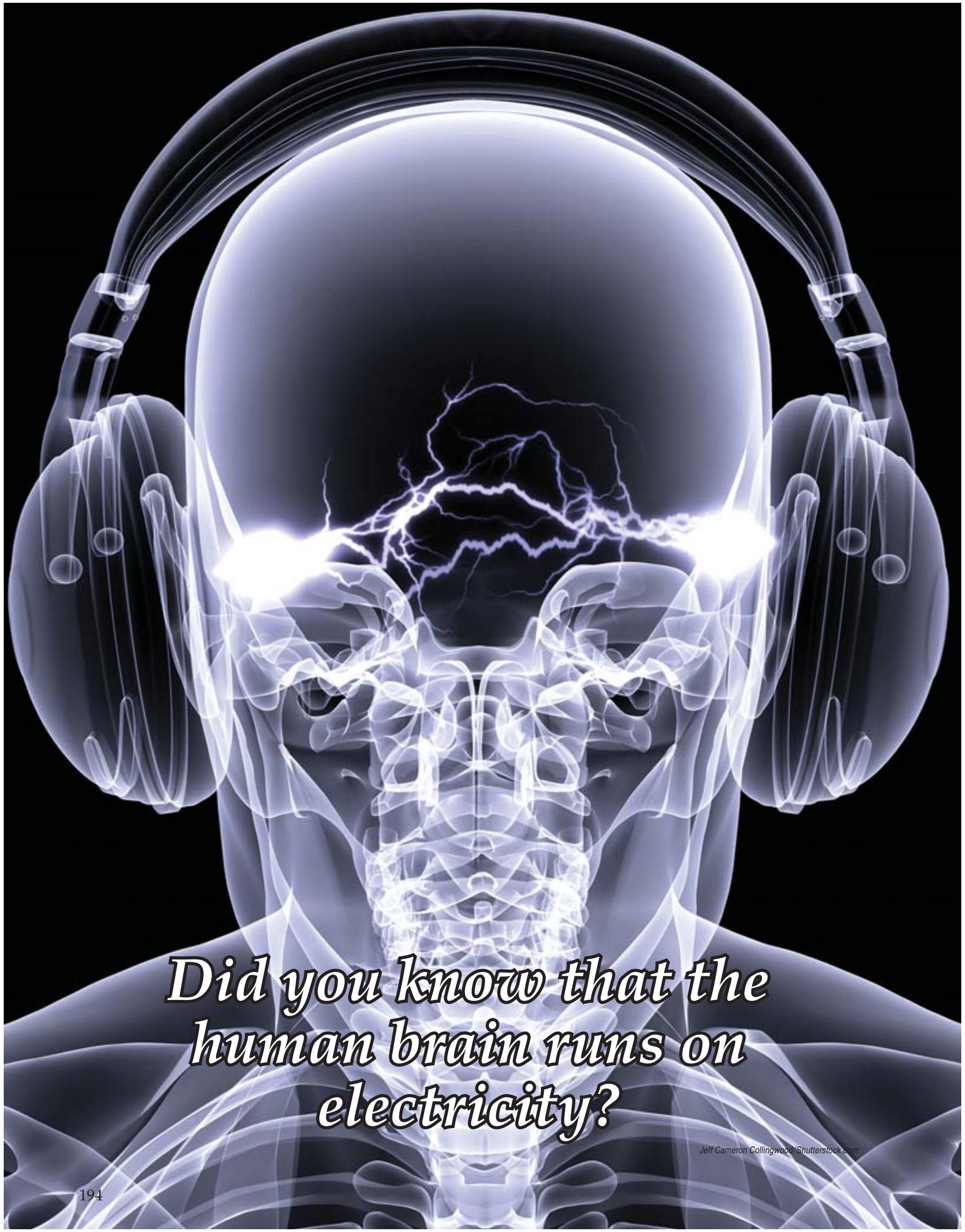

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Chapter 6

The Nervous System

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.

Chapter 6 Lessons

Lesson 6.1
Overview of the Nervous System

Lesson 6.2
Transmission of Nerve Impulses

Lesson 6.3
Functional Anatomy of the Central Nervous System

Lesson 6.4
Functional Anatomy of the Peripheral Nervous System

Lesson 6.5
Injuries and Disorders of the Nervous System

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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

E-Flash Cards

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.

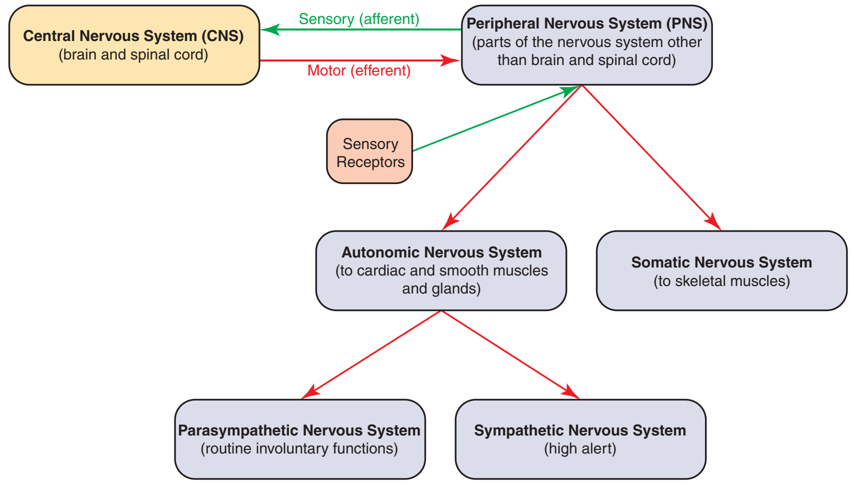

Figure 6.1 This diagram represents the organization of the nervous system and summarizes the relationships among the subdivisions. *If you were asked to put the word voluntary into one of the six boxes above and involuntary into another one of the boxes, where would you put each word?*

