross, and the individual walks on tiptoes.

With other types of cerebral palsy, motor function degradation may include twisting or jerking movements; tremors; unsteady gait; impaired coordination; and excessive, floppy movements.

Sensory and cognitive symptoms may include learning disabilities or diminished intelligence; problems with speech; problems with hearing or sight; seizures; pain; and problems with swallowing and digestion.

Other symptoms may include slowed growth; drooling; breathing irregularities; and incontinence. No cure for cerebral palsy exists, so the goal of treatment in moderate to severe cases is to promote quality of life and, when possible, independent living. In some cases, surgical intervention can improve gait, alleviate spasticity or pain, or restore joint range of motion.

### Spinal Cord Injury

Fractures or displacements of the vertebrae can result in injury to the spinal cord. Such injuries most commonly occur during automobile accidents or participation in high-speed or contact sports. Although injuries to the spinal cord can occur at any level, these injuries most commonly develop in the cervical region because of the flexibility of the neck compared to that of the trunk.

A complete severing of the spinal cord produces permanent paralysis, with a total lack of sensory and motor function below the point of injury. The level of the spine at which the injury occurs is a major factor in determining the extent of injury.

- C₁–C₄—Complete paralysis of the lower extremities, partial loss of function in the trunk and upper extremities
- T₁–L₅—Paraplegia (PAIR-ah-PLEE-je-ah), characterized by loss of function in the trunk and legs

Fortunately, most spinal cord injuries do not completely sever the spinal cord. In an incomplete injury, the ability of the spinal cord to transmit sensory and motor impulses is not completely lost. This allows some degree of sensory and/or motor function to remain below the point of injury. The prognosis in such cases is typically uncertain; some patients achieve nearly complete recovery, whereas others suffer complete paralysis.

Spinal cord injuries are medical emergencies. Immediate, aggressive treatment and follow-up rehabilitation can help minimize damage and preserve function. Because motion of a fractured or displaced vertebra can cause more damage to the spinal cord after the injury, it is critical that the head, neck, and trunk be immobilized before the victim is moved (Figure 6.24). In severe neck injuries of the spinal cord, breathing is affected in about one-third of the cases, and respiratory support is necessary. Surgery is often warranted to remove bone fragments or realign vertebrae to alleviate pressure on the spinal cord.

Ongoing research is aimed at developing techniques for repairing injured spinal cords.

Researchers are also working to advance our understanding of which rehabilitation approaches will be optimally successful at restoring lost function. Promising new rehabilitation techniques are helping patients with spinal cord injury become more mobile.

### Check Your Understanding

1. Evaluate the causes of traumatic brain injury (TBI).
2. List the conditions that can cause cerebral palsy (CP).
3. What is the usual result of a spinal cord injury that occurs at each of the following levels? C₁–C₂; C₂–C₃; C₃–C₄; and T₁–L₅.

### Common Diseases and Disorders of the CNS

In this section we will explore some of the common diseases and disorders that affect the central nervous system (CNS).

#### Meningitis

Meningitis (MEHN-in-JIGH-tis) is an inflammation of the meninges surrounding the brain and spinal cord. Swelling of these tissues, which is caused by an infection, often produces the signature symptoms of headache, fever, and a stiff neck.

Most infections that cause meningitis are viral, but bacterial and fungal infections can also lead to meningitis. Viral meningitis, the milder form, can resolve on its own. Bacterial meningitis is much more serious and potentially life threatening. Fortunately, bacterial meningitis can be treated with antibiotics. In either case, a person should seek immediate medical attention if meningitis is suspected.

#### Multiple Sclerosis

Multiple sclerosis (MS) is an autoimmune disease in which the body’s own immune system causes inflammation that destroys the myelin sheath of nerve cell axons. This damage to the myelin sheath, which can occur in any part of the brain or spinal cord, impairs the ability of the affected nerves to transmit impulses. MS can occur at any age, but it is most commonly diagnosed between 20 and 40 years of age and occurs with greater frequency in women. The cause of MS is unknown.

