chapter

10 Nervous System: Nervous Tissue and Brain

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Key Terms

action potential (p. 175)
brain stem (p. 187)
cerebellum (p. 188)
cerebrospinal fluid (CSF) (p. 190)
cerebrum (p. 182)
depolarize (p. 176)
frontal lobe (p. 184)
hypothalamus (p. 187)
limbic system (p. 188)
medulla oblongata (p. 187)
meninges (p. 190)
myelin (p. 174)
neuroglia (p. 173)
neuron (p. 173)
neurotransmitters (p. 180)
occipital lobe (p. 186)
parietal lobe (p. 185)
repolarize (p. 176)
reticular formation (p. 188)
synapse (p. 179)
temporal lobe (p. 185)

Objectives

1. Define the two divisions of the nervous system.
2. List three general functions of the nervous system.
3. Discuss the cellular composition of the nervous system, including:
   - Compare the structure and functions of the neuroglia and neuron.
   - Explain the function of the myelin sheath.
   - Explain how a neuron transmits information.
4. Describe the structure and function of a synapse.
5. Describe the functions of the four major areas of the brain and the four lobes of the cerebrum.
6. Describe how the skull, meninges, cerebrospinal fluid, and blood–brain barrier protect the central nervous system.

THE NERVOUS SYSTEM: STRUCTURE AND FUNCTION

If you have ever listened to an orchestra warming up before a performance, you know something about the need for its conductor. Without the conductor, the sound is more like noise than music. The conductor coordinates, interprets, and directs the sound into the beautiful strains of a symphony. So it is with the nervous system. The various organ systems of the body need an interpreter to coordinate and direct them. This role is performed magnificently by the nervous system. The music of the body is every bit as beautiful as the strains of a symphony!

DIVISIONS OF THE NERVOUS SYSTEM

The structures of the nervous system are divided into two parts: the central nervous system and the peripheral nervous system. The central nervous system (CNS) includes the brain and the spinal cord. The CNS is located in the dorsal cavity. The brain is located in the cranial cavity; the spinal cord is enclosed in the spinal cavity. The peripheral nervous system (PNS) is located outside the CNS and consists of the nerves that connect the CNS with the rest of the body (Figure 10-1).

FUNCTIONS OF THE NERVOUS SYSTEM

As the "conductor," the nervous system performs three general functions: a sensory function, an integrative function, and a motor function (Figure 10-2).

SENSORY FUNCTION

Sensory nerves gather information from inside the body and from the outside environment. The nerves then carry the information to the CNS. For example, information about a cat is picked up by special cells in the boy's eye.

INTEGRATIVE FUNCTION

Sensory information brought to the CNS is interpreted. The brain not only sees the cat, but also does much more. It recalls very quickly how a cat behaves. It may

3. According to Figure 9-3
  a. The motor unit is another name for the neuromuscular junction (NMJ).
  b. Acetylcholine (ACh) is the neurotransmitter within the NMJ.
  c. Acetylcholinesterase is stored within the vesicles of the nerve terminal.
  d. The somatic motor neuron innervates only one muscle fiber (cell).

4. According to Figure 9-4
  a. Curare induces muscle paralysis because it blocks the release of acetylcholine (ACh) from the nerve terminal.
  b. *C. botulinum* induces paralysis because its toxin blocks muscle receptors.
  c. Myasthenia gravis is caused by the inability of the neuron to synthesize ACh.
  d. Curare induces paralysis because it blocks the muscle membrane receptors.

5. According to Figure 9-5, which event occurs first?
  a. Calcium is released from the sarcoplasmic reticulum.
  b. The electrical signal runs along the T tubule.
  c. ACh is released from the terminal of the somatic motor neuron.
  d. ACh binds to the receptors on the muscle membrane.

6. According to Figure 9-6
  a. The triceps brachii acts synergistically with the biceps brachii.
  b. Contraction of the biceps brachii causes extension of the arm at the elbow.
  c. The heads of the biceps brachii attach to the proximal humerus.
  d. The biceps brachii lies across the elbow joint.

7. According to Figure 9-7 and Table 9-1, contraction of the pectoralis major causes
  a. abduction of the arm at the shoulder.
  b. internal or medial rotation of the arm at the shoulder.
  c. flexion of the forearm at the elbow and external rotation of the arm, as if pointing behind you.
  d. movement of the arm into a "scarecrow" position.

8. According to Figure 9-7 and Table 9-1, the sartorius
  a. is visible only on the posterior view of the body.
  b. works synergistically with the muscles of the pectoral girdle.
  c. lies obliquely across the anterior thigh.
  d. inserts on the Achilles tendon.

9. Which muscles are not illustrated in Figures 9-8 or 9-9?
  a. Sternocleidomastoid, buccinator, and masseter
  b. Diaphragm, trapezius, and intercostals
  c. Latissimus dorsi, trapezius, and sartorius
  d. Frontalis, orbicularis oris, and platysma

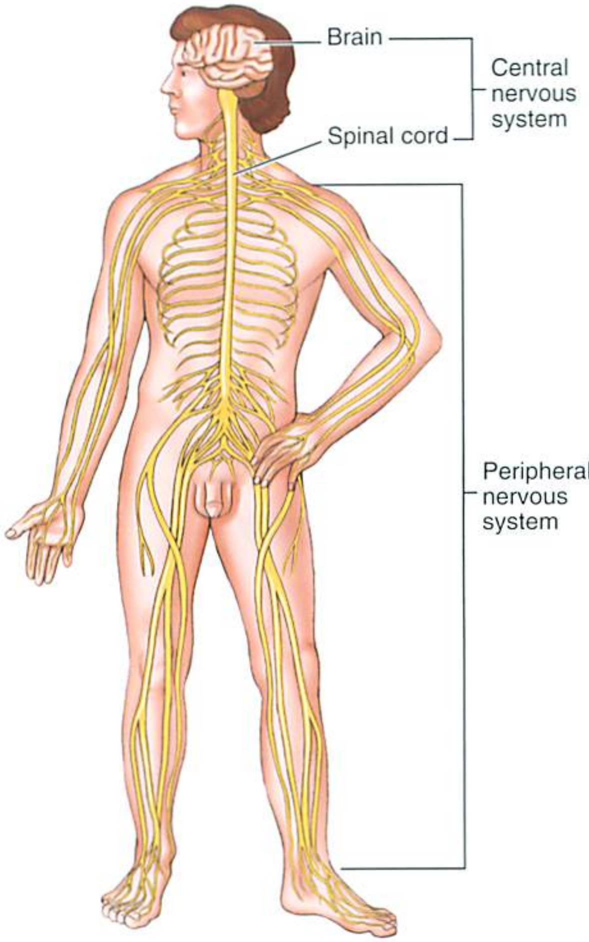


FIGURE 10-1 Nervous system: central nervous system and peripheral nervous system.

determine that the cat is acting hungry or is distressed and ready to attack. The brain integrates, or puts together, everything it knows about cats and then makes its plan.

MOTOR FUNCTION

Motor nerves convey information from the CNS toward the muscles and glands of the body. Motor nerves carry out the plans made by the CNS. For example, the person may decide to feed the hungry cat. Information must travel along the motor nerves from the CNS to all the skeletal muscles needed to feed the cat. The motor nerve converts the plan into action.

? Re-Think

Differentiate between sensory, integrative, and motor function; provide an example of each.

CELLS THAT MAKE UP THE NERVOUS SYSTEM

Nervous tissue is composed of two types of cells: the neuroglia and the neurons.

NEUROGLIA

Neuroglia (noo-ROHG-lee-ah), or glial cells, are the nerve glue. Neuroglia are the most abundant of the nerve cells; most glial cells are located in the CNS. Glial cells support, protect, insulate, nourish, and generally care for the delicate neurons. Some of the glial cells participate in phagocytosis; others assist in the secretion of cerebrospinal fluid. Glial cells, however, do not conduct nerve impulses.

Two of the more common glial cells are the astrocytes and the ependymal cells (Figure 10-3). The star-shaped astrocytes (ASS-troh-sytes) are the most abundant of the glial cells and have the most diverse functions; they support the neurons structurally, cover the entire surface of the brain, and help form a protective barrier, called the *blood–brain barrier*. This barrier helps prevent toxic substances in the blood from entering the nervous tissue of the brain and spinal cord. Astrocytes also secrete nerve growth factors that promote neuron growth and enhance synaptic development. A second glial cell is the ependymal (eh-PEN-di-mal) cell. These cells line the inside cavities of the brain and assist in the formation of cerebrospinal fluid. Other glial cells are listed in Table 10-1. Because glial cells undergo mitosis, most primary CNS tumors are composed of glial cells, such as astrocytomas.

NEURON

The second type of cell within the nervous system is the neuron. Of the two types of nerve cells, the **neuron** (NOO-ron) is the most important in the transmission of electrical signals. The neuron enables the nervous system to act as a vast communication network. Neurons have many shapes and sizes. Some neurons are extremely short; others are very long, with some measuring 4 feet in length. Unlike glial cells, neurons are nonmitotic and therefore do not replicate nor replace themselves when injured. Because they are nonmitotic, neurons generally do not give rise to primary malignant brain tumors.

PARTS OF A NEURON

Three Parts

The three parts of the neuron are the dendrites, cell body, and axon (Figure 10-4). Dendrites are treelike structures that receive signals from other neurons and then transmit the signals toward the cell body. One neuron may have thousands of dendrites, whereas other neurons have fewer dendrites. The neuron with the greater number of dendrites can receive signals from many other neurons. The cell body contains the nucleus and is essential for the life of the cell. The cell body usually receives thousands of signals from the dendrites and "decides" on the signal it wants to send to the axon. The axon is a long extension that transmits signals away from the cell body. The end of the axon

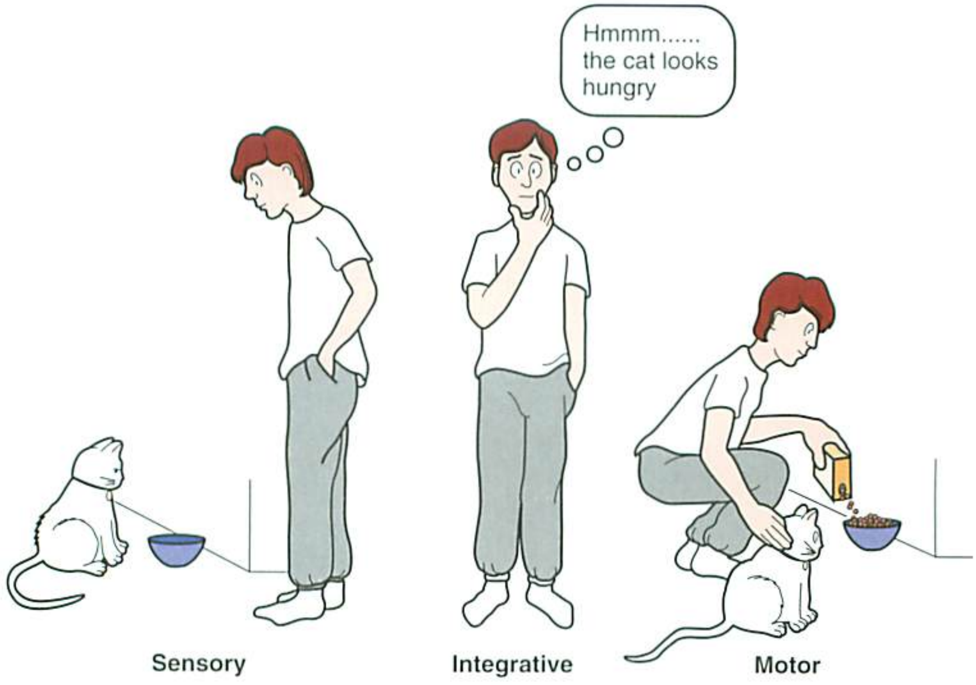


FIGURE 10-2 Three functions of the nervous system. **A,** Sensory function. **B,** Integrative function. **C,** Motor function.

undergoes extensive branching to form many axon terminals; it is within the axon terminals that the chemical neurotransmitters are stored. The arrow in Figure 10-4 indicates the direction in which signal travels over the neuron: from dendrites to cell body to axon.

The Axon: A Special Structure

What is so special about the axon? An enlarged view of the axon shows several unique structures: the myelin sheath, the neurilemma, and the nodes of Ranvier (see Figure 10-4). Most long nerve fibers of both the peripheral and central nervous systems are encased by a layer of white fatty material called the *myelin sheath.* **Myelin** (MY-eh-lin) protects and insulates the axon. Nerve fibers covered by myelin are said to be myelinated. Some neurons are not encased in myelin and are called *unmyelinated neurons.* Myelination begins during the fourth month of fetal life and continues into the teenage years. Because some axons of immature motor neurons lack myelination, the movements of an infant are slower and less coordinated than those of an older child. Severely restricting the fat intake of an infant or young child is unwise, because the child is still laying down myelin.

The formation of myelin sheath differs in the peripheral and central nervous systems. Surrounding the axon of a neuron in the peripheral nervous system is a layer of special cells called *Schwann* (shwon) *cells.* The Schwann cells form the myelin sheath that surrounds the axon. The nuclei and cytoplasm of the Schwann cells lie outside the myelin sheath and are called the *neurilemma.* The neurilemma is important in the regeneration of a severed nerve.

In the CNS, the myelin sheath is formed not by Schwann cells but by oligodendrocytes (ohl-i-go-DEN-droh-sytes), a type of glial cell (see Table 10-1). Because there are no Schwann cells, there is no neurilemma. The lack of the neurilemma surrounding the axons accounts, in part, for the inability of the CNS neurons to regenerate. Failure of the neurons of the CNS to regenerate, however, is not fully explained by the lack of neurilemma; other factors include the formation of scar tissue and the lack of critical nerve growth factors.

Nodes of Ranvier, axonal areas not covered by myelin, appear at regular intervals along the myelinated axon.

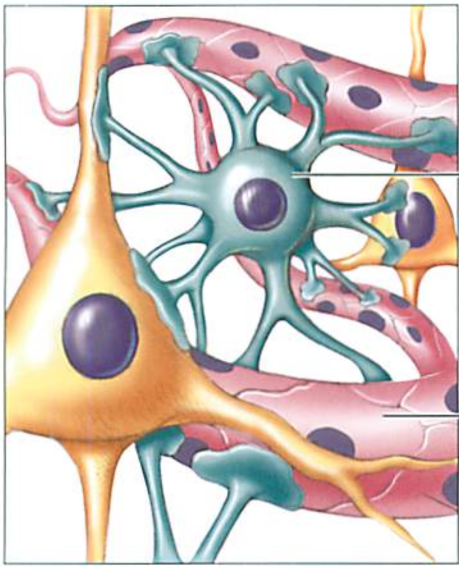
? Re-Think

1. What is the biggest functional difference between glial cells and the neuron?
2. List the three main parts of a neuron.