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

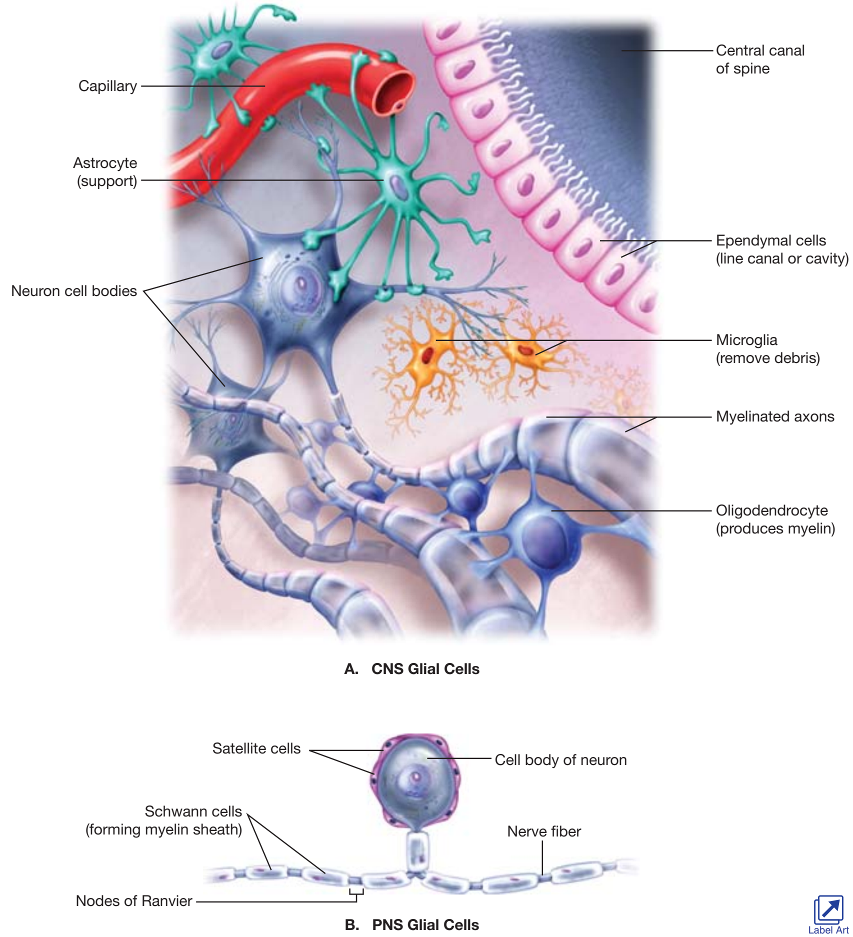

Figure 6.2 The glial cells of the central nervous system and peripheral nervous system. *Write one sentence summarizing in general terms the functions of the six types of glial cells.*

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** (SIN-aps). 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-rahnz), or *association neurons*.

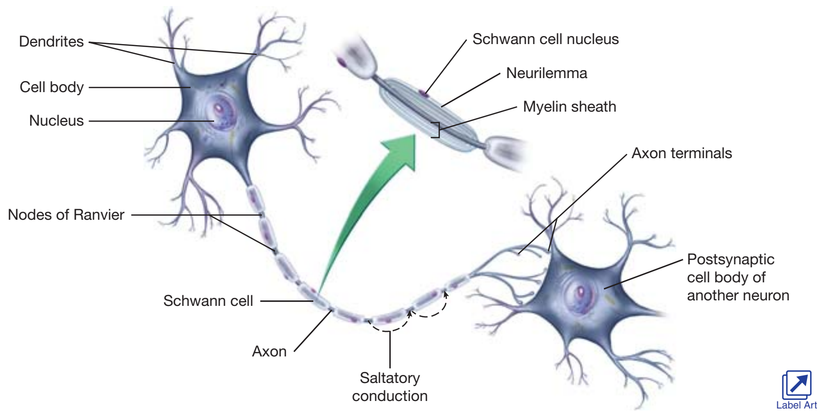

Figure 6.3 A typical neuron. *Why do neural impulses travel faster through myelinated axons than through nonmyelinated axons?*

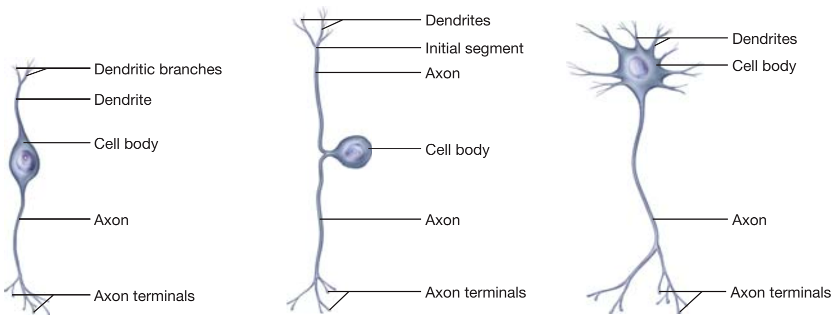

Figure 6.4 Different neuron structures. A—Bipolar neurons have two processes: an axon and a dendrite. B—Unipolar neurons have a single axon process, with the cell body in the middle and to the side. C—Multipolar neurons have a single axon and multiple dendrites.

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.

Check Your Understanding

1. List the four types of glial cells in the CNS and state their functions.
2. List the two types of glial cells in the PNS and state their functions.
3. What is the purpose of a myelin sheath?

Lesson 6.1 Review and Assessment

Mini Glossary

Make sure that you know the meaning of each key term.

Build vocabulary with e-flash cards and games

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

neurilemma the thin, membranous sheath enveloping a nerve fiber

neuroglia non-neural tissue that forms the interstitial or supporting elements of the CNS; also known as *glial cells*

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

Know and Understand

Assess

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.

Lesson 6.2 Transmission of Nerve Impulses

Before You Read

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

How fast do nerve impulses travel?

How can muscles contract without the brain being involved?

Lesson Objectives

1. Define *action potential* and explain how action potentials are generated.
2. Explain the factors that influence the speed of neural impulse transmission.
3. Describe how impulses are transmitted across the synapse.
4. Discuss the roles played by neurotransmitters.
5. Describe the three types of reflexes and explain how they work.

Key Terms

E-Flash Cards

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

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 reception 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.

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?

Transmission at Synapses

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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Figure 6.5 Although it may seem as though we feel pain instantly, nerve impulses communicating pain travel more slowly than other nerve impulses.

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 receptors 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-til-KOH-leen), the chemical that activates muscle fibers. Endorphins are neurotransmitters released to inhibit nerve cells from discharging more pain signals.