An active attack of MS can last for days, weeks, or months. Periods during which the symptoms vanish or diminish are called remissions. Exposure to heat and stress can trigger or worsen attacks.

The symptoms of MS vary widely, depending on location within the CNS and severity of each episode.

- Impairments in motor function may include difficulties with balance, coordination, movement of the arms and legs, tremors, weakness, muscle spasms, and difficulty with speaking or swallowing.
- Sensory impairments may involve numbness, tingling, pain, double vision, uncontrollable eye movements, and loss of vision or hearing.
- Autonomic functions related to urination, defecation, and sexual function can also be affected.
- Associated cognitive issues may include decreased attention span, difficulty with reasoning, loss of memory, and depression.

There is no known cure for multiple sclerosis, so treatments are designed to help control symptoms and maintain quality of life. Exercise is often beneficial during the early stages. General recommendations for the MS patient include sufficient rest, sound nutrition, avoidance of hot temperatures, and minimization of stress. Although MS is a chronic condition, life expectancy can be normal. Many individuals with MS are able to continue functioning well in their jobs until retirement.

#### Epilepsy

Epilepsy (EH-pi-LEHP-see) is a group of brain disorders characterized by repeated seizures over time. A seizure is triggered by abnormal electrical activity in the brain that
causes widely varying symptoms. Symptoms can range from changes in attention span or behavior to uncontrolled convulsions, depending on the type of epilepsy and area of the brain affected.

Epilepsy may be caused by a disease or injury that affects the brain, although in many cases the cause is unknown and genetics may play a role. Onset of epilepsy can happen at any age but occurs most frequently in infants and the elderly.

Epileptic seizures in a given individual are of a relatively consistent nature. Before a seizure, some people have an unusual sensation such as tingling, a strange smell, or an emotional change. This signal is referred to as an aura.

Epilepsy can be controlled with medication in most, but not all, people. Some types of epilepsy completely disappear after childhood. However, more than 30% of people with epilepsy are not able to control seizure incidence with medications. If epileptic seizures are caused by an observable problem, such as a tumor, abnormal blood vessels, or bleeding in the brain, surgery to address these issues may eliminate further seizures.

**Parkinson’s Disease**

Parkinson’s disease (PD) is one of the most common nervous system disorders among the elderly. It is characterized by tremors, difficulty with initiating movements—especially walking—and deficits in coordination. PD most often develops after the age of 50, although a genetic form of the disease may occur in younger adults. Men and women are equally affected.

PD is characterized by slow but progressive destruction of the brain cells responsible for production of the neurotransmitter dopamine, which plays a role in motor function. Without dopamine, the cells in the affected part of the brain cannot initiate nerve impulses, leading to progressive loss of muscle function. The cause of this condition is unknown.

The symptoms of PD tend to begin with a mild tremor of slight stiffness or weakness in one or both of the legs or feet. As brain cell destruction progresses, symptoms of motor dysfunction affecting one or both sides of the body may include:

- difficulty initiating and continuing movements;
- problems with balance and gait;
- stiff, painful muscles and tremors;
- slowed movement, including blinking;
- loss of fine motor control with hand movements;
- slowed speech, drooling, and difficulty swallowing;
- loss of facial expression; and
- stooped posture.

Autonomic and cognitive functions can also be impaired, as characterized by:

- sweating and fluctuations in body temperature;
- fainting and inability to control blood pressure;
- constipation;
- confusion or dementia; and
- anxiety or depression.

Currently, no cure for PD exists; the goal of treatment is control of symptoms. If untreated, the disorder will progress, resulting in deterioration of all brain functions and early death. The medications prescribed for Parkinson’s patients are designed to increase the levels of dopamine in the brain.