TYPES OF NEURONS

The three types of neurons are the sensory neuron, the motor neuron, and the interneuron. A sensory neuron carries information from the periphery toward the CNS. Sensory neurons are also called *afferent neurons.*

A motor neuron carries information from the CNS toward the periphery. Motor neurons are also called *efferent neurons.*



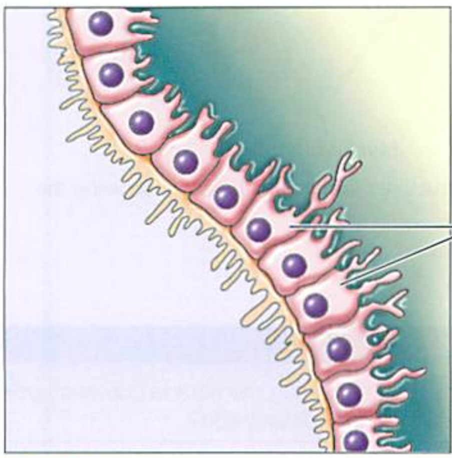


FIGURE 10-3 Neuroglia, or glia: astrocytes and ependymal cells.

Remember—what is the **SAME** about these fibers!

S **s**ensory
A **a**fferent
M **m**otor
E **e**fferent

The third type of neuron is the interneuron; it is found only in the CNS. Interneurons form connections between sensory and motor neurons. Interneurons also play a role in thinking, learning, and memory.

WHITE MATTER VERSUS GRAY MATTER

The tissue of the CNS is white or gray. White matter is white because of the myelinated axons, whereas gray matter is made up of unmyelinated axons, cell bodies, interneurons, and synapses.

Sometimes cell bodies appear in small clusters and are given special names. Clusters of cell bodies located in the CNS are generally referred to as *nuclei*. Small clusters of cell bodies in the peripheral nervous system are called *ganglia* (sing., ganglion). For example, patches of gray called the *basal nuclei* are located in the brain. (Sometimes, these patches of gray are called *basal ganglia,* despite their location in the CNS.)

Table 10-1 Types of Neuroglia

CELL NAME	FUNCTION
Astrocytes	Star-shaped cells present in blood–brain barrier; also anchor or bind blood vessels to nerves for support, act as phagocytes, and secrete nerve growth factors
Ependymal cells	Line the ventricles as part of the choroid plexus; involved in the formation of cerebrospinal fluid
Microglia	Protective role; phagocytosis of pathogens and damaged tissue
Schwann cells	Produce myelin sheath for neurons in the peripheral nervous system; assist in regeneration of damaged fibers
Oligodendrocytes	Produce myelin sheath for neurons in the central nervous system

2+2 Sum It Up!

The nervous system plays a crucial role in allowing us to interact with our environment, both internal and external. The nervous system has two divisions: the central nervous system (CNS) and the peripheral nervous system. The nervous system performs three major functions: sensory, integrative, and motor. There are two types of cells in the nervous system: the neuroglia and the neurons. The neuron is responsible for the rapid communication of electrical signals. The three parts of the neuron are the dendrites, cell body, and axon.

THE NEURON CARRYING INFORMATION

Neurons allow the nervous system to convey information rapidly from one part of the body to the next. A stubbed toe makes itself known almost immediately. Think of how fast the information travels from your toe, where the injury occurred, to your brain, where the injury is interpreted as pain. Information is carried along the neuron in the form of a nerve impulse.

THE NERVE IMPULSE: WHAT IT IS

The nerve impulse is an electrical signal that conveys information along a neuron. A series of events cause the electrical charge inside the cell to move from its negative resting state (–) to its positive depolarized state (+) and back to its negative resting state (–). The nerve impulse is called the **action potential**. There

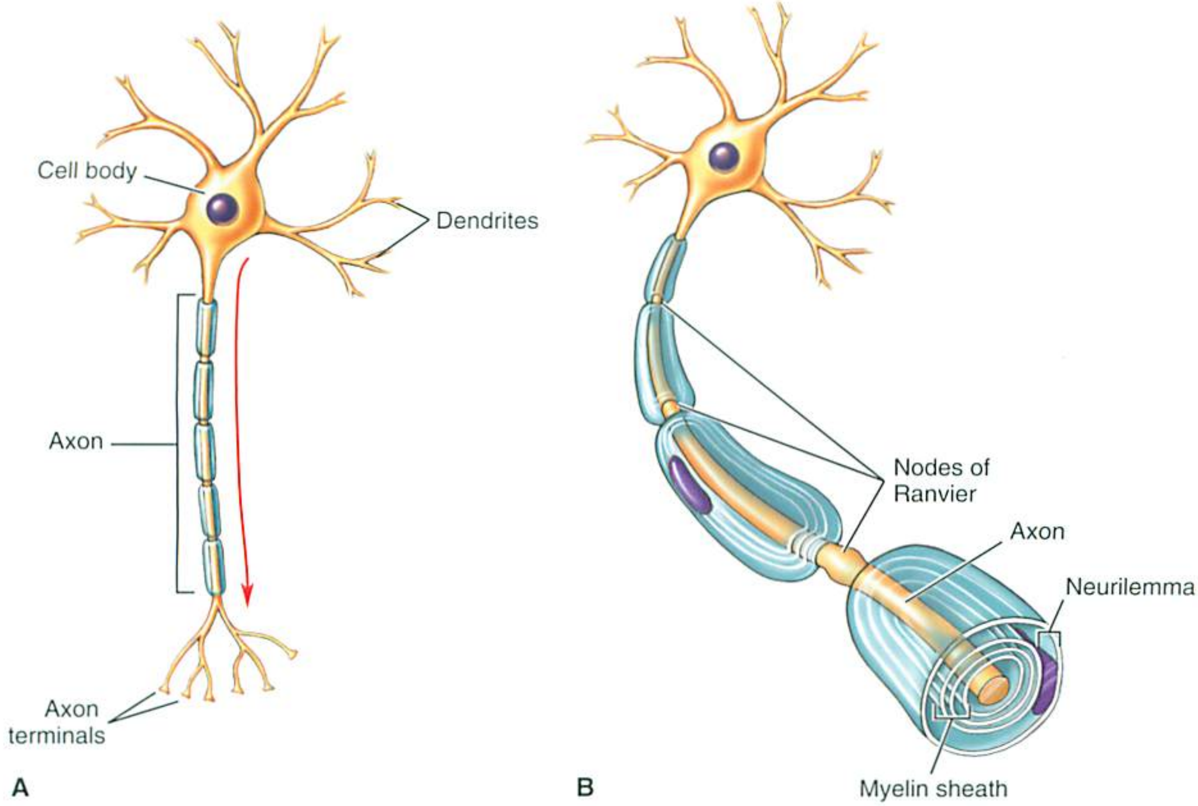


FIGURE 10-4 Structure of a neuron. **A,** Dendrites, cell body, axon, and axon terminals. **B,** Structure surrounding the axon, showing the myelin sheath, the nodes of Ranvier, and the neurilemma.

are two phases of an action potential: depolarization and repolarization. Follow Figure 10-5 through the events of the action potential, from its resting state (resting membrane potential) to depolarization to repolarization.

RESTING MEMBRANE POTENTIAL

The resting membrane potential refers to the electrical charge difference across the membrane of the resting neuron. The inside of a resting neuron is more negative (−) than the outside (+). The resting cell is said to be polarized. As long as the neuron is polarized, no nerve impulse is being transmitted. The cell is quiet, or resting.

DEPOLARIZATION

When the neuron is stimulated, a change occurs in the cell's electrical state. In the resting (polarized) state, the inside of the cell is negative. When the cell is stimulated, the inside becomes positive. As the inside of the cell changes from negative to positive, it is said to **depolarize**.

REPOLARIZATION

Very quickly, however, the inside of the cell again becomes negative; in other words, it returns to its resting state, or **repolarizes**. Unless the cell repolarizes, it cannot be stimulated again.

? Re-Think

What is the meaning of the resting membrane potential, polarization, depolarization, and repolarization?

THE NERVE IMPULSE: WHAT CAUSES IT

The changes associated with the action potential, or nerve impulse, are caused by the movement of specific ions across the cell membrane of the neuron. There is an ionic basis of the action potential. Follow the movement of the ions in Figure 10-6.

RESTING MEMBRANE POTENTIAL

What makes the inside of the cell negative in the resting state? The resting state is the result of the numbers and types of ions located inside the neuron. The chief intracellular ions include the positively charged potassium ions (K^+) and several anions (negatively charged ions). How do these ions get into the cell in such high concentrations? They are pumped in by ATP-driven pumps in the cell membrane. The chief intracellular cation is K^+. In the resting state, however, some of the K^+ ions leak out of the cell, taking with them the positive charge. The lost positive charge and the excess anions trapped in the cell make the inside of the cell negative. Remember: it is the outward leak of K^+ that is responsible for the resting membrane potential!

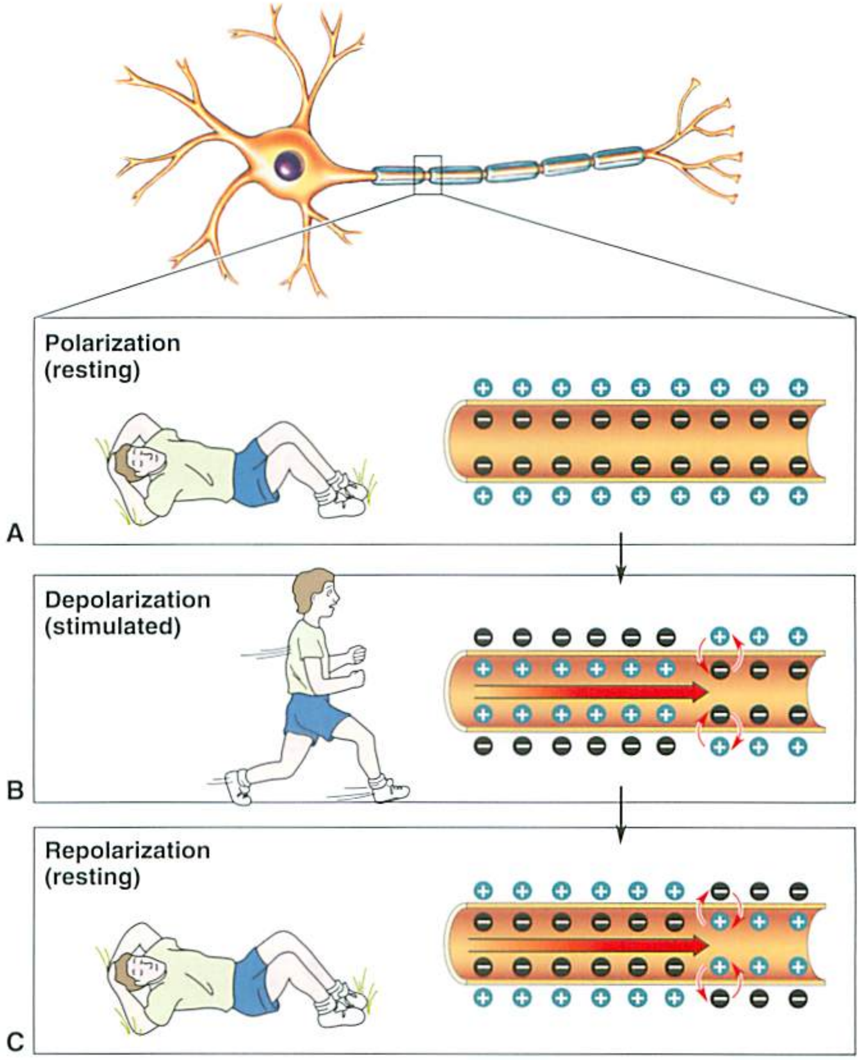


FIGURE 10-5 Nerve impulse (action potential). **A,** Polarization. **B,** Depolarization. **C,** Repolarization.

DEPOLARIZATION (STIMULATED STATE)

Why does the interior of the cell become positive when stimulated? When the neuron is stimulated, the permeability of the neuronal membrane changes in a way that allows sodium ions (Na^+) to diffuse rapidly across the membrane into the cell, carrying with it a positive (+) charge. Thus, it is the inward diffusion of Na^+ that causes depolarization. (Na^+ is the chief extracellular cation.)

REPOLARIZATION (RETURN TO RESTING)

Why does the inside of the cell quickly return to its resting negative state? Soon after the cell depolarizes, the neuronal membrane undergoes a second change. The change in the membrane permeability does two things: (1) it stops additional diffusion of Na^+ into the cell, and (2) it allows K^+ to rapidly diffuse out of the cell. The outward diffusion of K^+ decreases the positive charge from the inside of the cell, leaving behind the negatively charged anions. Thus, the outward movement of K^+ causes repolarization and a return to the resting state.

Eventually, membrane pumps restore intracellular ion concentrations; Na^+ is pumped out of the cell, while K^+ is pumped into the cell. Note that the repolarizing phase of the nerve impulse is not caused by the active transport pumps. Repolarization is caused by the rapid outward diffusion of K^+. In addition to their physiological roles, these active transport pumps are often the target of drugs. Digoxin, for example, poisons the Na^+/K^+ pumps, causing calcium to accumulate in cardiac muscle. This action accounts for the increased force of cardiac muscle contraction, a desired effect in the treatment of heart failure.

? Re-Think

What is the ionic basis of the resting membrane potential (polarization), depolarization, and repolarization?