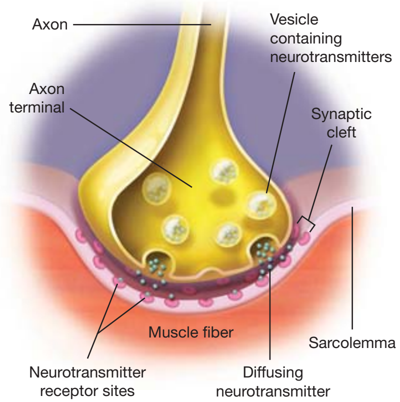


Figure 6.6 The synapse is the site at which the neurotransmitter is released from the nerve axon terminal. The neurotransmitter then diffuses across the synaptic cleft to receptor sites on the next nerve cell body, or to a muscle fiber, as shown here. *What two decidedly different effects can neurotransmitters have on the receiving cells?*

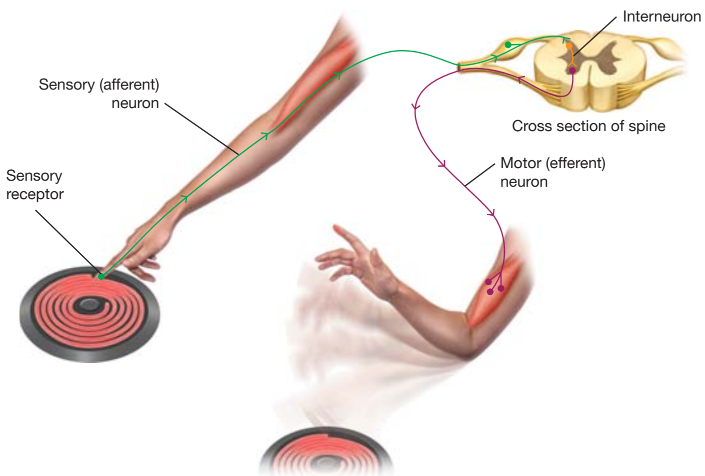


Figure 6.7 A sensory receptor is stimulated by a hot surface, sending an afferent signal to the spinal cord. The signal is then transferred by an interneuron directly to a motor neuron, stimulating quick removal of the hand from the hot surface.

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-til-KOH-leen-EHS-ter-ays).

Reflexes

Reflexes are simple, rapid, involuntary, programmed responses to stimuli. The transmission of impulses follows a reflex arc that includes both PNS and CNS structures (**Figure 6.7**). There are two categories of reflexes.

WHAT RESEARCH TELLS US

...about Measuring Nerve Impulses

How do scientists and clinicians measure the speed and function of nerve impulses? One common method is the use of a nerve conduction velocity (NCV) test.

Conducting and Interpreting NCV Tests

The NCV test begins with the attachment of three small, flat, disc-shaped electrodes to the skin. The electrodes are attached over the nerve being studied and over the muscle supplied by the nerve. The third electrode is attached over a bony site, such as the elbow or ankle, to serve as an electrical ground.

The technician then administers short, tiny electrical pulses to the nerve through the first electrode and records the time it takes for the muscle to contract (as sensed by the second electrode). Computer software calculates the NCV as the distance between the stimulating and sensing electrodes divided by the elapsed time between stimulation and contraction.

Placing stimulating electrodes at two or more different locations along the same nerve makes it possible to determine the NCV across different segments of the nerve. To test for sensory neuron function, the stimulating electrode is placed over a region of sensory receptors such as a fingertip. 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 our current 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. Sympathetic recordings have also been used to study the effects of performance at high altitudes, as well as in space.

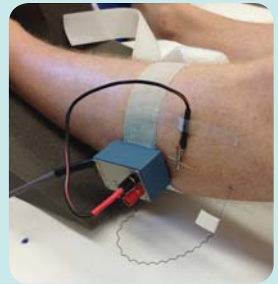


Figure 6.8 Microneurography is a technique involving insertion of fine wire electrodes into a nerve for direct recording of electrical impulse activity.

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.

Somatic reflexes are those that involve stimulation of skeletal muscles. For example, have you ever withdrawn your hand quickly from something hot, even before you realized that it was hot? If so, you were experiencing a somatic reflex. In such a situation the motion of your hand occurs so quickly because a motor nerve has been directly stimulated by a sensory neuron, by way of an interneuron in the spinal cord. The signal between neurons is so fast because it did not have to travel to the brain and back.

Autonomic reflexes are those that send involuntary stimuli to the cardiac muscle of the heart and the smooth muscle of internal organs. Digestion, elimination, sweating, and blood pressure are all activities that are regulated by autonomic reflexes.

Check Your Understanding

1. Why is the transmission of nerve impulses often referred to as an electrochemical event?
2. Give an example of both an excitatory neurotransmitter and an inhibitory neurotransmitter.
3. What are the two types of reflexes discussed in this lesson?

Lesson 6.2 Review and Assessment

Mini Glossary

Make sure that you know the meaning of each key term.

Build vocabulary with e-flash cards and games

autonomic reflexes involuntary stimuli transmitted to cardiac and smooth muscle

conductivity the ability of a neuron to transmit a nerve impulse

depolarized a condition in which the inside of a cell membrane is more positively charged than the outside

nerve impulse electrical charge that travels along a nerve fiber when stimulated

polarized a condition that occurs when the inside of a cell membrane is more negatively charged than the outside

reflexes simple, rapid, involuntary, programmed responses to stimuli

refractory period the time between the completion of the action potential and repolarization

repolarization the reestablishment of a polarized state in a cell after depolarization

saltatory conduction the rapid skipping of an action potential from node to node on myelinated neurons

somatic reflexes involuntary stimuli transmitted to skeletal muscles from neural arcs in the spinal cord

Know and Understand

Assess

1. Name two behavioral properties of a nerve impulse.
2. Describe a neuron at rest compared to a neuron activated by a stimulus.
3. What has to happen before a cell membrane can respond to a second stimulus?
4. Do myelin sheaths slow down or speed up nerve impulses?
5. How does body temperature affect the conduction speed of an electrical impulse?
6. What are the two categories of reflexes? Name a body part that would be affected by each of the two types.

Analyze and Apply

7. How would submerging a person in a tub of cold water affect the conduction speeds of the person's nerve impulses?
8. Is conduction of nerve impulses always faster in axons with a larger diameter, compared to axons with a smaller diameter? Explain.
9. Aside from touching a hot surface, in what other circumstances might a sensory receptor bypass the brain and stimulate an interneuron to instigate quick action?

In the Lab

10. Using a toothpick and a piece of ice, test a fellow student's sensory impulse reaction. Gently poke the student's ventral forearm (the part of the forearm closer to the wrist) with the toothpick and note the length of time it takes for your partner to sense pain. Then place a piece of ice on the same spot on the student's ventral forearm for one minute. Remove the ice and again gently poke the forearm. Note the length of time and amount of pressure required before the student senses pain. Explain your results.

Lesson 6.3 Functional Anatomy of the Central Nervous System

Before You Read

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

Is brain size related to intelligence?

Which functions do the left brain and right brain control?

Which brain structure functions particularly well in athletes?

Lesson Objectives

1. Identify the four lobes of the brain and their functions.
2. Describe the location, structures, and functions of the diencephalon, or interbrain.
3. Describe the location, structures, and functions of the brain stem.
4. Explain the role of the cerebellum.
5. Identify the membranes that comprise the meninges and explain their purposes.
6. Describe how the capillaries in the brain are different from other capillaries and explain why this is important.
7. Identify the location and functions of the spinal cord.