**Dementia and Alzheimer’s Disease**

Dementia (deh-MEHN-shee-a) is a condition involving loss of function in two or more areas of cognition including memory, thinking, judgment, behavior, perception, and language. Dementia usually occurs after the age of 60, and risk increases with advancing age. Although forgetfulness is often the first sign of dementia, occasional forgetfulness alone does not qualify as dementia.

Dementia can be caused by disruption in the blood supply to the brain, as in stroke or related disorders. However, the single most common cause of dementia is Alzheimer’s disease.

Alzheimer’s disease (AD), or senile dementia, is a progressive loss of brain function with major consequences for memory, thinking, and behavior. In one form of the disease, called early onset AD, symptoms appear before 60 years of age. This type of AD tends to worsen quickly and is believed to involve genetic predisposition. The more common form, known as late onset AD, occurs after 60 years of age. The risk for developing Alzheimer’s disease increases with advancing age. The cause of AD is currently unknown.

Early symptoms of AD may include difficulty with tasks that previously were routine; difficulty learning new ideas, concepts, or tasks; becoming lost in familiar territory; difficulty recalling the names of familiar objects; misplacing objects; a flat mood and loss of interest in activities; and personality changes and loss of social skills.

Worsening symptoms can include difficulty performing activities of daily living; progressive loss of short- and long-term memories; depression and agitation; delusions and aggressive behavior; inability to speak coherently; loss of judgment; and change in sleep patterns.

Advanced symptoms include the inability to understand language and recognize family members. Although no cure currently exists for Alzheimer’s disease, medications can help to slow the worsening of symptoms.

**Check Your Understanding**

1. Describe meningitis.
2. What happens to the body of a person with multiple sclerosis (MS)?
3. Describe Parkinson’s disease.

**Lesson 6.5 Review and Assessment**

**Mini Glossary**

**Alzheimer’s disease** — condition involving a progressive loss of brain function with major consequences for memory, thinking, and behavior

**cerebral palsy** — a group of nervous system disorders resulting from brain damage before or during birth, or in early infancy

**dementia** — an organic brain disease involving loss of function in two or more areas of cognition

**epilepsy** — a group of brain disorders characterized by repeated seizures over time

**meningitis** — an infection-induced inflammation of the meninges surrounding the brain and spinal cord

**multiple sclerosis** — a chronic, slowly progressive disease of the central nervous system that destroys the myelin sheath of nerve cell axons

**paraplegia** — disorder characterized by loss of function in the lower trunk and legs

**Parkinson’s disease** — a chronic nervous system disease characterized by a slowly spreading tremor, muscular weakness, and rigidity

**quadriplegia** — disorder characterized by loss of function below the neck

**traumatic brain injury** — mild or severe trauma that can result from a violent impact to the head

**Know and Understand**

1. Describe the body functions that may be affected in a person with cerebral palsy (CP)?
2. What is meant by the term “incomplete injury” as it relates to a spinal cord injury?
3. What are the two types of meningitis and which is easier to treat?

**Analyze and Apply**

4. What autoimmune disease did you learn about in chapter 4? How are that disease and MS similar?

5. Explain what happens in the brain when a person has a seizure.

6. Do some research on images of brains. Find one brain image for each of the following: epilepsy, Alzheimer’s disease, and dementia. Explain how the images are alike and how they are different. Point out specific areas in the brain in your explanations.
### Career Corner

**Anatomy and Physiology at Work**

The nervous system is a complex organ system that plays an important role in your body’s responses to numerous stimuli, both internal and external. That’s quite a wide-ranging, significant role! Several careers are dedicated to the study of the nervous system, as well as to the diagnosis and treatment of neural disorders. We will explore two of these careers.

**Neurologist**

A neurologist (noo-RAHL-oh-jist) is a physician trained in the specialty field of neurology. Neurology involves the diagnosis and treatment of neurological injuries and diseases. A patient is typically referred to a neurologist by another physician who suspects that specialized treatment is needed.