THE NERVE IMPULSE: WHAT CAUSES IT TO MOVE

To convey information, a nerve impulse (action potential) must move the length of the neuron, from the cell

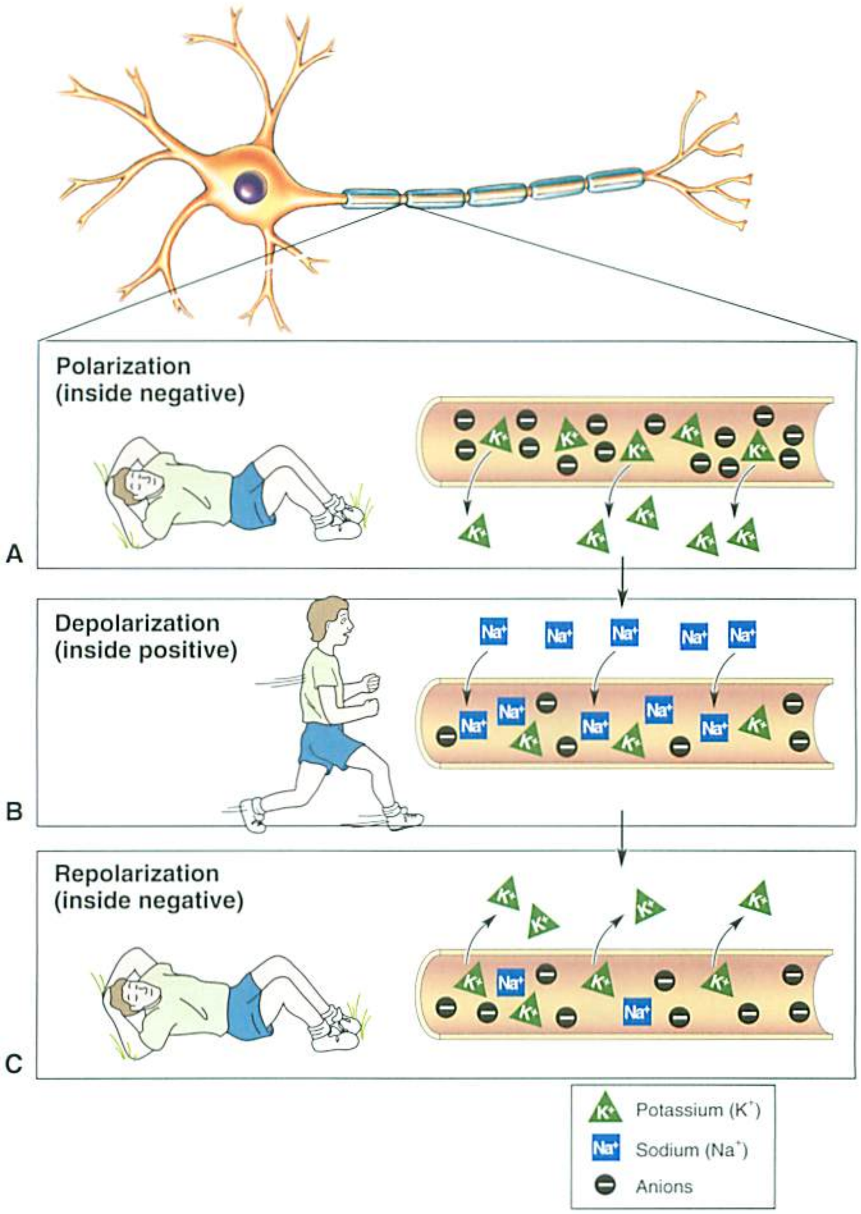


FIGURE 10-6 The cause of the nerve impulse. **A,** Polarization. **B,** Depolarization. **C,** Repolarization.

body to the axon terminal. Figure 10-7 shows that when nerve impulse one (NI-1) forms at point A, it also depolarizes the next segment of the membrane (point B), causing nerve impulse two (NI-2) to form. Nerve impulse 2 then depolarizes the next segment of membrane at point C, causing the formation of nerve impulse three (NI-3).

Because of the ability of each nerve impulse to depolarize the adjacent membrane, the nerve impulse moves toward the axon terminal much like a wave. In addition to showing the movement of the nerve impulse, Figure 10-7 also shows that each nerve impulse fires in an all-or-nothing manner. The all-or-nothing firing means that the height of each nerve impulse is the same. This is important because it ensures that the nerve impulse does not weaken as it travels the length of a long axon.

THE NERVE IMPULSE: WHAT CAUSES IT TO MOVE QUICKLY

We understand why the nerve impulse moves, but why does it move so quickly? Myelination increases the movement of the nerve impulse along the axonal membrane. Recall that the axons of most nerve fibers are wrapped in myelin, a fatty material. At the nodes of Ranvier, the axonal membrane is bare or unmyelinated.

The nerve impulse arrives at the axon but cannot develop on any part of the membrane covered with myelin. The nerve impulse can, however, develop at the nodes of Ranvier, the bare axonal membrane. Thus in a myelinated fiber, the nerve impulse jumps from node to node, much like a kangaroo, to the end of the axon (Figure 10-8). This "jumping" from node to

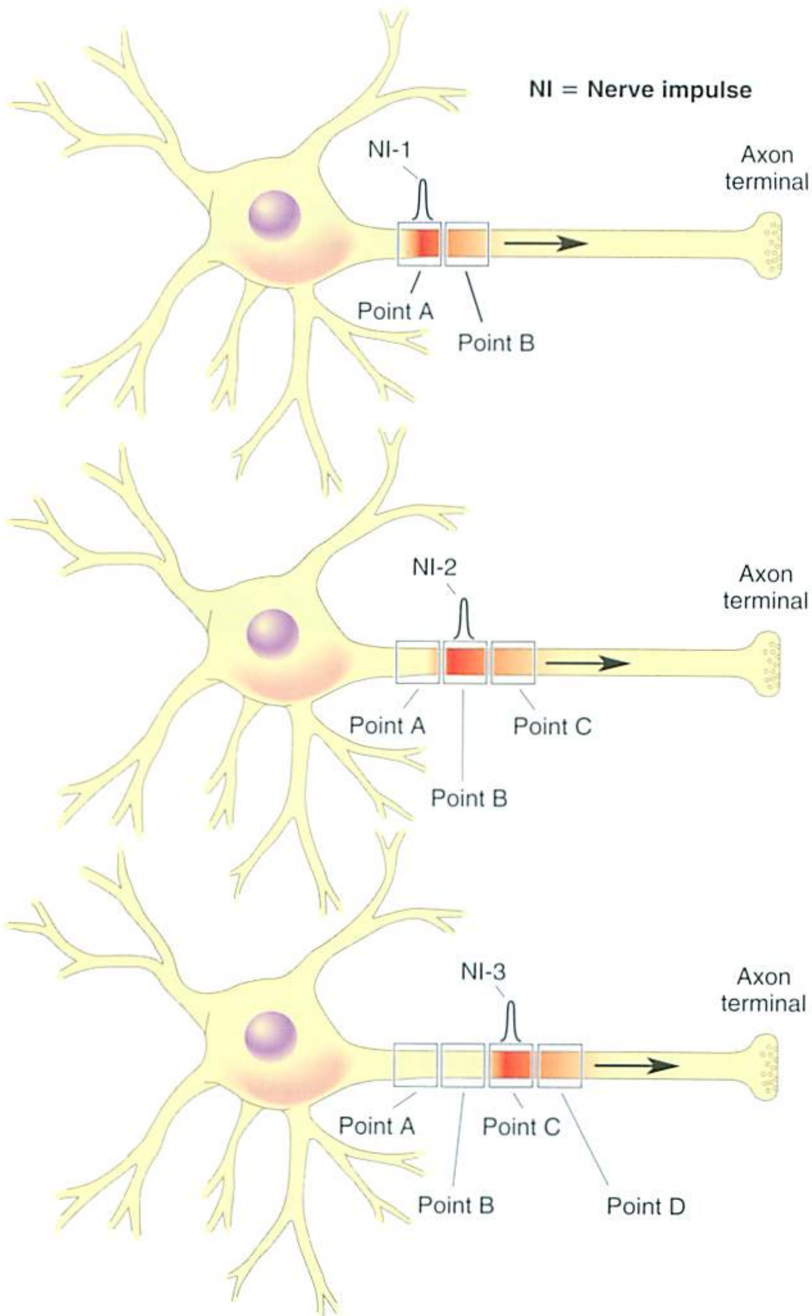


FIGURE 10-7 What causes the nerve impulse to move from the cell body to the axon terminals?

node is called *saltatory conduction* (from the Latin word *saltare,* meaning "to leap"). Saltatory conduction increases the speed with which the nerve impulse travels along the nerve fiber. For this reason, myelinated fibers are considered fast-conducting nerve fibers.

? Re-Think

Explain how myelination affects the rate of nerve impulse (action potential) conduction.

SYNAPSE ACROSS NEURONS

The nerve impulse travels the length of the axon. However, the signal is unable to jump from one neuron to the next. A **synapse** helps information move from one neuron to the next. The big question is how.

PARTS OF A SYNAPSE

SYNAPTIC CLEFT

The synaptic (si-NAP-tik) cleft is a space (much like the neuromuscular junction in Chapter 9). The space

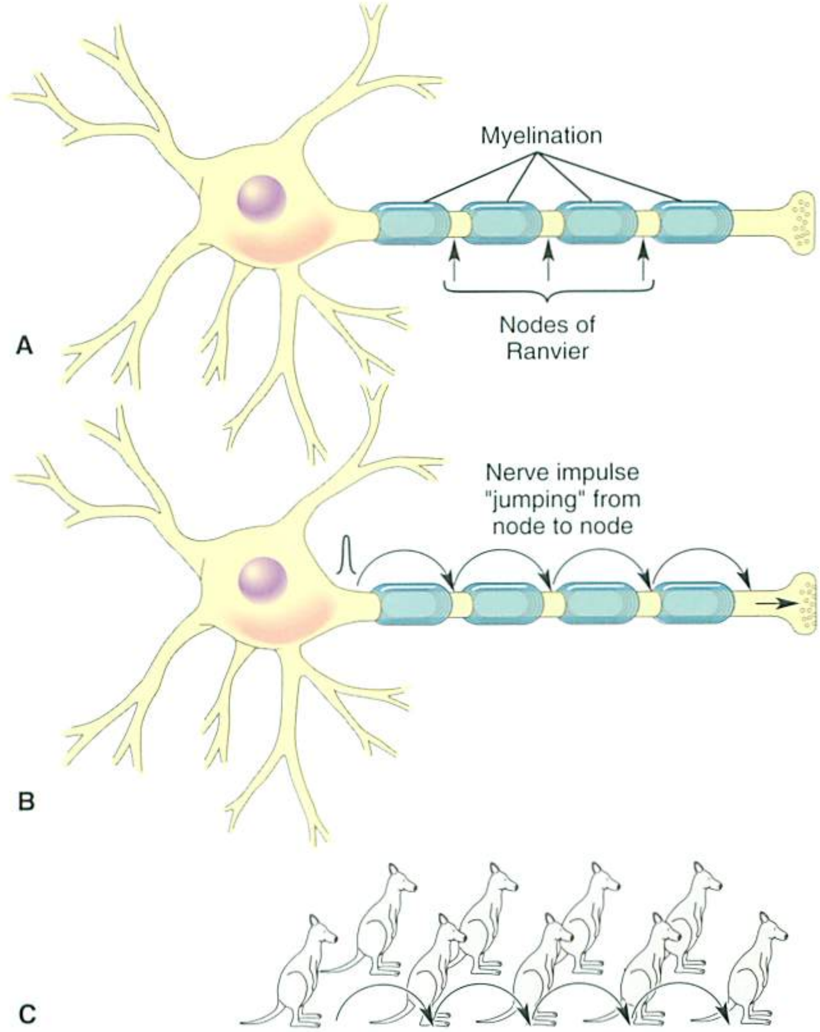


FIGURE 10-8 Jumping from node to node. **A,** A myelinated axon and the nodes of Ranvier. **B,** The nerve impulse jumps from node to node toward the axon terminal. **C,** The jumping of the nerve impulse resembles the jumping of a kangaroo.

exists because the axon terminal of neuron A (presynaptic neuron) does not physically touch the dendrite of neuron B (postsynaptic neuron). Follow Figure 10-9 as the synaptic structures listed below are described.

Receptors

The dendrite of neuron B contains receptor sites. Receptor sites are places on the membrane to which the neurotransmitters bind. For example, acetylcholine (ACh) binds to the receptors on dendrite B. Each receptor site has a specific shape and accepts only those neurotransmitters that "fit" its shape.

Neurotransmitters

The axon terminal of neuron A contains thousands of tiny vesicles that store chemical substances called **neurotransmitters** (noo-roh-TRANS-mit-ters). The most common neurotransmitters are ACh and norepinephrine (NE). Other CNS transmitters include epinephrine, serotonin, glutamate, dopamine, gamma-aminobutyric acid (GABA), and endorphins.

Inactivators

Inactivators are substances that terminate the activity of the neurotransmitters when they have completed their task. For example, the neurotransmitter ACh is terminated by acetylcholinesterase. Acetylcholinesterase is an enzyme located in the same area as the receptor sites on neuron B. Once ACh has completed its task, it is inactivated by acetylcholinesterase.

EVENTS AT THE SYNAPSE

The following details the events at the synapse (see Figure 10-9).