Key Terms

E-Flash Cards

cerebellum	midbrain
cerebrum	occipital lobes
diencephalon	parietal lobes
epithalamus	pons
fissures	primary motor cortex
frontal lobes	primary somatic sensory cortex
hypothalamus	spinal cord
lobes	temporal lobes
medulla oblongata	thalamus
meninges	

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 6.7% of individual variation in intelligence is attributed to brain size. The four major anatomic 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* (JIGH-rus), and each of the grooves between the gyri is called a *sulcus* (SUL-kus). Together, these structures are referred

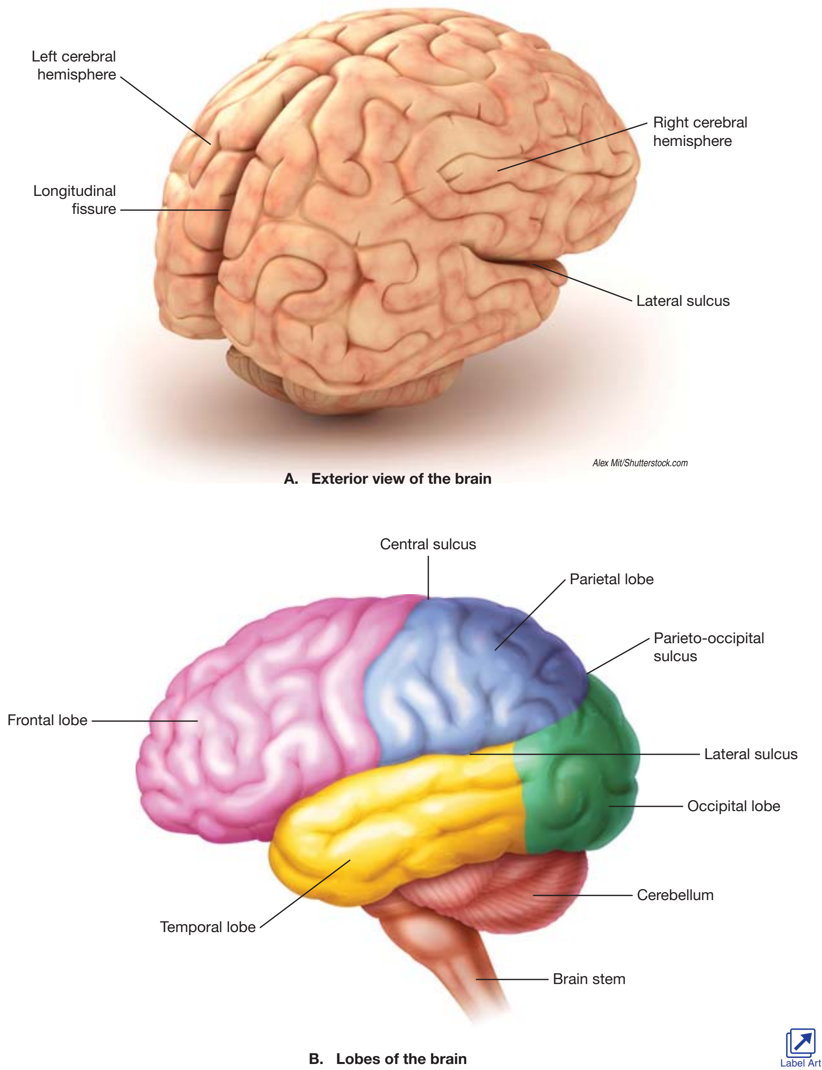


Figure 6.9 A—The hemispheres of the cerebrum. B—The four lobes of the cerebrum (shown in contrasting colors) are separated by indentations called sulci.

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.

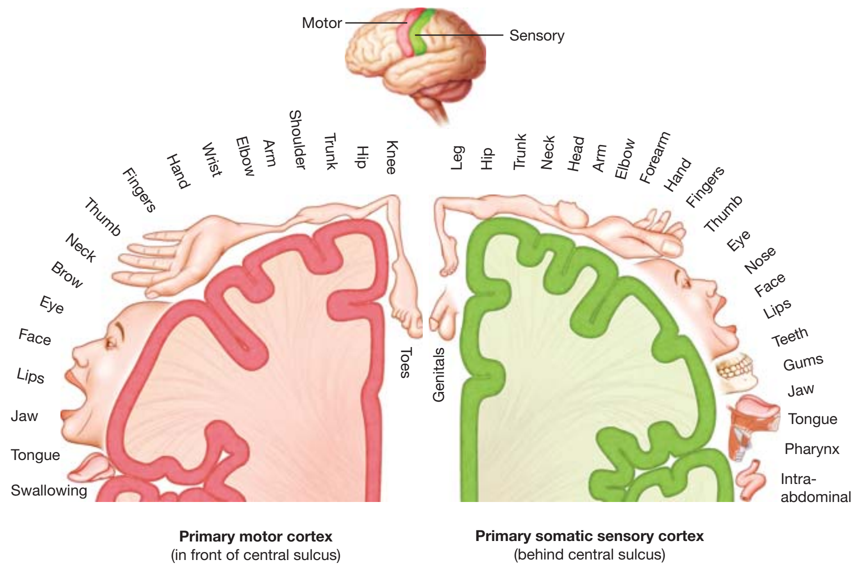


Figure 6.10 The primary motor and somatic sensory cortexes, with mapped regions of motor output and sensory input depicted. *Why do smaller areas of the body, such as the fingers or lips, require more nerves than larger areas, such as the shoulder or trunk?*

WHAT RESEARCH TELLS US

...about Studying the Brain

An increasing variety of approaches is available for studying the functional roles of different parts of the central nervous system. As technology advances, more sophisticated techniques emerge.

fMRI Scans

One procedure extremely useful for both scientific and clinical evaluation of the brain is called *functional magnetic resonance imaging (fMRI)*. 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 which 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.

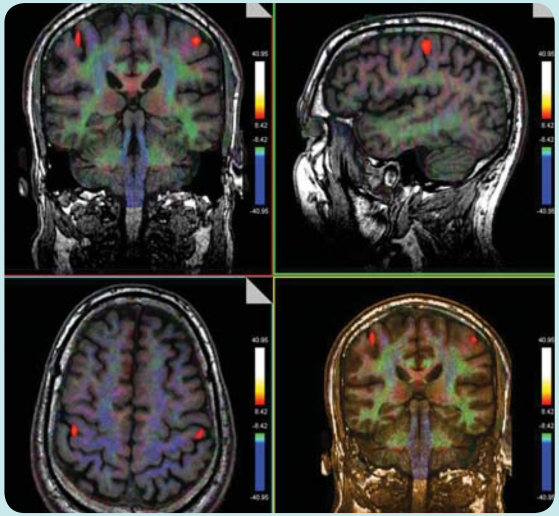


Figure 6.11 Functional magnetic resonance imaging (fMRI) scans of the brain show different areas of activation.