Evaluation of a patient by a neurologist typically begins with a related medical history, followed by a physical examination that focuses on the nervous system. Components of the neurological examination may include assessment of the patient’s cognitive function, muscular strength, sensation, reflexes, coordination, and gait. The neurologist may order diagnostic imaging studies when warranted (Figure 6.25).

Conditions commonly treated by neurologists include all of those discussed in this lesson. Treatment options vary by condition, and may include prescription of medications, referral for physical or occupational therapy, or referral to a surgeon.

Training to become a neurologist begins with four years of medical school, followed by a residency program or fellowship in pediatric or general neurology. The residency, which is usually four years, involves specific training. After residency, doctors may choose to pursue board certification through the American Board of Psychiatry and Neurology. Some neurologists voluntarily participate in additional training in a fellowship program to gain experience in a subspecialty area.

![Figure 6.25 A neurologist examines the MRI scans of a patient.](James Smith/Shutterstock.com)

**Neuroscientist**

A scientist who specializes in research of the nervous system is called a neuroscientist. Neuroscientists usually work in a controlled laboratory environment. They conduct experiments to further our understanding of how the nervous system works. They also study the causes, treatment, and prevention of neurological diseases and disorders.

Some neuroscientists study topics such as the characteristics of the normal, aging nervous system and the characteristics of exceptionally well-functioning nervous systems, such as those of elite athletes. The graph in Figure 6.26 provides an example of the kind of information these scientists gather and study. The graph shows the delay between the electrical stimulation of a muscle and the initiation of tension development in that muscle. This delay increases with aging, but is very short in both speed- and power-trained athletes. Neuroscientists and neurologists often collaborate on research projects—each bringing a different, specialized perspective to the work.

Becoming a neuroscientist requires a four-year bachelor’s degree in an area of science, followed by a PhD in neuroscience. It typically takes four to six years to complete the PhD program. This education is often followed by an optional postdoctoral fellowship that lasts two to four years. A neuroscientist is typically employed as a university professor or research scientist. Neuroscientists working as researchers are often employed by a hospital or private company.

### Planning for a Health-Related Career

Do some research on the career of a neurologist or neuroscientist. Note that both neurologists and neuroscientists may have dual careers. A neurologist, for example, may practice medicine and teach at a college or university. Likewise, a neuroscientist may teach in addition to performing research.

Alternatively, select a profession from the list of Related Career Options. Using the Internet or resources at your local library, find answers to the following questions:

1. What are the main tasks and responsibilities of a neurologist or neuroscientist?
2. What is the outlook for this career? Are workers in demand, or are jobs dwindling? For complete information, consult the current edition of the Occupational Outlook Handbook, published by the US Department of Labor. This handbook is available online or at your local library.
3. What special skills or talents are required? For example, do you enjoy research? Do you need to be good at problem solving—a skill that would be useful when developing a complicated diagnosis?

#### Related Career Options

- Neuroanatomist
- Neurochemist
- Neuroscience Nurse
- Neurosurgeon
- Pathologist
- Psychiatrist

![Graph courtesy of Dr. Chris Knight, University of Delaware.](Image 195x61 to 288x178)

**Figure 6.26** This graph shows electrical activity (EMG) in a quadriceps muscle during tension development and the corresponding force output from the leg. Notice that the onset of electrical activity clearly precedes the onset of force production, demonstrating electromechanical delay (EMD). EMD has been found to be longer in elderly individuals and shorter in athletes, particularly those who specialize in speed and power events.
Lesson 6.1 Overview of the Nervous System

Key Points
- The structures within the nervous system are divided into two major divisions: the central nervous system and the peripheral nervous system.
- The CNS includes the brain and spinal cord.
- The PNS includes spinal nerves and cranial nerves.
- The two subdivisions of the efferent nerves are the somatic and autonomic nervous systems.
- The two types of tissue within the nervous system are neuroglia and neurons.