1. The nerve impulse travels along neuron A to its axon terminal.
2. The nerve impulse causes the vesicles to fuse with the membrane of the axon terminal. The vesicles open and release the neurotransmitter into the synaptic cleft.
3. The neurotransmitter diffuses across the synaptic cleft and binds to the receptor site. The binding of

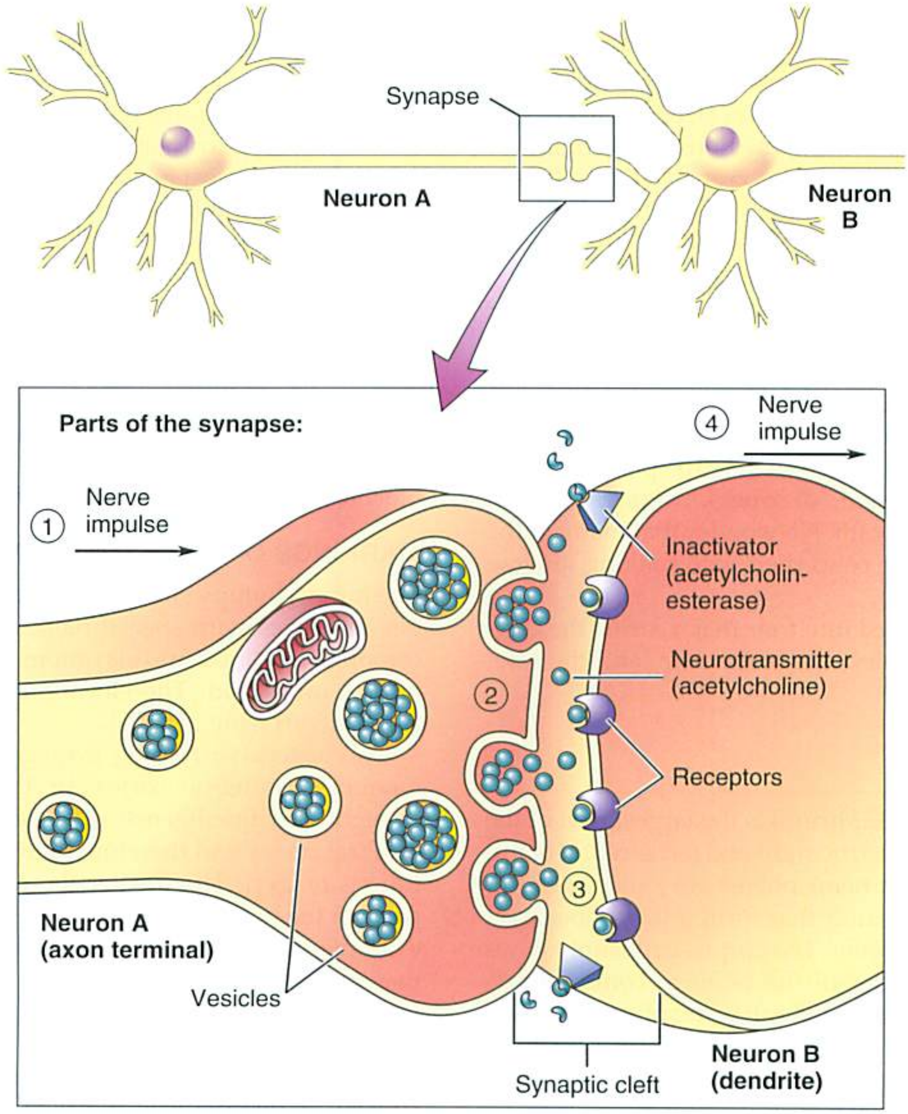


FIGURE 10-9 The synapse. The steps in the transfer of information across the synapse are shown.

the neurotransmitter to the receptor site causes a change in the membrane potential of the dendrite of neuron B, thereby developing a nerve impulse. The neurotransmitter vacates the receptor and is degraded.

4. Electrical information travels toward the cell body and axon of neuron B. What has happened at the synapse? Information from neuron A has been transmitted chemically to neuron B.

? Re-Think

How does the nerve impulse (action potential) of the first neuron stimulate the dendrites of a second neuron?

2+2 Sum It Up!

The electrical signal that travels along the neuron is called the *nerve impulse* or *action potential*. The nerve impulse has two phases: depolarization and repolarization. The resting membrane potential and the phases of the nerve impulse are caused by the movement of ions, particularly Na^+ and K^+. The resting membrane potential is due to the outward leak of K^+. Depolarization is due to the influx of Na^+. Repolarization is due to the efflux of K^+. The nerve impulse travels along the neuron from the cell body to the end of the axon. Many of the axons are myelinated to increase the speed of the nerve impulse. During saltatory conduction, the nerve impulse jumps from node to node. The nerve impulse stimulates the release of neurotransmitters into the synaptic cleft; the transmitter diffuses across the synaptic cleft, binds to the postsynaptic receptor, and stimulates the dendrites of the second neuron. This is how information is transmitted from one neuron to the next.

BRAIN: STRUCTURE AND FUNCTION

You read a book, listen to music, sing a song, laugh, rage, remember, learn, feel, move, sleep, awaken, and so much more. All these are functions of the brain.

The brain is located in the cranial cavity. It is a pinkish-gray, delicate structure with a soft consistency. The surface of the brain appears bumpy, much like a walnut. The "boss of it all" weighs only 3 lb!

The blood supply to the brain is unique and is described in Chapter 18. Despite the fact that the brain weighs only 2% of the total body weight, it requires 20% of the body's oxygen supply. The primary source of energy for the brain is glucose. When blood glucose levels get very low (hypoglycemia), the person experiences mental confusion, dizziness, seizures, loss of consciousness, and death. No wonder that many of the body's hormones are concerned with making glucose available to the brain.

The brain is divided into four major areas: the cerebrum, the diencephalon, the brain stem, and the cerebellum (Figure 10-10).

CEREBRUM

The **cerebrum** (seh-REE-brum) is the largest part of the brain. It is divided into the right and left cerebral hemispheres. The cerebral hemispheres are joined together by bands of white matter that form a large fiber tract called the *corpus callosum*. The corpus callosum allows the right and left sides of the brain to communicate with each other. Each cerebral hemisphere has four major lobes: frontal, parietal, temporal, and occipital (Figure 10-11). These four lobes are named for the overlying cranial bones.

GRAY ON THE OUTSIDE, WHITE ON THE INSIDE

The cerebrum contains both gray and white matter. A thin layer of gray matter, called the *cerebral cortex*, forms the outermost portion of the cerebrum. The cerebral cortex is composed primarily of cell bodies and interneurons. The gray matter of the cerebral cortex allows us to perform higher mental tasks such as learning, reasoning, language, and memory.

The bulk of the cerebrum is composed of white matter located directly below the cortex. The white matter is composed primarily of myelinated axons that form connections between the parts of the brain and spinal cord. Scattered throughout the white matter are patches of gray matter called *nuclei*.

MARKINGS OF THE CEREBRUM

The lumpy, bumpy surface of the cerebrum has numerous markings with special names. The surface of the cerebrum is folded into elevations that resemble speed bumps on a road. The elevations are called *convolutions*, or *gyri* (sing., gyrus).

This extensive folding arrangement increases the amount of cerebral cortex, or thinking tissue. It is thought that intelligence is related to the amount of cerebral cortex and therefore to the numbers of convolutions or gyri. The greater the numbers of convolutions in the brain, the more intelligent the species. For example, the cerebral cortex of the human brain has many more convolutions than the brain of an elephant (except in the memory part of the brain). (Big bumps, big thoughts.)

Gyri are separated by grooves called *sulci* (sing., sulcus). A deep sulcus is called a *fissure*. Sulci and

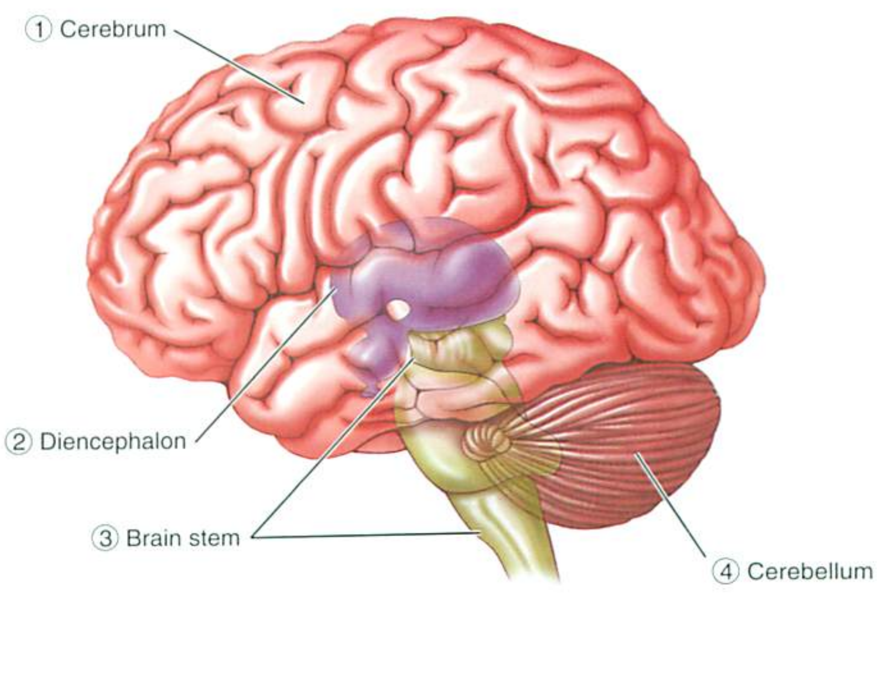


FIGURE 10-10 Four major areas of the brain: cerebrum, diencephalon, brain stem, and cerebellum.

fissures separate the cerebrum into lobes. Figure 10-11 illustrates two of the numerous sulci and fissures: the central sulcus and the lateral sulcus. (Identify each structure on the diagram as it is described in the text.)

The central sulcus separates the frontal lobe from the parietal lobe. The central sulcus is an important landmark, separating the precentral and postcentral gyri. The precentral gyrus is located in the frontal lobe,

Do You Know...

If You Are a Left-Brain or a Right-Brain Person?

Some years ago, a surgeon severed the corpus callosum in the brain of a patient with severe epilepsy. This surgical procedure eliminated all communication between the left and right cerebral hemispheres. From these and other experiments, neuroscientists learned that there is a left brain and a right brain, and that these two brains have different abilities. The differences in function between the two cerebral hemispheres is called *cerebral lateralization*. The left brain is more concerned with language and mathematical abilities; it is the reasoning and analytical side of the brain. The right side of the brain is far superior with regard to spatial relationships, art, music, and the expression of emotions. The right brain is intuitive; it is the poet and the artist. Many of us are predominantly left-brain or right-brain persons. How much richer our lives are when we use both sides of our brains!

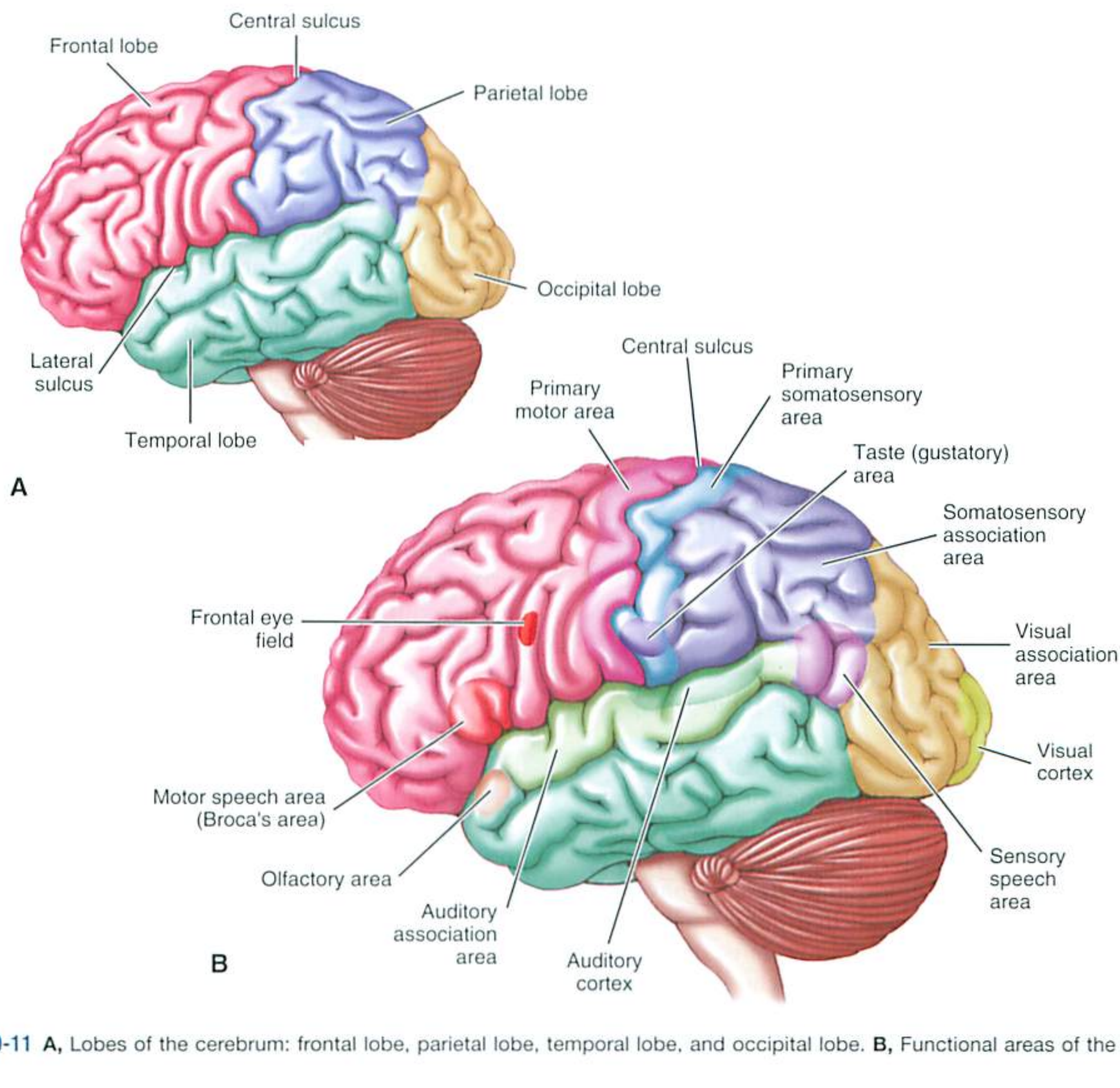


FIGURE 10-11 **A,** Lobes of the cerebrum: frontal lobe, parietal lobe, temporal lobe, and occipital lobe. **B,** Functional areas of the cerebrum.

Table 10-2 Brain Structure and Function

STRUCTURE	FUNCTIONS
Cerebrum	
Frontal lobe	Motor area, personality, behavior, emotional expression, intellectual functions ("executive" functions), memory storage
Parietal lobe	Somatosensory area (especially from skin and muscle; taste; speech; reading)
Occipital lobe	Vision, vision-related reflexes and functions (reading, judging distances, seeing in three dimensions)
Temporal lobe	Hearing (auditory area), smell (olfactory area), taste, memory storage, part of speech area
Diencephalon	
Thalamus	Relay structure and processing center for most sensory information going to the cerebrum
Hypothalamus	Integrating system for the autonomic nervous system; regulation of temperature, water balance, sex, thirst, appetite, and some emotions (pleasure and fear); regulates the pituitary gland and controls endocrine function
Brain Stem	
Midbrain	Relays information (sensory and motor); associated with visual and auditory reflexes
Pons	Relays information (sensory and motor); plays a role in respiration
Medulla oblongata	Vital function (regulation of heart rate, blood flow, blood pressure, respiratory centers); reflex center for coughing, sneezing, swallowing, and vomiting
Cerebellum	Smoothes out and coordinates voluntary muscle activity; helps in the maintenance of balance and muscle tone
Other Structures	
Limbic system	Experience of emotion and behavior (emotional brain)
Reticular formation	Mediates wakefulness and sleep; includes the reticular activating system (RAS)
Basal nuclei	Smoothes out and coordinates skeletal muscle activity

directly in front of the central sulcus, and the postcentral gyrus is located in the parietal lobe, directly behind the central sulcus. The lateral fissure separates the temporal lobe from the frontal and the parietal lobes. The longitudinal fissure separates the left and right cerebral hemispheres (not shown).