PET Scans

Another approach for studying brain function involves positron emission tomography (toh-MAHG-ra-fee), or 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 fMRI 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 fMRI or PET scan?

The left frontal lobe also includes *Broca's area*, which controls the tongue and lip movements required for speech. Damage to this area in stroke patients produces difficulty with speaking. The *association cortex* on the most anterior portion of the frontal lobe is believed to be responsible for intellect.

The **parietal** (pa-RIGH-eh-tal) **lobes** are immediately posterior to the frontal lobes. The parietal lobes include the **primary somatic sensory cortex**, which interprets sensory impulses received from the skin, internal organs, muscles, and joints. The display of body parts in the somatic sensory part of **Figure 6.10** represents the density, or amount, of sensory neural input received from different parts of the body. Notice that the fingertips and lips, in particular, have a lot of sensory receptors. This is why they occupy large portions of the sensory cortex.

The **occipital** (ahk-SIP-i-tal) **lobes**, posterior to the parietal lobes, are responsible for vision. The lateral sulci divide the **temporal** (TEHM-poh-ral) **lobes**, the most inferior lobes, from the frontal and parietal lobes above them. The temporal lobes are involved in speech, hearing, vision, memory, and emotion. The region responsible for speech is located at the intersection of the occipital, temporal, and parietal lobes.

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-a-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-a-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-a-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** (EHP-i-THAL-a-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-DOOL-a 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-lar) *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.

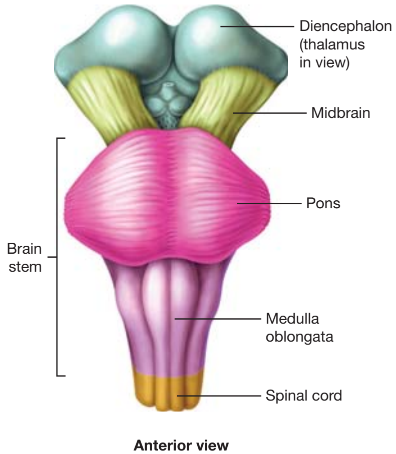


Figure 6.12 The diencephalon includes the thalamus (exterior), and the hypothalamus and epithalamus (both interior). The brain stem includes the midbrain, pons, and medulla oblongata. *Which area of the brain identified above controls your sneezing reflex?*

Cerebellum

The **cerebellum** (SER-eh-BEHL-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.

To coordinate body movements and balance, the cerebellum receives input from the eyes, inner ears, and sensory receptors throughout the body. It also continuously monitors body segment positions and motions. If the body's positions and motions are not what the cerebellum intended them to be, it sends out signals to make adjustments.

The primary functions of the different structures of the brain are summarized in **Figure 6.13**.

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.

The middle membrane, the *arachnoid mater*, is composed of weblike 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

Figure 6.13 Functions of the Brain

Part of Brain	Primary Functions
Cerebral Lobes	
Frontal lobe	memory, intelligence, behavior, emotions, motor function, smell
Parietal lobe	somatic sensations (pain, touch, hot/cold), speech
Occipital lobe	vision, speech
Temporal lobe	hearing, smell, memory, speech
Diencephalon	
Thalamus	relays sensory impulses up to the sensory cortex
Hypothalamus	autonomic center regulating metabolism, heart rate, blood pressure, thirst, hunger, energy level, and body temperature
Epithalamus	regulates hormones secreted by pineal gland
Brain Stem	
Midbrain	relays sensory and motor impulses
Pons	assists with regulation of breathing
Medulla oblongata	regulates heart rate, blood pressure, and breathing, and controls the reflexes of coughing, sneezing, and vomiting
Reticular formation	regulates waking from slumber and heightened states of awareness
Cerebellum	coordinates body movements and balance

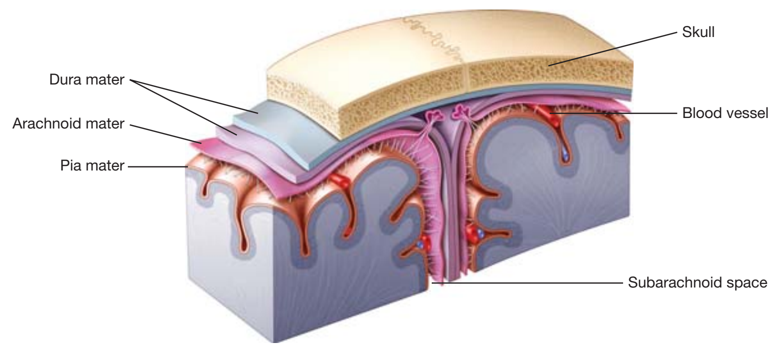


Figure 6.14 The three meninges (the protective linings of the brain and spinal cord) include the double-layered dura mater, the arachnoid mater, and the pia mater. *How do each of the meninges contribute to the protection of the brain and spinal cord?*

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?

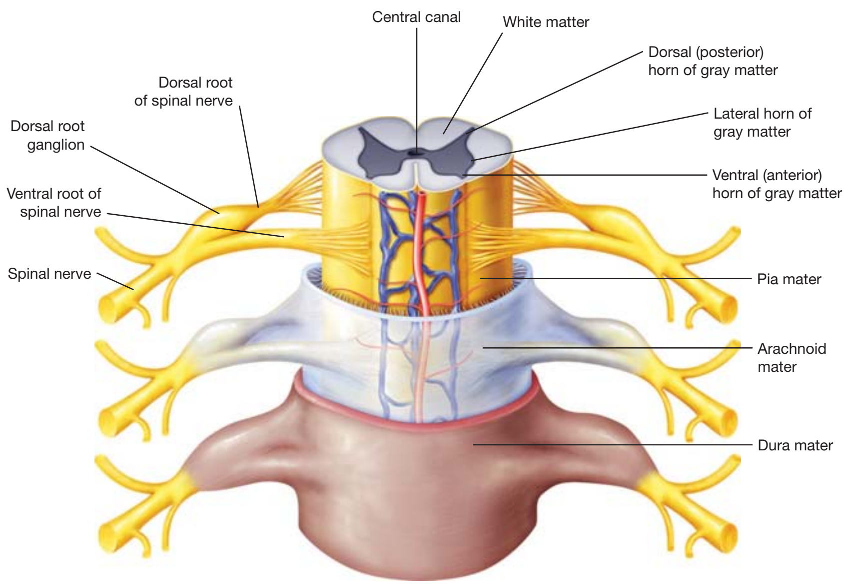


Figure 6.15 Layers and regions of the spinal cord. *Which is shaped like a butterfly—the layers and regions of the spinal cord, the gray matter, or the white matter?*

Lesson 6.3 Review and Assessment

Mini Glossary

Make sure that you know the meaning of each key term.