Key Terms
- afferent nerves
- autonomic nervous system
- cell body
- central nervous system (CNS)
- dendrites
- efferent nerves
- myelin sheath
- neurilemma
- neuroglia
- nodes of Ranvier
- peripheral nervous system
- PNS
- somatic nervous system
- synapse

Lesson 6.2 Transmission of Nerve Impulses

Key Points
- Neurons have two main properties: irritability and conductivity.
- Stimuli bring about depolarization, which creates a nerve impulse, or action potential.
- Two major factors influence the speed at which a nerve impulse travels: the presence or absence of a myelin sheath and the diameter of the axon.
- Communication between nerve cells occurs at gap junctions; communication between neurons occurs at synapses.

Key Terms
- autonomic reflexes
- conductivity
- depolarized nerve impulse
- polarized
- reflexes
- refractory period
- repolarization
- saltatory conduction
- somatic reflexes

Lesson 6.3 Functional Anatomy of the Central Nervous System

Key Points
- The brain consists of four major anatomical regions: the cerebrum, diencephalon, brain stem, and cerebellum.
- The cerebrum consists of four main lobes: the frontal, parietal, occipital, and temporal lobes. Each controls different bodily functions.
- The meninges surround and protect the brain and spinal cord.
- The spinal cord serves as a major pathway for relaying sensory and motor impulses.

Key Terms
- cerebellum
- cerebrum
- diencephalon
- epiphysis
- thalassemia
- cerebrospinal fluid
- midbrain
- occipital lobes
- parietal lobes
- pons
- primary motor cortex
- primary somatosensory cortex
- spinal cord
- temporal lobes
- thalamus

Lesson 6.4 Functional Anatomy of the Peripheral Nervous System

Key Terms
- cranial nerves
- craniosacral division
- dorsal ramus
- endoneurium
- epineurium
- ganglion
- norepinephrine
- paravertebral ganglia
- perineurium
- plexuses
- postganglionic neuron
- preganglionic neuron
- spinal nerves
- thoraocolumbar division
- ventral ramus

Lesson 6.5 Injuries and Disorders of the Nervous System

Key Points
- The brain and spinal cord are well protected, but injuries do occur, and they can have serious consequences.
- The location of a spinal injury is a major factor in determining the extent of injury.
- Some common disorders and diseases of the CNS include meningitis, multiple sclerosis (MS), epilepsy, Parkinson’s disease (PD), cerebral palsy (CP), dementia, and Alzheimer’s disease.

Key Terms
- Alzheimer’s disease
- cerebral palsy
- dementia
- epilepsy
- meningitis
- multiple sclerosis
- paraplegia
- Parkinson’s disease
- quadriplegia
- traumatic brain injury

Chapter Assessments

Thinking Critically
8. Create a flowchart that shows the main components or structures of the nervous system and each of its subdivisions. List the functions and processes that each component controls.

Learning Key Terms and Concepts
1. The central nervous system (CNS) includes the and the.
2. The peripheral nervous system (PNS) is made up of the nerves and the nerves.
3. Nerves that transmit impulses from sensory receptors to the CNS are known as .
4. Nerves that transmit impulses from the CNS to the muscles and glands are known as .
5. The two subdivisions of the efferent nerves are the nervous system and the nervous system.
6. The four types of glial cells in the CNS are , , and .
7. The main function of an axon’s myelin sheath is to .
9. The two behavioral properties of a neuron are and .
10. Because of the difference in electrical charge between the inside and outside of a resting cell, the cell membrane is said to be .
11. Some factors that can influence the speed of a nerve impulse are:
   A. body temperature
   B. diameter of the axon
   C. presence of a myelin sheath
   D. all of the above
12. Communication between cells occurs through direct transfer of electrical signals. The point at which this transfer occurs is called the __________.

13. A rapid, involuntary, programmed response to a stimulus is known as an _____.

14. __________ reflexes send involuntary stimuli to the cardiac muscle of the heart and the smooth muscle of internal organs.