? Re-Think

1. What are the four major divisions of the brain?
2. What is the role of the corpus callosum?
3. In what cerebral lobe is the precentral gyrus? The postcentral gyrus?

LOBES OF THE CEREBRUM

What does each cerebral lobe do? (See Table 10-2.)

Frontal Lobe

The **frontal lobe** is located in the front of the cranium under the frontal bone (see Figure 10-11). The frontal lobe plays a key role in voluntary motor activity, personality development, emotional and behavioral expression, and performance of high-level tasks such as learning, thinking, and making plans; these are sometimes called *executive functions*. The frontal lobe contains the primary motor area. Nerve impulses that originate in the motor area control voluntary muscle movement. When you decide to move your leg, the nerve impulse originates in the precentral gyrus, or primary motor cortex, of the frontal lobe. The axons of these motor neurons form the voluntary motor tracts that descend down the spinal cord.

The function of the precentral gyrus of the frontal lobe is illustrated by a homunculus, meaning "little man" (Figure 10-12). The homunculus represents the amount of brain tissue that corresponds to a function of a particular body part. The homunculus shows two important points; each part of the body is controlled by a specific area of the cerebral cortex of the precentral gyrus, and the complicated nature of certain movements requires large amounts of brain tissue. (Locate the specific points for the toe, foot, leg, trunk, hand, and face.)

For example, the movements of the hand are much more delicate and complicated than the movements of the foot. Therefore, the amount of brain tissue devoted to hand and finger movement is much greater than the amount devoted to foot and toe movement. Consequently, the homunculus has huge hands and small feet. Note also the amount of brain tissue required to run your mouth.

In addition to its role in voluntary motor activity, the frontal lobe plays a key role in motor speech. Motor speech refers to the movements of the mouth and tongue necessary for the formation of words.

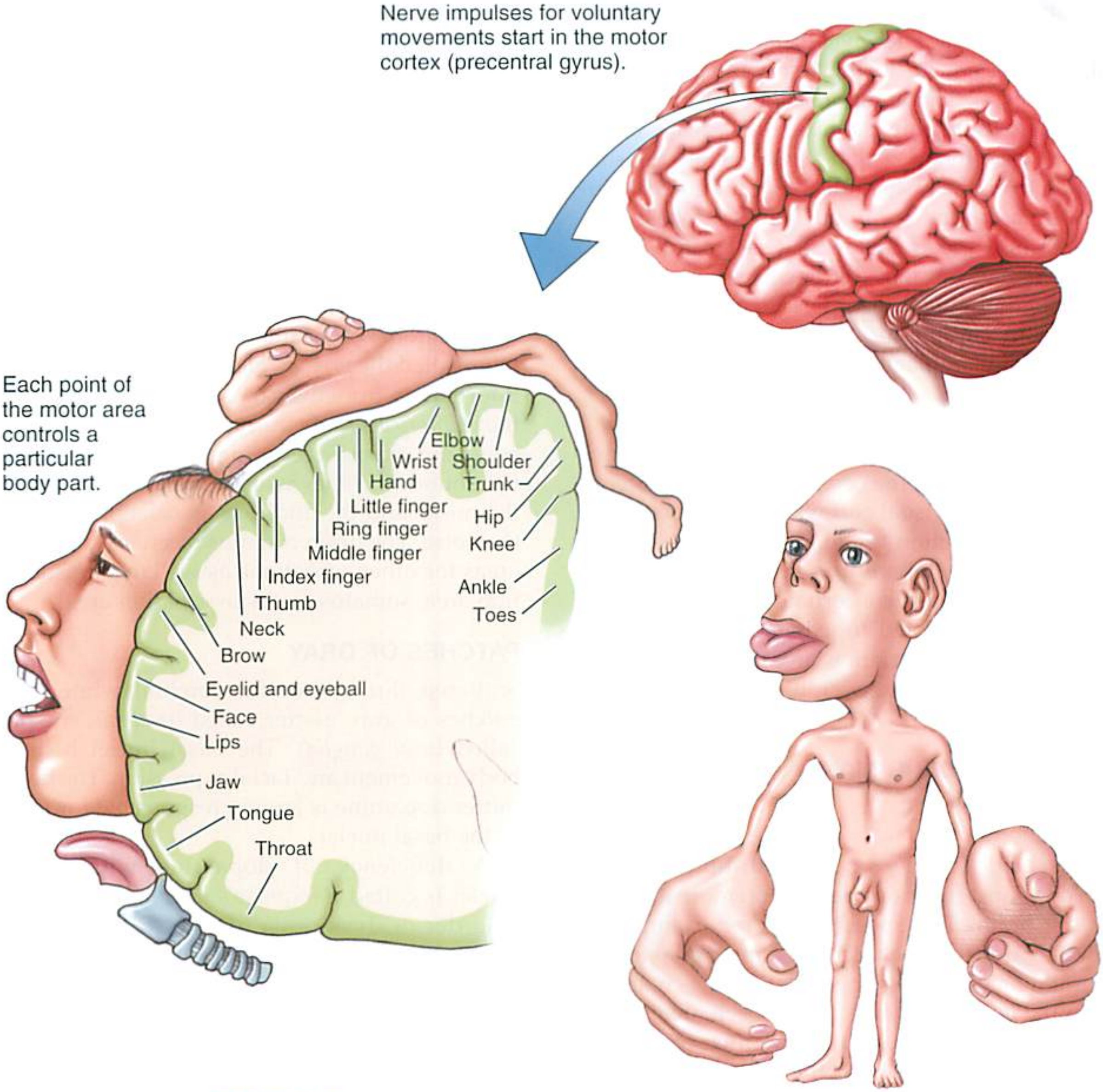


FIGURE 10-12 Motor area of the frontal lobe, illustrated with a homunculus.

The part of the frontal lobe concerned with motor speech is called *Broca's area*. In most persons, Broca's area is in the left hemisphere (see Figure 10-11). What happens when Broca's area is broken? If damaged, as happens with a stroke, the person develops a type of aphasia. The person knows what he or she wants to say but cannot say it. Just above Broca's area is an area called the *frontal eye field*. It controls voluntary movements of the eyes and the eyelids. Your ability to scan this paragraph is a function of this area.

? Re-Think

1. What are the functions of the frontal lobe? Of Broca's area? Of the frontal eye fields?
2. What information is attained from a homunculus?

Parietal Lobe

The **parietal lobe** is located posterior to the central sulcus (see Figure 10-11). The parietal lobe, particularly the postcentral gyrus, is primarily concerned with receiving general sensory information from the body. Because it receives sensations from the body, the parietal lobe is called the *primary somatosensory area*. This area receives information primarily from the skin and muscles and allows you to experience the sensations of temperature, pain, light touch, and proprioception (a sense of where your body is). The parietal lobe is also concerned with reading, speech, and taste. Like the motor homunculus in the precentral gyrus, a sensory homunculus can be drawn along the postcentral gyrus (not shown).

Temporal Lobe

The **temporal lobe** is located inferior to the lateral fissure in an area just above the ear. The temporal lobe contains the primary auditory cortex, the area that allows you to hear. It receives sensory information from the ears. Damage to the temporal lobe causes cortical deafness. The temporal lobe also receives sensory information from the nose; this area is called the *olfactory area,* the area that senses smell. Sensory information from the taste buds in the tongue is interpreted in both the temporal and parietal lobes. Wernicke's area is a broad region that is located in the parietal and temporal lobes; it is concerned with the translation of thought into words. Damage to this area, as occurs with chronic alcohol abuse, can result in severe deficits in language comprehension.

Occipital Lobe

The **occipital** (ok-SIP-it-al) **lobe** is located in the back of the head, underlying the occipital bone. The occipital lobe contains the visual cortex. Sensory fibers from the eye send information to the primary visual cortex of the occipital lobe, where it is interpreted as sight. The occipital lobe is also concerned with many visual reflexes and vision-related functions such as reading (through the visual association area). Damage to the primary visual cortex of the occipital lobe causes cortical blindness.

FUNCTIONS INVOLVING MANY CEREBRAL LOBES

Speech Area

Although specific functions can be attributed to each cerebral lobe, most functions depend on more than one area of the brain. The speech area, for example, is located in an area that includes the temporal, parietal, and occipital lobes. In most people, the speech area is located in the left hemisphere. The speech area allows you to understand words, whether written or spoken. When you have gathered your thoughts, Broca's area in the frontal lobe directs the muscles of the larynx, tongue, cheeks, and lips to speak.

Do You Know...

Why a Person Might "Neglect" Half of his Face?

A person with a lesion in the parietal lobe may become unaware of the opposite side of his body. For example, he may not recognize his left leg as his own. When shaving, he may shave only one side of his face. When dressing, he may dress only one side of his body. When eating, he may eat only foods on one side of his plate. This neurological condition is called *contralateral neglect syndrome.*

Other functions require input from more than one brain structure. The ability to read, for example, requires interpretation of the visual information by the occipital lobe. It also requires understanding of the words and the coordination of the eyes as they scan the page. A vast amount of brain tissue beyond the occipital lobe is involved in vision and vision-related functions such as reading.

? Re-Think

1. Identify the cerebral lobes concerned with these functions: vision, hearing, taste, smell, and speech.
2. Identify one consequence of damage to Wernicke's area.

ASSOCIATION AREAS

Large areas of the cerebral cortex are called *association areas* (see Figure 10-11). These areas are concerned primarily with analyzing, interpreting, and integrating information. For example, a small area of the temporal lobe, called the *primary auditory cortex,* receives sensory information from the ear. The surrounding area, called the *auditory association area,* uses a large store of knowledge and experience to identify and give meaning to the sound. In other words, the auditory cortex hears the noise, and the auditory association area interprets the noise. The brain contains receiving and association areas for other sensations as well (e.g., visual association area, somatosensory association area).

PATCHES OF GRAY

Scattered throughout the cerebral white matter are patches of gray matter called *basal nuclei* (sometimes called *basal ganglia*). The basal nuclei help regulate body movement and facial expression. The neurotransmitter dopamine is largely responsible for the activity of the basal nuclei.

A deficiency of dopamine within the basal nuclei is called *Parkinson's disease.* It is a movement disorder or dyskinesia (dis-kin-EE-see-ah). Because of the characteristic shaking (tremors), Parkinson's disease is sometimes called *shaking palsy.* Dopamine-producing drugs are usually prescribed to treat this condition.

DIENCEPHALON

The diencephalon (dye-en-SEF-ah-lon) is the second main area of the brain. It is located beneath the cerebrum and above the brain stem. The diencephalon includes the thalamus and the hypothalamus (Figure 10-13).

The thalamus serves as a relay station for most of the sensory fibers traveling from the lower brain and spinal cord region to the sensory areas of the cerebrum. The thalamus sorts out the sensory information, gives us a hint of the sensation we are to experience, and then directs the information to the specific cerebral areas for more precise interpretation. For example, pain fibers coming from the body to the brain pass through the thalamus. At the level of the thalamus, we become aware of pain, but we are not yet aware of the type of pain or the exact location of the pain. Fibers that transmit pain information from the thalamus to the cerebral cortex provide us with that additional information.

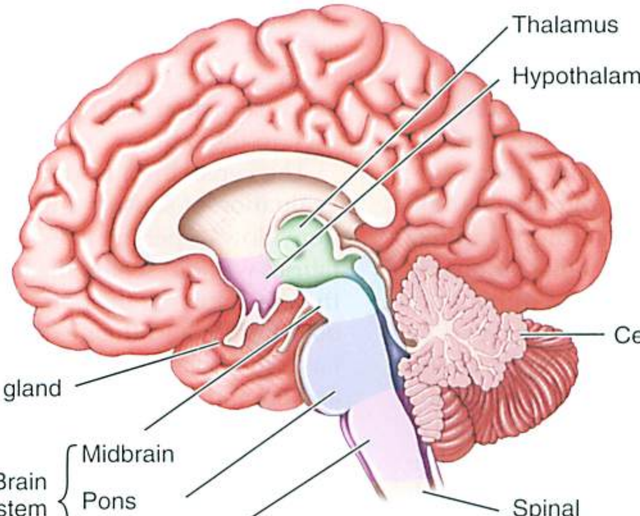


FIGURE 10-13 Diencephalon, brain stem, and cerebellum.

The **hypothalamus** is the second structure in the diencephalon. It is situated directly below the thalamus and helps regulate many body processes, including body temperature (thermostat), water balance, and metabolism. Because the hypothalamus helps regulate the function of the autonomic (involuntary) nerves, it exerts an effect on heart rate, blood pressure, and respiration.

Located under the hypothalamus is the pituitary gland. The pituitary gland directly or indirectly affects almost every hormone in the body. Because the hypothalamus controls pituitary function, the widespread effects of the hypothalamus are obvious. (The relationship of the hypothalamus to endocrine function is described in Chapter 14.)

? Re-Think

1. What role do association areas play? The basal nuclei?
2. What functions are influenced by the hypothalamus?

BRAIN STEM

The **brain stem** connects the spinal cord with higher brain structures. It is composed of the midbrain, pons, and medulla oblongata (see Figure 10-13). The white matter of the brain stem includes tracts that relay both sensory and motor information to and from the cerebrum. Scattered throughout the white matter of the brain stem are patches of gray matter called *nuclei*. These nuclei exert profound effects on functions such as blood pressure and respiration.

MIDBRAIN

The midbrain extends from the lower diencephalon to the pons. Like the rest of the brain stem structures, the midbrain relays sensory and motor information. The midbrain also contains nuclei that function as reflex centers for vision and hearing.

PONS

The pons (bridge) extends from the midbrain to the medulla oblongata. It is composed primarily of tracts that act as a bridge for information traveling to and from several brain structures. The pons also plays an important role in the regulation of breathing rate and rhythm.

MEDULLA OBLONGATA

The **medulla oblongata** (meh-DUL-ah oh-blohn-GAHT-ah) connects the spinal cord with the pons. The medulla acts as a relay for sensory and motor information. Several important nuclei within the medulla control heart rate, blood pressure, and respiration. Because of its importance with regard to vital functions, the medulla oblongata is called the *vital center*. Because these functions are vital to the body, you can understand the seriousness of a fracture at the base of the skull.