Build vocabulary with e-flash cards and games

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 epithalamus, thalamus, metathalamus, and hypothalamus; 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

lobes the name for the four regions of the brain—frontal, parietal, occipital, and temporal

medulla oblongata the lower portion of the brain stem, which regulates heart rate, blood pressure, and breathing, and controls several reflexes

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 the 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

Assess

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

E-Flash Cards

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.

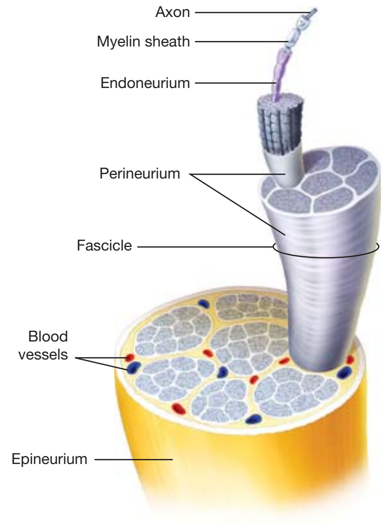


Figure 6.16 Structure of a nerve showing the protective, fibrous tissue sheaths. *How does the structure of a nerve help to protect it from injury?*

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.

Figure 6.17 Functions of the Cranial Nerves

Nerve	#	System	Function
Olfactory	I	sensory	smell
Optic	II	sensory	sight
Oculomotor	III	both	eye movements
Trochlear	IV	both	eye movements
Trigeminal	V	both	facial sensation, jaw motion
Abducens	VI	both	eye movements
Facial	VII	both	facial movements, taste
Vestibulocochlear	VIII	sensory	hearing, balance
Glossopharyngeal	IX	both	throat muscle movements, taste
Vagus	X	both	autonomic control of heart, lungs, digestion, taste, communication between brain and organs
Accessory	XI	mostly motor	trapezius movements, sternocleidomastoid movements
Hypoglossal	XII	both	tongue muscle movements, tongue sensation

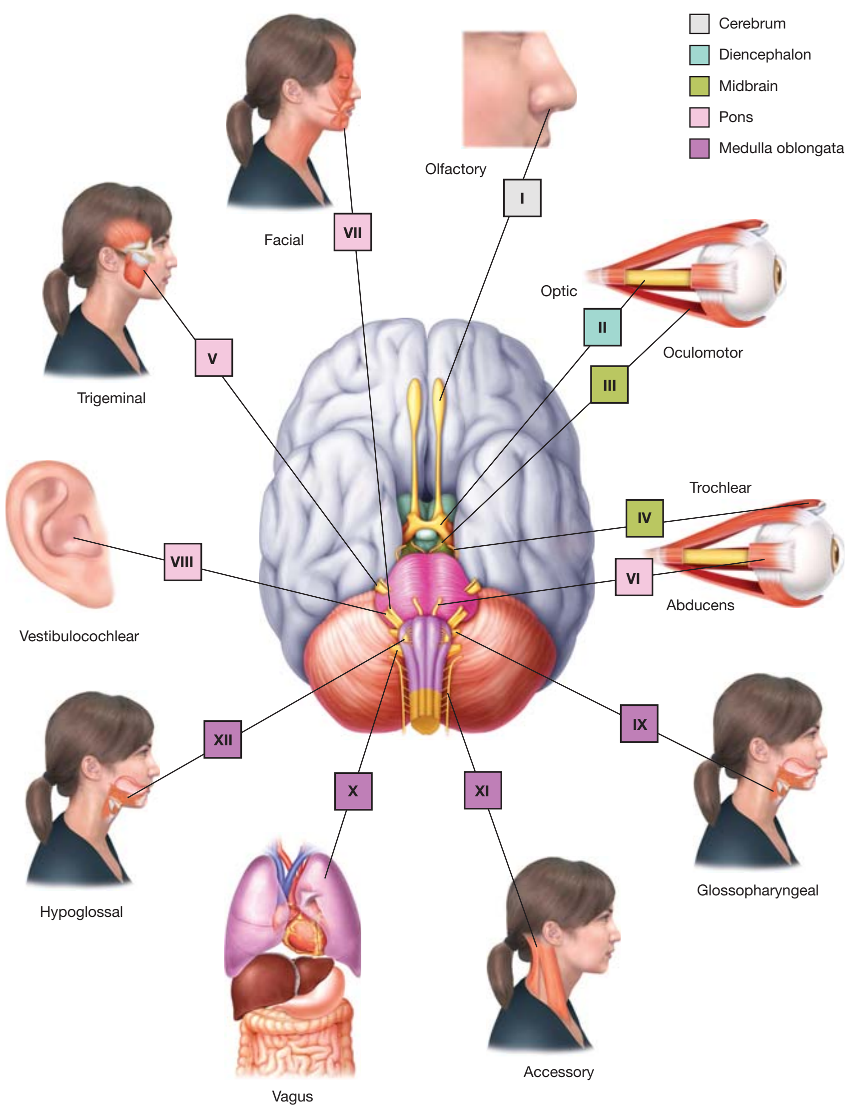


Figure 6.18 The cranial nerves. *Name at least two organs that receive impulses from the vagus nerve.*

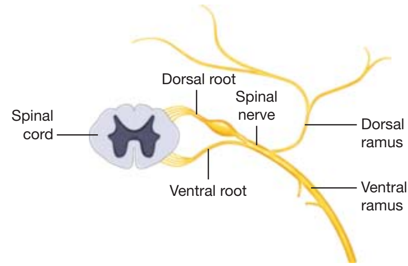


Figure 6.19 The spinal nerves, formed from dorsal and ventral roots, immediately branch into dorsal and ventral rami. *What motor impulses do the dorsal and ventral rami transmit? What sensory nerve impulses do they transmit?*

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 (T_1–T_{12}) 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-ahn). 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 T_1–L_2. 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).