**Thinking Critically**

15. Recalling what you have learned about nerve impulses, how do you think each of the following substances affects conduction speeds: caffeine, sedatives, and energy drinks?

16. If a person has extremely low blood calcium levels, will that affect the transmission of electrical signals from one cell to another? Explain your answer.

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**Lesson 6.4**

**Functional Anatomy of the Peripheral Nervous System**

**Learning Key Terms and Concepts**

26. In a nerve, each axon fiber is covered by a fine sheath called the ________.

27. Groups of these sheathed fibers are bundled into fascicules surrounded by the ________.

28. Groups of fascicles and blood vessels are surrounded by the ________.

29. Mixed nerves carry both _____ impulses and _____ impulses.

30. The body has how many pairs of cranial nerves?

31. The body has how many pairs of spinal nerves?

32. Spinal nerves are divided into a(n) _____ ramus and a(n) ______ ramus.

33. The parasympathetic nervous system controls all of the automatic functions of the ______, ______, and ______ systems.

**Thinking Critically**

34. Explain what happens physiologically when the fight-or-flight response is activated in the body.

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**Lesson 6.5**

**Injuries and Disorders of the Nervous System**

**Learning Key Terms and Concepts**

35. Name at least five symptoms of mild traumatic brain injury.

36. True or False? Cerebral palsy can be caused by several disorders or conditions.

37. Meningitis is inflammation of the _____ that _______.

38. True or False? Multiple sclerosis (MS) is considered an autoimmune disease.

39. Alzheimer’s disease is a progressive loss of brain function with consequences for ______, ______, and ______.

**Thinking Critically**

40. Evaluate the cause and effect of cerebral palsy on the structure and function of cells, tissues, organs, and systems.

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**Building Skills and Connecting Concepts**

**Analyzing and Evaluating Data**

The bar graph to the right shows approximate transmission speeds for several different types of nerve impulses. Use the graph to answer the following questions.

43. About how much faster do you think than feel pain?

44. Do nerve impulses signaling the sense of touch travel at approximately two, three, or four times the speed of thought impulses?

45. Assume that rising temperatures increase all the nerve impulse speeds by 5%. If the limb movement speed shown is 119 m/s (meters per second), what will it be at the higher temperature?

46. Give approximate fps (feet-per-second) speeds for each type of nerve transmission shown in the graph. (Use the conversion chart in the appendices if necessary).

**Communicating about Anatomy and Physiology**

47. Speaking Working in a group, brainstorm ideas for creating classroom tools (posters, flash cards, and/or games, for example) that will help your classmates learn and remember the different divisions and subdivisions of the nervous system. Choose the best idea(s), then delegate responsibilities to group members for constructing the tools and presenting the final products to the class.

48. Reading With a partner, make flash cards of the chapter terms for which phonetic spellings have been provided. On the back of the card, write the term. On the back, write the phonetic spelling as written in the text. (You may also choose to use a dictionary.) Practice reading about the terms, clarifying pronunciations where needed.

49. Speaking Pick 5–10 of the key terms that you practiced pronouncing. Write a brief scene in which those 5–10 terms are used as you imagine them being used by medical professionals in a real-life context. Then rewrite the dialogue using simpler sentences and transitions, as though an adult were describing the same scene to elementary or middle-school students. Read both scenes to the class and ask for feedback on whether the two scenes were appropriate for their different audiences.

**Lab Investigations**

50. Materials: large Styrofoam™ ball, scalpel or knife, markers, poster board, shower cap.

A. Using the scalpel or knife, gently cut grooves in the Styrofoam™ ball and shape it to look like a brain.

B. Using different colored markers, color each area of the brain: the four lobes (frontal, temporal, parietal, and occipital), the brain stem, cerebellum, and diencephalon.

C. On a small piece of poster board, using the same colors to correspond to the different colored areas of the model brain, list the bodily functions that each lobe or area controls (some will overlap).

D. Use the shower cap to illustrate meninges and how they protect and encase the delicate brain.