The medulla oblongata is also extremely sensitive to certain drugs, especially opioids such as morphine. An overdose of an opioid causes depression of the medulla oblongata and death because the person stops breathing. This danger is the reason for counting the respiratory rate before giving a patient an opioid. If the respiratory rate is less than 10 respirations per minute, the drug cannot be safely administered.

Do You Know...

How the Brain Tranquilizes Itself?

The brain produces natural morphine-like substances called *endorphins* (endogenous morphine) and *enkephalins* (meaning "in the head"). Like morphine, these substances bind to opiate receptors in the CNS, moderating pain, relieving anxiety, and producing a sense of well-being. The "high" experienced by joggers may be caused by endorphins and enkephalins.

Vomiting Center

The medulla oblongata contains the vomiting center, or emetic center (emesis refers to vomiting). The vomiting center can be activated directly or indirectly. Direct activation includes stimuli from the cerebral cortex (fear), stimuli from sensory organs (distressing sights, bad odors, pain), and signals from the equilibrium apparatus of the inner ear (spinning). Indirect stimulation of the vomiting center comes from the chemoreceptor trigger zone (CTZ) located in the floor of the fourth ventricle. The CTZ can be stimulated by emetogenic compounds, such as anticancer drugs and opioids. Signals from the digestive tract, especially the stomach, travel via the vagus nerve to the CTZ. The CTZ, in turn, activates the vomiting center. Antiemetic agents can work on both the CTZ and medullary vomiting center to relieve nausea and vomiting. The pharmacological management of vomiting is a common clinical problem. Another interesting point is that nausea, which usually precedes vomiting, is derived from the Greek word for "ship," as in seasickness.

? Re-Think

1. List the three parts of the brain stem.
2. Why is the medulla oblongata called the "vital center"?
3. Differentiate between the vomiting center and the CTZ.

CEREBELLUM

The **cerebellum** (sair-eh-BELL-um), the fourth major area, is the structure that protrudes from under the occipital lobe at the base of the skull (see Figure 10-13). The cerebellum is connected to the brain stem by three pair of cerebellar peduncles (sair-eh-BELL-ahr peh-DUN-kuls); these stalks or connections allow the cerebellum to receive, integrate, and deliver information to many parts of the brain and spinal cord. The cerebellum is concerned with the coordination of voluntary muscle activity. Information is sent to the cerebellum from many areas throughout the body, including the eyes, ears, and skeletal muscles. The cerebellum integrates all the incoming information to produce a smooth, coordinated muscle response. Damage to the cerebellum produces jerky muscle movements, staggering gait, and difficulty maintaining balance or equilibrium. The person with cerebellar dysfunction may appear intoxicated. To help diagnose cerebellar dysfunction, the physician may ask the person to touch the tip of his or her nose with a finger. Why? The cerebellum normally coordinates skeletal muscle activity. In attempting to touch the nose, a patient with cerebellar dysfunction may overshoot, first to one side and then to the other.

The cerebellum also plays an important role in the evaluation of sensory input. For example, the cerebellum allows a person to evaluate the texture of different fabrics without seeing the fabric. It also "times" events, thereby allowing the person to predict where a moving object will be in the next few seconds. For example, a basketball player has a keen sense of where the ball is and should be in the next dribble or two. And, most of us can rhythmically drum our fingers on a desk—a task that is impaired in someone with cerebellar dysfunction.

Do You Know...

Where and Why There Is a Tent in Your Brain?

At several areas in the brain, the dura mater forms rigid membranes that separate and support parts of the brain. One such membrane is the tentorium cerebelli; it forms a tentlike membrane over the cerebellum, separating it from the upper cerebral structures. The tentorium also functions as a common landmark in the brain. Brain tumors are classified according to their locations; those that occur in structures located above the tentorium are called *supratentorial brain tumors*, and those occurring below the tentorium are called *infratentorial brain tumors*. An increase in intracranial pressure can force the brain downward past the tentorium, causing life-threatening symptoms. The displacement is called *tentorial herniation*.

? Re-Think

Locate and list two functions of the cerebellum.

STRUCTURES ACROSS DIVISIONS OF THE BRAIN

Three important structures are not confined to any of the four divisions of the brain because they "overlap" several areas. These structures are the limbic system, the reticular system, and the memory areas.

LIMBIC SYSTEM: THE EMOTIONAL BRAIN

Parts of the cerebrum and the diencephalon form a wishbone-shaped group of structures called the *limbic system*. The **limbic system** functions in emotional states and behavior. For example, when the limbic system is stimulated by electrodes, states of extreme pleasure or rage can be induced. Because of these responses, the limbic system is called the *emotional brain*.

RETICULAR FORMATION: WAKE UP!

What keeps us awake? Why don't we slip into a coma when we go to sleep? Extending through the entire brain stem, with numerous connections to the cerebral cortex, is a special mass of gray matter called the **reticular formation**. The reticular formation is concerned with the sleep–wake cycle and consciousness. Signals passing up to the cerebral cortex from the reticular formation stimulate us, keeping us awake and tuned in.

Other nuclei within the reticular formation include the gaze centers (allow the eyes to track an object) and special groups of cells that rhythmically send signals to the muscles that control breathing and swallowing. The reticular formation is also concerned with habituation, the process whereby the brain learns to ignore repetitive background information. For example, a parent may ignore the background noise of children playing and horns honking, but responds immediately to a crying child. Similarly, while driving a car, you ignore much of the background visual information, but are aware of traffic signals, nearby cars and, hopefully, any oncoming vehicles.

The reticular formation is very sensitive to the effects of certain drugs and alcohol. For example, the dangerous combination of benzodiazepines (tranquilizers) and alcohol can damage the reticular formation, causing permanent unconsciousness.

Consciousness, Sleep, and Coma

Consciousness is a state of wakefulness and is dependent on the reticular activating system (RAS). The RAS continuously samples sensory information from all over the body and then selects and presents essential, unusual, and threatening information to the higher structures in the cerebral cortex. The different levels of consciousness include attentiveness, alertness, relaxation, and inattentiveness. Sleep occurs when the RAS is inhibited or slowed. What causes sleep? In the sixth century BC, it was believed that sleep was caused by a temporary retreat of blood from the brain. Death was attributed to the permanent retreat of blood from the brain. As to the cause of sleep? We still do not know. What we do know is that neurotransmitters are replenished during sleep. We also know that most Americans do not get enough sleep (most adults require 7 to 8 hours of sleep) and that sleep deprivation is linked to numerous health problems, such as obesity, diabetes mellitus, and hypertension.

Coma is a hyporesponsive state with several stages, ranging from light to deep coma. In the lightest stages of coma, some reflexes are intact; the patient may respond to light, sound, touch, and painful stimuli. As the coma deepens, however, these reflexes are gradually lost, and the patient eventually becomes unresponsive to all stimuli. Damage to the reticular formation is associated with a state of deep coma, which can be permanent.

Many clinical conditions affect level of consciousness (LOC), often leading to coma. These include brain tumors, brain injury, drugs, toxins, hypoxia, hyperglycemia, acid-base imbalance, and electrolyte imbalance. As a clinician, you must be able to assess the patient's LOC.

? Re-Think

1. Locate the limbic system and explain why it is called the "emotional brain."
2. State a major role of the reticular activating system.
3. Why is LOC evaluated?

Stages of Sleep

The two types of sleep are non–rapid eye movement (NREM) sleep and rapid eye movement (REM) sleep. The four stages of NREM sleep progress from light to deep. In a typical 8-hour sleep period, a person regularly cycles through the various stages of sleep, descending from light to deep sleep and then ascending from deeper sleep to lighter sleep.

REM sleep is characterized by fluctuating blood pressure, respiratory rate and rhythm, and pulse rate. The most obvious characteristic of REM sleep is rapid eye movements, for which the sleep segment is named. REM sleep totals 90 to 120 minutes per night; most dreaming occurs during REM sleep. For unknown reasons, REM sleep deprivation is associated with mental and physical distress. Most sedatives and CNS depressants adversely affect REM sleep, perhaps accounting for that "hangover" feeling that often follows their use.

Do You Know...

About Chemo Fog?

We all know that many drugs exert profound effects on the brain. There is the euphoria of opioids, the hallucinogenic effects of LSD, the "buzz" of methamphetamines, the sedation of antihistamines, and the list goes on. For many years, breast cancer survivors have complained of (while being ignored) the lingering effects of their cancer chemotherapy. Many noted difficulty with memory, attention span, retrieving words, multitasking, and clarity of thought. (One woman filled the water glasses with turkey gravy at a Thanksgiving Day dinner.) They complained of "living in a fog"—hence, the term *chemo fog* or *chemobrain*. Chemo fog is real and lingers for many months, even years, after the chemo has ended! Today it has a new respectable name: *postchemotherapy cognitive impairment*, or *postchemotherapy cognitive dysfunction*.

MEMORY AREAS

Memory is the ability to recall thoughts and images. Many areas of the brain are concerned with memory. There are three categories of memory: immediate memory, short-term memory, and long-term memory. Immediate memory lasts for a few seconds. An example of your immediate memory is your ability to remember the words in the first part of the sentence so that you can get the thought of the entire sentence. Short-term memory lasts for a short period (seconds to a few hours). It allows you to recall bits of information, such as the price of those new jeans or a phone number that you looked up. Unfortunately, cramming for exams falls into this category—short-term memorization, 5-second retention, and then—BLANK. Long-term memory lasts much longer—years, decades, or lifetime. If you continuously use the new address or phone number, you will enter that information into your long-term memory. The same effect is achieved when you study over a longer period. Another interesting point: although memory is important, forgetting is also important. Imagine all the trivial information that you take in every second. Think of the many stones, trees, birds, street signs, and other things that you pass on your way to work. Persons who have difficulty in forgetting trivia have a great deal of difficulty in comprehension and in remembering things that need to be remembered.

? Re-Think

1. What is REM sleep?
2. List the three categories of memory. Explain why "cramming" for an exam is an ineffectual learning process.

Do You Know...

Why People in Ancient Times Bored Holes in the Skull?

Trephination refers to the drilling of holes into the skull for the purpose of reducing intracranial pressure. Today, it is performed in the operating room under sterile conditions; the surgically drilled holes are called *burr holes*. People in ancient times also performed trephination procedures. The patient sat on a log while the priest chipped a hole in the skull using a sharp stone. Ouch! It was thought that trephination could relieve headaches and release the devils of madness.

PROTECTING THE CENTRAL NERVOUS SYSTEM

The tissue of the CNS (brain and spinal cord) is very delicate. Injury to CNS neuronal tissue cannot be repaired. Thus, the CNS has an elaborate protective system that consists of four structures: bone, meninges, cerebrospinal fluid, and the blood–brain barrier.

BONE: FIRST LAYER OF PROTECTION

The CNS is protected by bone. The brain is encased in the cranium, and the spinal cord is encased in the vertebral column.

MENINGES: SECOND LAYER OF PROTECTION

Three layers of connective tissue surround the brain and spinal cord (Figure 10-14). These tissues are called the **meninges** (meh-NIN-jeez). The outermost layer is a thick, tough, connective tissue called the *dura mater*, literally meaning "hard mother." Inside the skull, the dural membrane splits to form the dural sinuses. These sinuses are filled with blood. Beneath the dura mater is a small space called the *subdural space*. The middle layer is the arachnoid (ah-RAK-noyd) mater (meaning "spider-like"), so-named because the membrane looks like a spider web.

The pia mater is the innermost layer and literally means soft, or gentle, mother. The pia mater is a very thin membrane that contains many blood vessels and lies delicately over the brain and spinal cord. These blood vessels supply the brain with much of its blood. Between the arachnoid layer and the pia mater is a space called the *subarachnoid space*. A fluid called the **cerebrospinal fluid (CSF)** circulates within this space and forms a cushion around the brain and spinal cord. If the head is jarred suddenly, the brain first bumps into this soft cushion of fluid. Specialized projections of the arachnoid membrane, called the *arachnoid villi* (sing., villus), protrude up into the blood-filled dural sinuses and are involved in the drainage of the CSF (described in the next section).

Remember—the meninges form a brain **PAD** (noting that the brain is closer to pia, the softer mother):

P **p**ia mater
A **a**rachnoid mater
D **d**ura mater

The meninges can become inflamed or infected, causing meningitis. Meningitis is serious because the infection can spread to the brain, sometimes causing serious, irreversible brain damage. The bacterial or viral organism causing the meningitis can often be found in a sample of CSF obtained by lumbar puncture.

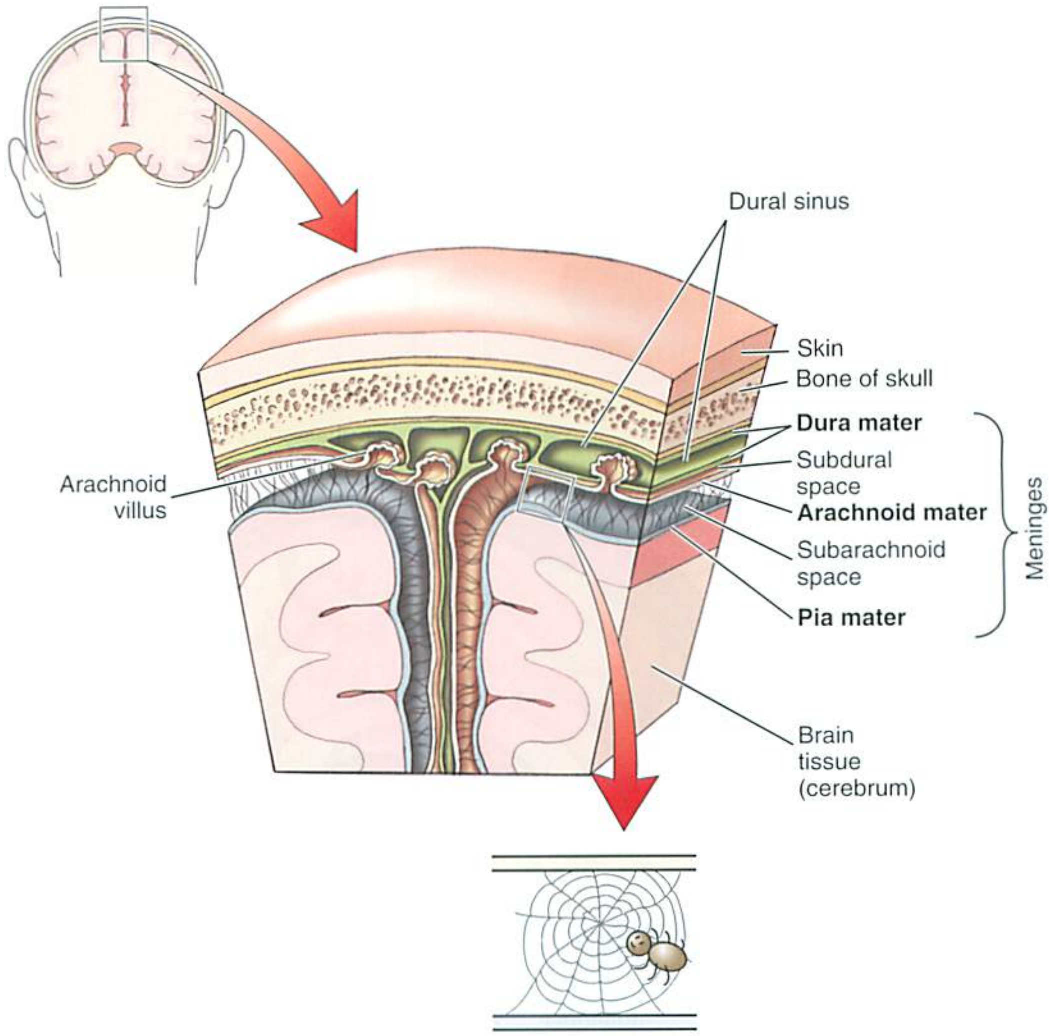


FIGURE 10-14 Three layers of meninges: the dura mater, arachnoid mater, and pia mater.