Figure 6.20 Spinal Nerve Plexuses

Plexus	Spinal nerves	Exiting nerves	Region supplied
Cervical	C_1–C_5	phrenic	diaphragm, skin and muscles of neck and shoulder
Brachial	C_5–C_8 and T_1	axillary	skin and muscles of shoulder
		radial	skin and muscles of lateral and posterior arm and forearm
		median	skin and flexor muscles of forearm, some hand muscles
		musculocutaneous	skin of lateral forearm, elbow flexor muscles
		ulnar	skin of hand, flexor muscles of forearm, wrist and some hand muscles
Lumbar	L_1–L_4	femoral	skin of medial and anterior thigh, anterior thigh muscles
		obturator	skin and muscles of medial thigh and hip
		saphenous	skin of the medial thigh and medial lower leg
Sacral	L_4–L_5 and S_1–S_4	sciatic	two of the hamstrings (semimembranosus, semitendinosus), adductor magnus
		tibial	muscles of knee flexion, plantar flexion, and toe flexion; skin of the posterior lower leg and sole of the foot
		common fibular	biceps femoris, tibialis anterior, muscles of toe extension, skin of the anterior lower leg, superior surface of foot, and lateral side of foot
		superior and inferior gluteal	gluteal muscles
		posterior femoral cutaneous	skin of posterior thigh and posterior lower leg

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?

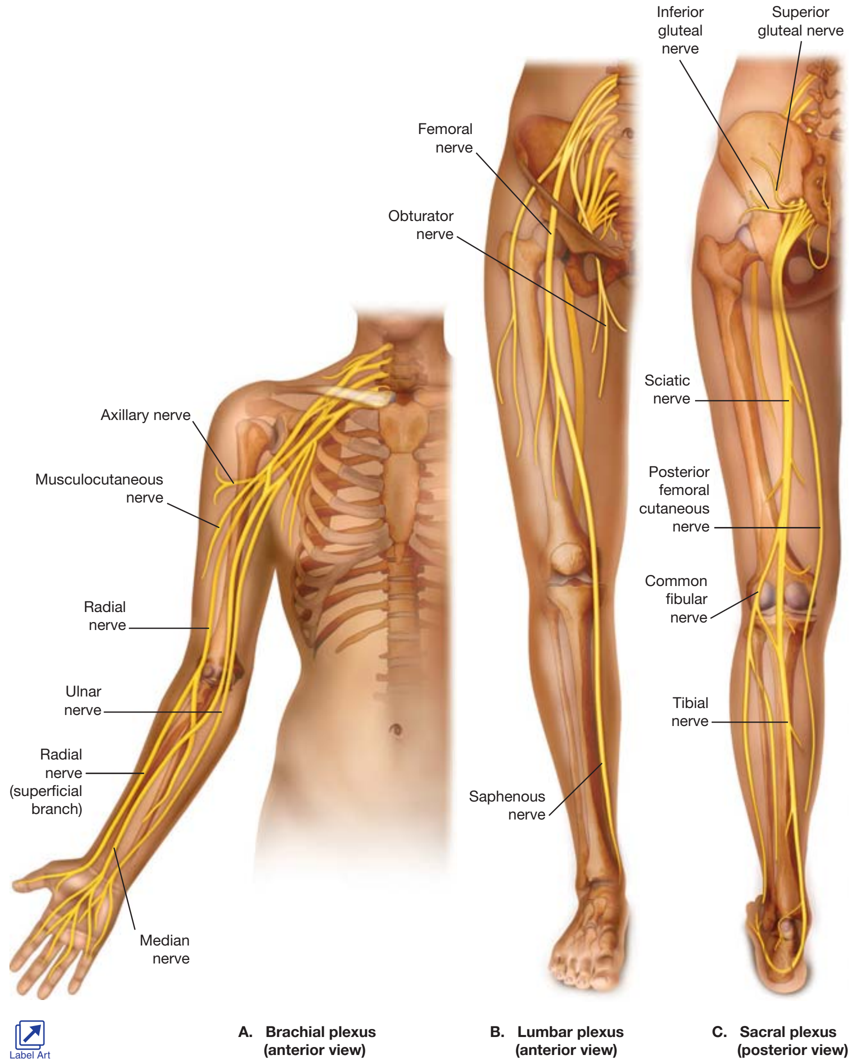


Figure 6.21 Major nerves emanate from the brachial, lumbar, and sacral plexuses. *The word plexus is derived from the Latin plectere, meaning "to braid." Why is this a fitting term for a group of nerves?*

Lesson 6.4 Review and Assessment

Mini Glossary

Make sure you that know the meaning of each key term.

Build vocabulary with e-flash cards and games

cranial nerves 12 pairs of nerves that originate in the brain and relay impulses to and from the PNS

craniosacral division the parasympathetic nervous system, in which nerves originate in the brain stem or sacral region of the spinal cord

dorsal ramus the division of posterior spinal nerves that transmit motor impulses to the posterior trunk muscles and relay sensory impulses from the skin of the back

endoneurium a delicate, connective tissue that surrounds each nerve fiber

epineurium the tough outer covering of a nerve

ganglion a mass of nervous tissue composed mostly of nerve-cell bodies

norepinephrine a neurotransmitter released by postganglionic neurons in the sympathetic nervous system

paravertebral ganglia mass of nerve cell bodies close to the spinal cord

perineurium a protective sheath that surrounds a bundle of nerve fibers

plexuses complex interconnections of nerves

postganglionic neuron the second neuron in a series that transmits impulses from the CNS

preganglionic neuron the first neuron in a series that transmits impulses from the CNS

spinal nerves neural transmitters that branch from the left and right sides of the spinal cord

thoracolumbar division the sympathetic system of nerves that lies near the thoracic and lumbar regions of the spine

ventral ramus the anterior division of spinal nerves that communicate with the muscle and skin of the anterior and lateral trunk

Know and Understand

Assess

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 call *ganglions*. 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 6.5 Injuries and Disorders of the Nervous System

Before You Read

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

What are the important first steps to take—and actions not to take—when someone may have an injury to the brain or spinal cord?

What causes multiple sclerosis and what are the symptoms?

What are the symptoms of early and advanced Alzheimer's disease?

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

E-Flash Cards

Alzheimer's disease
cerebral palsy
dementia
epilepsy
meningitis
multiple sclerosis
paraplegia
Parkinson's disease
quadriplegia
traumatic brain injury

Given the critical roles played by the central nervous system, injuries and disorders of the CNS can have potentially serious consequences. Let's look at some of the more common injuries and disorders of the CNS.

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 three 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, dilation 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 3½ 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.

Martynova Anna/Shutterstock.com

Figure 6.22 Russian and British athletes with cerebral palsy play a game of soccer in preparation for the Paralympics.

WHAT RESEARCH TELLS US

...*about* Concussions

The most common form of traumatic brain injury is a concussion. Symptoms can include headache as well as problems with concentration, memory, judgment, balance, and coordination. Fortunately, these effects are usually temporary. Although a concussion can cause a loss of consciousness, most concussions do not. Thus, many people experience mild concussions without realizing it.

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 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 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 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.

Figure 6.23 The NFL has implemented several new rules and regulations in an effort to prevent concussions.

NFL Takes Action

The NFL has donated $30 million to help establish the Sports and Health Research Program within the National Institutes of Health (NIH). This initiative provides funding for research on concussions and other common injuries in athletes across all sports, as well as members of the military.

The NFL also has taken steps to help prevent concussions, such as fining players for dangerous hits, notably helmet-to-helmet tackles. Rule changes at both the professional and collegiate levels now prevent players diagnosed with concussions from returning to play until they have been declared free of symptoms by a medical doctor.

Taking It Further

1. Working with a group of classmates, determine the standard operating procedure in athletic departments at local high schools and colleges for dealing with concussions. Are medical professionals involved in evaluating the severity of the concussion and determining when the athlete can resume practice and competitive events? What tests are used for the evaluations? Have rules been instituted to help prevent concussions? Report your findings to the class.

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:

- C_1–C_3—usually fatal
- C_1–C_4—**quadriplegia** (KWAH-dri-PLEE-jee-a), characterized by loss of function below the neck
- C_5–C_7—complete paralysis of the lower extremities, partial loss of function in the trunk and upper extremities
- T_1–L_5—**paraplegia** (PAIR-ah-PLEE-jee-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.

Corepics/Shutterstock.com

Figure 6.24 It is critically important that the head, neck, and trunk are immobilized before transporting a patient with a potential spinal cord injury. *What might happen if a patient's head, neck, and truck are not immobilized after a potential spinal cord injury?*

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? C_1–C_3; C_1–C_4; C_5–C_7; and T_1–L_5.

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 (EHP-i-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.
4. Compare and contrast dementia and Alzheimer's disease.

Lesson 6.5 Review and Assessment

Mini Glossary

Make sure that you know the meaning of each key term.

Build vocabulary with e-flash cards and games

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

Assess

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.

In the Lab

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.

James Steidl/Shutterstock.com

Figure 6.25 A neurologist examines the MRI scans of a patient.

Neurosurgery is a different specialty that involves surgical treatment of neurological conditions. Training to be a neurosurgeon requires completion of four years of medical school followed by residency training under the supervision of neurosurgeons for an additional seven to eight years.

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?
4. What personality traits do you think are necessary for success in the career you have chosen to research? For instance, neurologists must work closely with their patients. Do you enjoy working with others?
5. Does the work involve a great deal of routine, or are the day-to-day responsibilities varied?
6. Does the career require long hours, or is it a standard, "9-to-5" job?
7. What is the salary range for this job?
8. What do you think you would like about this career? Is there anything about it that you might dislike?

Related Career Options

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

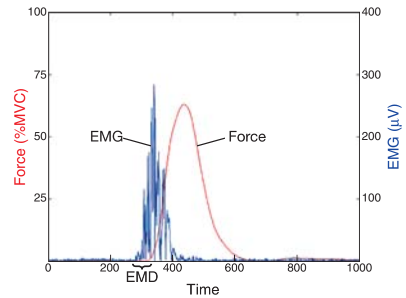


Figure 6.26 This graph shows electrical activity (EMG) in a quadriceps muscle during tension development and the corresponding force output from the leg. Notice that the onset of electrical activity clearly precedes the onset of force production, demonstrating electromechanical delay (EMD). EMD has been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

Chapter 6

Review and Assessment

Chapter Summaries

Lesson 6.1 Overview of the Nervous System

Build vocabulary with e-flash cards and games

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
epithalamus
fissures
frontal lobes
hypothalamus
lobes
medulla oblongata
meninges
midbrain
occipital lobes
parietal lobes
pons
primary motor cortex
primary somatic sensory cortex
spinal cord
temporal lobes
thalamus

Lesson 6.4 Functional Anatomy of the Peripheral Nervous System

Key Points

- The structures of the PNS transmit information to the CNS.
- Twelve pairs of cranial nerves relay impulses to and from the right and left sides of the brain.
- Thirty-one pairs of spinal nerves branch out from the right and left sides of the spinal cord.
- The PNS has two subdivisions: the somatic nervous system and the autonomic nervous system.
- The sympathetic nerves activate the fight-or-flight response; the parasympathetic nerves control day-to-day functions.

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

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

Assess

Lesson 6.1 Overview of the Nervous System

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 _____.

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.

Lesson 6.2 Transmission of Nerve Impulses

Learning Key Terms and Concepts

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 a(n) _____.
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.

Lesson 6.3

Functional Anatomy of the Central Nervous System

Learning Key Terms and Concepts

17. The adult human brain weighs approximately _____ pounds, and it contains about _____ neurons.
18. *True or False?* Recent evidence suggests that the size of a person's brain does have some relationship to intelligence.
19. Each curved, raised area of the brain is called a _____.
    A. sulcus
    B. gyrus
    C. white matter
    D. lobe
20. Each of the grooves between the gyri in the brain is called a(n) _____.
21. The four lobes of the brain are the _____, _____, _____, and _____.
22. The diencephalon is also called the _____.
    A. interbrain
    B. middle brain
    C. left brain
    D. outer brain
23. The three protective membranes that surround the brain are called the _____.

Thinking Critically

24. If one component or structure in the brain gets damaged, do you think the other structures can compensate enough for the person to function fairly normally? Explain your answer.
25. Examine the importance of the blood-brain barrier. Explain what you think would happen if this protective measure was no longer in place.

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 fascicles 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.

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 surround the brain and spinal cord.
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 _____, thinking, and _____.

Thinking Critically

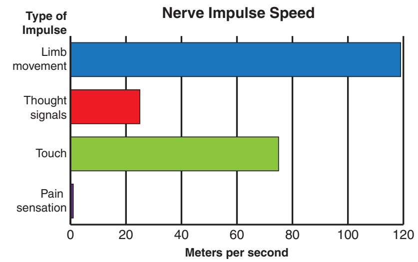
40. Evaluate the cause and effect of cerebral palsy on the structure and function of cells, tissues, organs, and systems.
41. Explain the range of problems that can result from injuries to different parts of the spinal column.
42. Evaluate the cause and effect of TBI on the structure and function of cells, tissues, organs, and systems.

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 front 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 aloud 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.

Expand your learning with additional online resources
- Supplemental Lab Activities
- Interactive Exercises
- Animations

Expand

Companion Website

www.g-wlearning.com/healthsciences