CEREBROSPINAL FLUID: THIRD LAYER OF PROTECTION

The CSF forms a third protective layer of the CNS. CSF is formed from the blood within the brain. It is a clear fluid that looks like clear soda and is similar in composition to plasma. The CSF is composed of water, glucose, protein, and several ions, especially Na^+ and Cl^-. An adult circulates about 130 mL of CSF; 500 mL is formed every 24 hours, so that CSF is replaced every 8 hours. In addition to its protective function, CSF also delivers nutrients to the CNS and removes waste.

Where is CSF formed? CSF is formed within the ventricles of the brain by a structure called the *choroid plexus* (Figure 10-15). The four ventricles are two lateral ventricles and a third and fourth ventricle. The choroid plexus, a grapelike collection of blood vessels and ependymal cells (see Table 10-1), is suspended from the roof of each ventricle. Water and dissolved substances are transported from the blood across the walls of the choroid plexus into the ventricles (see Figure 10-15).

Where does the CSF flow? As CSF leaves the ventricles, it follows two paths. Some of the CSF flows through a hole in the center of the spinal cord called the *central canal*. The central canal eventually drains into the subarachnoid space at the base of the spinal cord. The rest of the CSF flows from the fourth ventricle laterally through tiny holes, or foramina, into the subarachnoid space that encircles the brain.

How does the CSF leave the subarachnoid space? Eventually, CSF flows into the arachnoid villi; water and waste diffuse from CSF in the arachnoid villi into the blood of the dural sinuses. Blood then flows from the dural sinuses into the cerebral veins and back to the heart. Remember that the CSF is formed across the walls of the choroid plexus within the ventricles, circulates throughout the subarachnoid space around the brain and spinal cord, and then drains into the dural sinuses. The rate at which CSF is formed must equal the rate at which it is drained. If excess CSF is formed or drainage is impaired, CSF will accumulate in the ventricles of the brain, increasing the pressure within the skull. The resulting increase in intracranial pressure can cause brain damage and death.

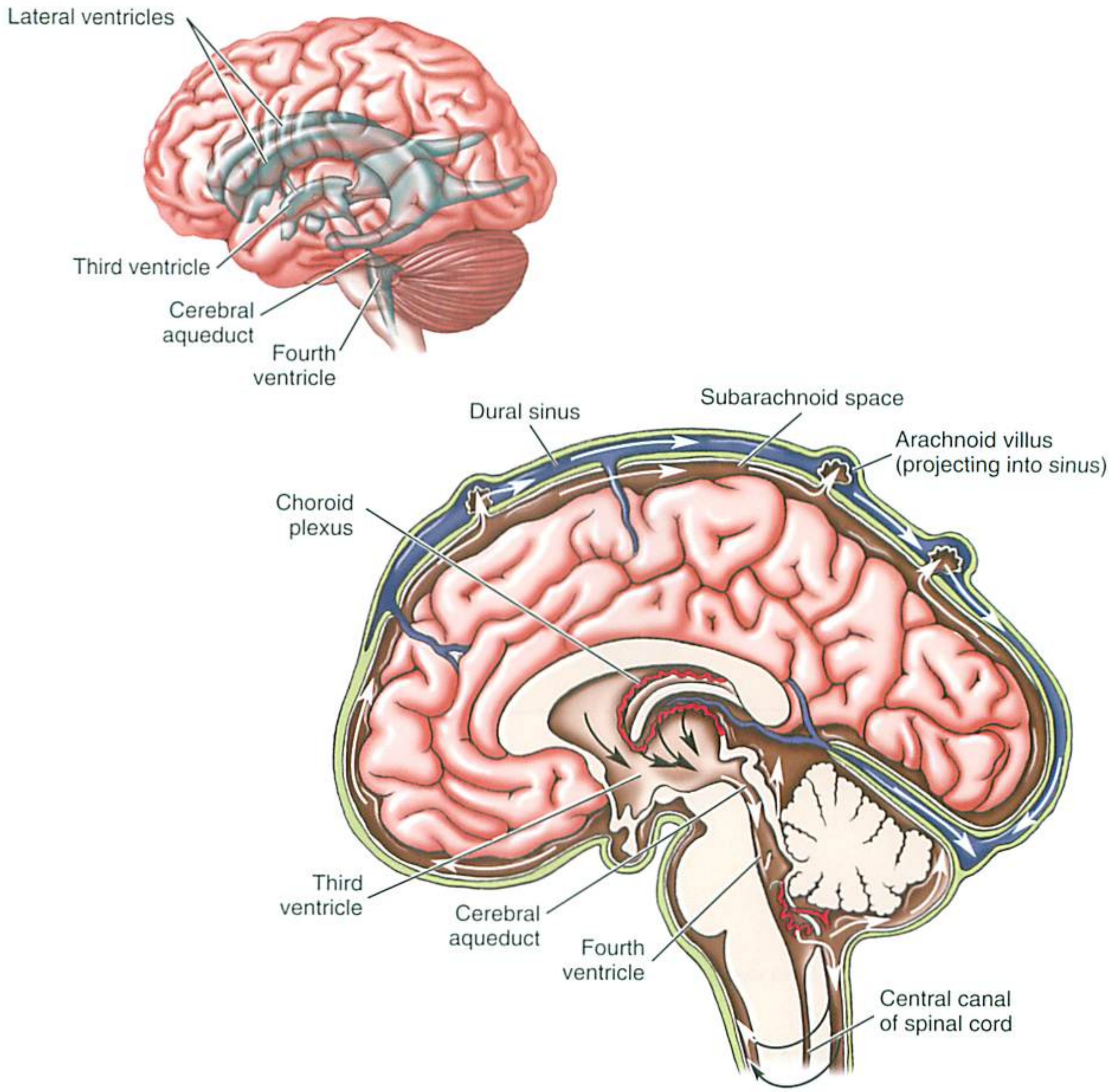


FIGURE 10-15 Cerebrospinal fluid: formation (choroid plexus in ventricles), circulation within the subarachnoid space, and drainage (arachnoid villus and dural sinus).

Do You Know...

Why an Infant May Develop Water on the Brain?

Occasionally, a newborn infant is born with an obstruction (e.g., tumor) in the ventricular system of the brain. Cerebrospinal fluid (CSF) is formed at a normal rate but cannot be drained because of the obstruction. The fluid accumulates within the ventricles, thereby increasing intracranial pressure and causing the skull to enlarge. This condition is called *hydrocephalus* (water on the brain). Head expansion in the infant is possible because the suture lines of the skull bones have not yet fused. If an obstruction were to occur in an older child or adult, the intracranial pressure would increase. The skull, however, could not expand because of the fused sutures. Without surgical intervention or the use of a shunt that bypasses the obstruction, the increased pressure would result in death.

Do You Know...

What a Little Red Worm's Doing in Your Brain?

In the 1300s, an anatomist claimed that mental function was controlled by a red worm. The worm referred to the fleshy choroid plexus of the ventricles of the brain. The plexi allegedly controlled brain functions by wiggling back and forth and modifying the flow of cerebrospinal fluid, which was supposed to contain the animal spirit. Several things have since been cleared up; mental function is the result of neuronal activity and not the flow of animal spirit, and the choroid plexus secretes cerebrospinal fluid and does not wiggle and shake. There is, however, a little red worm—the choroid plexus—and it is located in the ventricles of your brain where it secretes CSF.

? Re-Think

1. Trace the formation, flow, and drainage of cerebrospinal fluid.
2. What is the consequence of obstructed drainage of CSF?

BLOOD–BRAIN BARRIER: FOURTH LAYER OF PROTECTION

The blood–brain barrier is an arrangement of cells, particularly the glial astrocytes and the selectively permeable capillary cells; they act as a barrier to the movement of potentially harmful chemicals into the CNS. The astrocytes and the capillary cells select the substances allowed to enter the CNS from the blood. For example, oxygen, glucose, and certain ions readily cross the membrane. However, if a potentially harmful substance is present in the blood, the cells of the blood–brain barrier prevent that substance from entering the brain and the spinal cord.

Although the blood–brain barrier is successful in screening many harmful substances, not all toxic substances are blocked. Alcohol, for example, crosses the blood–brain barrier and affects brain tissue.

The blood–brain barrier may present a problem in the pharmacological treatment of infections within the CNS. Most antibiotics, for example, cannot cross the blood–brain barrier and therefore cannot reach the site of infection. Given this problem, how is an infection of the CNS treated? The two options are to select an antibiotic that does cross the blood–brain barrier or inject the antibiotic directly into the subarachnoid space; this mode of drug delivery is called an *intrathecal injection*.

2+2 Sum It Up!

The CNS, especially the brain, performs eloquently as a conductor. It coordinates the various organ systems of the body efficiently, with fine precision. The brain makes us humans—that is, thinking, caring, feeling, remembering persons. The brain is divided into four regions: the cerebrum, diencephalon, brain stem, and cerebellum. The cerebrum is the largest part of the brain and has four lobes: frontal, parietal, temporal, and occipital. The diencephalon is composed of the thalamus and the hypothalamus. The brain stem is composed of the midbrain, pons, and medulla oblongata. The medulla oblongata is considered the vital structure in that it affects basic functions such as respiration, cardiac function, and blood vessel tone. Three other areas are the reticular formation, which keeps us awake; the limbic system (emotional brain); and the memory areas. Because of the crucial role played by the CNS, it is afforded excellent protection—that is, bone, three layers of meninges, a soft cushion of fluid, and a blood–brain barrier.

? Re-Think

What effect may the blood–brain barrier have on drug distribution?

As You Age

1. Beginning at the age of 30, the number of neurons decreases. The number lost, however, is only a small percentage of the total number of brain cells and does not cause mental impairment. Although a decrease in short-term memory may cause some forgetfulness, most memory, alertness, intellectual functioning, and creativity remain intact. Severe alteration of mental functioning is generally caused by age-related diseases such as arteriosclerosis.
2. Impulse conduction speed decreases along an axon, amounts of neurotransmitters are reduced, and the number of receptor sites decreases at the synapses. These changes result in progressive slowing of responses and reflexes.

MEDICAL TERMINOLOGY AND DISORDERS Disorders of the Brain

Medical Term	Word Parts	Word Part Meaning or Derivation	Description
Words			
meninges		From a Latin word meaning "membrane"	The **meninges** are *the three membranes that form the outer lining of the brain and spinal cord.* The Arabians referred to these membranes as *mater* (mother) because they believed these membranes were the "mother" of all membranes.
neurology	neur/o-	nerve	**Neurology** is *the study of the structure, function, and organic disorders of the nervous system.*
	-logy	study of	
polarize		From a French word meaning a "division within a group"	*Refers to a separation of electrical charge.* A **polarized** nerve cell has a negative charge on the inside of the cell membrane and a positive charge on the outside of the cell membrane. The electric charge of a **depolarized** (*de* = away from) cell becomes positive. A **repolarized** (*re* = again) cell has returned to an internal negative charge.
synapse	syn-	together	A **synapse** is *a junction or meeting place for two neurons.* The axon of one neuron interacts chemically at a **synapse** with the dendrite of a second neuron.
	-apse	From a Greek word, *haptein*, meaning "to clasp"	
Disorders			
cephalgia	cephal/o-	head	*Pain in the head or headache.* An example is the **migraine headache,** a severe, recurring headache that usually affects only one side of the head. (Migraine comes from the Latin *hemicranium,* meaning "one side of the head.") A simple **tension headache** may develop when a person is anxious or tense. Headaches may also develop secondarily in response to increased intracranial pressure (e.g., brain tumor), irritation of the meninges, or spasm of the cerebral blood vessels. **Cluster headaches** occur in cyclical patterns and are called "alarm clock headaches" because they often awaken the person with intense and sharp pain in and around one eye.
	-algia	pain	
cerebrovascular accident (CVA)			Called a **CVA, stroke,** or **brain attack.** A CVA is caused by a sudden lack of blood, causing oxygen deprivation and brain damage. Depending on the location and severity of the brain damage, a CVA can result in loss of sensory and motor function and speech impairment. The patient often experiences **hemiparalysis** (hemi- = half) and **hemiparesis.** In addition to loss of motor function, the patient experiences various types of **aphasia** (a- = without; phas/o = speech), *an impairment of language.* Prior to suffering a stroke, many persons will have experienced a **transient ischemic attack** (TIA), or *mini stroke.* During a TIA, blood flow to the brain is temporarily stopped or diminished.
dementia	de-	without	Originally from the Latin meaning "madness." **Dementia** is not a single disease, but *a group of symptoms affecting intellectual and social abilities to the extent that daily living is impaired.* There is a serious loss of cognitive ability, with impairment of language, problem solving, memory, attention, and judgment. Behavior may be disorganized, restless, and inappropriate. **Static dementia** is commonly caused by traumatic brain injury. **Progressive dementia** refers to a long-term decline and is caused by chronic conditions such as Alzheimer's disease, multiple sclerosis, and small or mini strokes **(vascular dementia).**
	-ment/o-	mind	
	-ia	condition of	

MEDICAL TERMINOLOGY AND DISORDERS Disorders of the Brain—cont'd

Medical Term	Word Parts	Word Part Meaning or Derivation	Description
dyskinesias	dys- -kinesi/o- -ia	difficulty movement condition of	*Any medical disorder that is characterized by diminished voluntary muscle control (a movement disorder).* This broad term includes Parkinson's disease, Tourette's syndrome (muscle tics, verbal outbursts, sometimes profanity), chorea ("dance-like" muscle contractions that begin in one part of the body [toe] and work their way to another part [leg]), athetosis (graceful but purposeless movements primarily of the extremities), and asterixis ("flapping tremor" of the wrists). The term **dyskinesia** also includes many dystonias (impaired muscle tone), sustained muscle contractions that twist or contort the body. Some types of dyskinesias are localized, as in torticollis (lateral flexion of the neck caused by muscle spasm), whereas others are generalized, as in epileptic seizures. Tardive dyskinesias (TDs), often a result of antipsychotic drug therapy and dopaminergic antagonists, are characterized by involuntary movement of the lips (lip smacking), tongue (tongue rolling, protrusions), face, trunk, and extremities. Drug-induced TDs are usually irreversible.
encephalopathy	en- -cephal/o- -path/o- -y	within head disease condition or process	*A broad term that refers to disease, damage, or dysfunction of the brain.* There are more than 150 types. The term **encephalopathy** is often described by its cause. **Anoxic encephalopathy** is due to a lack of oxygen, whereas **hepatic encephalopathy** is a response to liver disease. Chronic and excessive ingestion of alcohol causes irreversible injury to the nervous system. The result is mental deterioration, loss of memory, inability to concentrate, irritability, and uncoordinated movement. **Wernicke-Korsakoff syndrome** is an alcohol-related type of encephalopathy.
epilepsy	epi-	upon From a Latin word meaning "seized upon" (by the gods)	Historically referred to as the "sacred disease" by the ancients because they believed that epilepsy was a punishment for offending the gods. Epilepsy is a group of neurological disorders that all present with spontaneous seizure activity. Neurons in the brain fire suddenly, unpredictably, and repetitively, creating "electrical storms" in the brain. Although most cases of epilepsy are idiopathic (arising spontaneously; unknown) in origin, many underlying conditions cause seizure activity: brain tumors, toxins, trauma, fever **(febrile seizures),** and emotional stress. Epileptic seizures are classified as primarily generalized seizures (widespread electrical storm including both sides of the brain) and partial seizures (more limited brain involvement and localized responses). There are many types of seizures, two of which are **tonic-clonic seizures** (grand mal) and **absence seizures** (petit mal). **Grand mal** (big bad) seizures are described as tonic-clonic. The tonic phase of a grand mal seizure occurs when the motor areas fire repetitively, causing muscle stiffening, and loss of consciousness. The clonic phase is characterized by jerking activity. **Status epilepticus,** a medical emergency, refers to the failure of the seizures to resolve or to the rapid succession of seizure activity. **Petit mal** (small bad) seizures occur when sensory areas are affected, causing a brief period (5-15 sec) of altered consciousness. Petit mal seizures are not accompanied by generalized stiffening or prolonged unconsciousness and are often unnoticed. Epileptic seizures are described by the term **ictus.**
glioma	gli/o- -oma	glue tumor	**Glioma** is *the most common type of primary brain tumors in adults.* They arise from glial tissue, most commonly astrocytic (star-shaped) tissue (astrocytoma). The second most common brain tumor is a **meningioma,** arising from the meninges. Brain tumors can be malignant or benign.

Continued

MEDICAL TERMINOLOGY AND DISORDERS Disorders of the Brain—cont'd

Medical Term	Word Parts	Word Part Meaning or Derivation	Description
head injury			*Due to trauma of the head, and may or may not involve the brain.* A **traumatic brain injury** (TBI) occurs when an external force traumatically injures the brain. TBI is a major cause of death and disability worldwide. Initially, brain injury is due to direct impact or by acceleration/deceleration alone; additional injury is sustained secondarily by injury-induced diminishment of blood flood and increases in intracranial pressure. A mechanism-related classification system divides TBIs into closed and penetrating head injuries. A **closed head injury** occurs when the brain is not exposed, as in blunt trauma. A **penetrating (open) head injury** occurs when the penetrating object pierces the dura mater. Depending on its severity and location, TBI causes numerous deficits: physical, emotional, social, and cognitive. Trauma to the head can cause bleeding and the formation of a **hematoma,** *a swelling or tumor formed by a collection of blood.* An **epidural hematoma** forms between the dura mater and the skull. A **subdural hematoma** forms under the dura mater.
hydrocephalus	hydro- -cephal/o-	water head	Called "water on the brain." There is an abnormal accumulation of cerebrospinal fluid (CSF) within the cerebral ventricles that can cause enlargement of the cranium. The clinical presentation is dependent on chronicity and age. There is also a **normal pressure hydrocephalus** (NPH), which develops more gradually in the elderly and is characterized by intermittent episodes of increased intracranial pressure.
infection		From the Latin word *inficere,* meaning transmission of disease by agency of air or water	The brain can be infected by a large number of microorganisms, most commonly bacteria and viruses. The pathogens cause inflammation of the surrounding tissue. **Encephalitis** is *inflammation of the brain itself.* **Meningitis** is *inflammation of the meninges.* A **brain abscess** is *a collection of infectious material within the brain.* Globally, bacterial meningitis is a major health concern in children. African children living in the "meningitis belt" are particularly vulnerable.
neurotoxin	neur/o- -tox/o-	nerve poison	*Any natural or artificial toxic substance that is toxic or harmful to nervous tissue.* Commonly encountered neurotoxins include chemotherapeutic drugs, organic solvents, pesticides, cosmetics, heavy metals, alcohol ingestion, and exposure to radiation. There are some naturally occurring neurotoxins, including beta-amyloid and glutamate.
palsy			A generalized term that refers to a loss of motor function. Three types of palsy are cerebral palsy, Bell's palsy, and brachial palsy (Erb's palsy). **Cerebral palsy** (CP), also called **spastic paralysis,** is a consequence of brain injury most often occurring in response to anoxic conditions around birth. All persons with CP experience muscle tightness and spasm causing limitations in muscle movement. **Bell's palsy** is due to inflammation or injury to the facial nerve (CN VII). **Brachial palsy** is usually caused by damage to the brachial plexus during a traumatic birth experience.
Parkinson's disease		Named after J. Parkinson, an English professor who wrote extensively about the disease	Called "shaking palsy." **Parkinson's disease** (PD) is *a dyskinesia that is classified as a movement disorder; it is due to diminished dopaminergic cell activity in the basal ganglia.* PD is characterized by tremors (rest tremors) or shaking of the extremities, especially the hands and jaw; rigidity (muscle stiffness), **akinesia** (inability to initiate voluntary movement), **bradykinesia** (slow voluntary movement), stooped posture, shuffling or freezing gait, poor balance, slow speech, and drooling. Cognitive abilities are generally preserved. **Parkinsonism** is a broad term that refers to disorders that present with similar symptoms. For instance, prolonged use of antipsychotic drugs and brain injuries sustained by boxers cause symptoms similar to PD.

Get Ready for Exams!

Summary Outline

The purpose of the nervous system is to bring information to the central nervous system, interpret the information, and enable the body to respond to the information.

I. The Nervous System: Overview

A. Divisions of the nervous system
1. The central nervous system (CNS) includes the brain and the spinal cord.
2. The peripheral nervous system includes the nerves that connect the CNS with the rest of the body.

B. Cells that make up the nervous system
1. Neuroglia (glia) support, protect, and nourish the neurons.
2. Neurons conduct the nerve impulse.
3. The three parts of a neuron are the dendrites, cell body, and axon.

C. Types of neurons
1. Sensory, or afferent, neurons carry information toward the CNS.
2. Interneurons are located in the CNS (make connections).
3. Motor, or efferent, neurons carry information away from the CNS toward the periphery.

D. White matter and gray matter
1. White matter is the result of myelinated fibers.
2. Gray matter is composed primarily of cell bodies, interneurons, and unmyelinated fibers.
3. Clusters of cell bodies (gray matter) are called *nuclei* and *ganglia*.

II. The Neuron Carrying Information

A. Nerve impulse
1. The electrical signal is called the *action potential* or *nerve impulse*.
2. The nerve impulse is caused by the following changes in the neuron: polarization, depolarization, and repolarization.
3. The nerve impulse results from the flow of ions: polarization (outward leak of K^+), depolarization (influx of Na^+), and repolarization (outward flux of K^+).
4. The nerve impulse jumps from node to node as it travels along a myelinated fiber. Myelination increases the speed of the nerve impulse.
5. The nerve impulse causes the release of the neurotransmitter at the synapse.

B. Synapse
1. The synapse is a space between two neurons.
2. The nerve impulse of the first (presynaptic) neuron causes the release of neurotransmitter into the synaptic cleft. The neurotransmitter diffuses across the synaptic cleft and binds to the receptors on the second (postsynaptic) membrane. The activation of the receptors stimulates a nerve impulse in the second neuron.

III. Brain: Structure and Function

A. Cerebrum
1. The right and left hemispheres are joined by the corpus callosum.
2. The four main cerebral lobes are the frontal, parietal, temporal, and occipital lobes. Functions of each lobe are summarized in Table 10-2.
3. Large areas of the cerebrum, called *association areas,* are concerned with interpreting, integrating, and analyzing information.

B. Diencephalon
1. The thalamus is a relay station for most sensory tracts traveling to the cerebrum.
2. The hypothalamus controls many body functions such as water balance, temperature, and the secretion of hormones from the pituitary gland. It exerts an effect on the autonomic nervous system.

C. Brain stem
1. Brain stem: midbrain, pons, and medulla oblongata
2. The medulla oblongata is called the *vital center* because it controls the heart rate, blood pressure, and respirations (the vital functions).
3. The vomiting center is located in the medulla oblongata; it receives input directly and indirectly from activation of the chemoreceptor trigger zone (CTZ).

D. Cerebellum
1. The cerebellum is sometimes called the *little brain*.
2. The cerebellum is concerned primarily with the coordination of voluntary muscle activity.

E. Structures involving more than one lobe
1. The limbic system is sometimes called the *emotional brain*.
2. The reticular formation is concerned with the sleep–wake cycle. It keeps us conscious and prevents us from slipping into a coma state.
3. The memory areas handle immediate, short-term, and long-term memory.

IV. Protection of the CNS

A. Bone: cranium and vertebral column
B. Meninges: pia mater, arachnoid mater, and dura mater
C. Cerebrospinal fluid (CSF): circulates within the subarachnoid space
D. Blood–brain barrier

Review Your Knowledge

Matching: Nerve Cells

Directions: Match the following words with their descriptions below.

a. efferent
b. ganglia
c. CNS
d. neuroglia
e. afferent
f. axon
g. nodes of Ranvier
h. Schwann cell
i. dendrite
j. myelin

1. ___ Also described as sensory neurons
2. ___ Nerve glue—astrocytes and ependymal cells
3. ___ Part of the neuron that carries the action potential away from the cell body
4. ___ Also described as motor neurons
5. ___ Composed of the brain and the spinal cord
6. ___ Clusters of cell bodies located outside of the CNS
7. ___ White insulating material that surrounds the axon; increases the speed that the signal travels along the axon
8. ___ Short segments of an axon that are not covered with myelin; allow for saltatory conduction
9. ___ A glial cell that makes myelin
10. ___ Treelike structure of the neuron that receives information from another neuron and transmits that information to the cell body

Matching: Brain

Directions: Match the following words with their descriptions below.

a. medulla oblongata
b. frontal
c. occipital
d. hypothalamus
e. temporal

1. ___ Cerebral lobe that performs the "executive functions" and contains the primary motor cortex
2. ___ Part of the brain stem that is called the *vital center*
3. ___ Part of the diencephalon that controls body temperature (thermostat) and endocrine function by its influence on the pituitary gland
4. ___ Cerebral lobe that contains the primary visual cortex
5. ___ Cerebral lobe that contains the primary auditory cortex

Multiple Choice

1. The precentral gyrus is
   a. located in the parietal lobe.
   b. the primary motor cortex.
   c. the primary visual cortex.
   d. a brain stem structure.
2. Which of the following is not descriptive of Broca's area?
   a. Located in the frontal lobe
   b. Concerned with motor speech
   c. Most often located in the left cerebral hemisphere
   d. Is the name of the frontal eye field area
3. Which of the following "brain claims" is true?
   a. The medulla oblongata is a cerebral structure.
   b. The hypothalamus is a brain stem structure.
   c. The medulla oblongata descends as the spinal cord.
   d. The midbrain, pons, and medulla oblongata are supratentorial structures.
4. Which of the following is not descriptive of the medulla oblongata?
   a. It is a brain stem structure.
   b. It is called the *vital center*.
   c. It is sensitive to the effects of narcotics (opioids).
   d. It performs the "executive" functions.
5. The postcentral gyrus
   a. is located in the parietal lobe.
   b. controls all voluntary motor activity.
   c. is the home of Broca's area.
   d. contains the primary visual cortex.
6. Cerebrospinal fluid (CSF)
   a. drains out of the subarachnoid space into the choroid plexus.
   b. circulates within the subarachnoid space.
   c. looks like blood.
   d. flows up the central canal into the fourth, third, and lateral ventricles.
7. Which of the following relationships is accurate?
   a. Temporal lobe: vision
   b. Frontal lobe: somatosensory (touch, pressure, pain)
   c. Occipital lobe: vision
   d. Parietal lobe: hearing
8. Neuroglia
   a. are classified as sensory and motor.
   b. include astrocytes, oligodendrocytes, Schwann cells, and ependymal cells.
   c. fire action potentials when stimulated.
   d. contain dendrites and axons.
9. Depolarization and repolarization
   a. are both caused by the movement of Na^+ into the neuron.
   b. are phases of the action potential.
   c. occur only in the neuroglia.
   d. are both caused by the movement of K^+ out of the neuron.
10. Activation of the emetic center or CTZ
    a. elevates blood pressure.
    b. lowers body temperature.
    c. causes diaphoresis.
    d. induces vomiting.
11. The hypothalamus
    a. is part of the diencephalon.
    b. synthesizes antidiuretic hormone and oxytocin.
    c. controls pituitary gland activity.
    d. All of the above are true.