Nervous Tissue and the Central Nervous System

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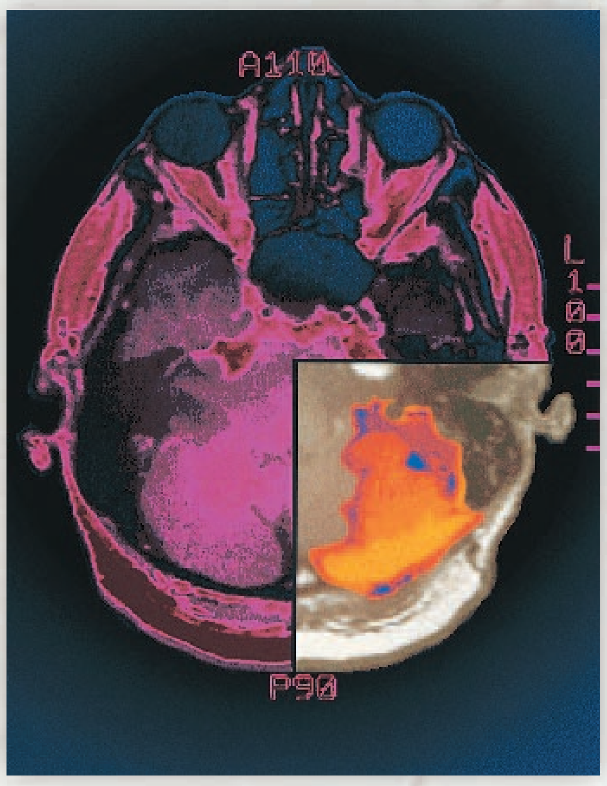

Clinical Case Study

A 56-year-old woman visited her family doctor for evaluation of a headache that had persisted for nearly a month. Upon questioning the patient, the doctor learned that her left arm, as she put it, "was a bit unwieldy, hard to control, and weak." Through examination, the doctor determined that the entire left upper extremity was generally weak. He also found weakness, although less significant, of the left lower extremity. Sensation in the limbs seemed to be normal, although mild rigidity and hyperactive reflexes were present. Expressing concern, the doctor told the patient that she needed a CT scan of her head, and explained that there could be a problem within the brain, possibly a tumor or other lesion. The doctor then picked up the phone and contacted a radiologist. After explaining the patient's case, the doctor remarked parenthetically that he believed he knew where the problem was located.

Why did the doctor suggest to the patient that there might be a problem within her brain when the symptoms were weakness of the extremities, and then just on one side of her body? Also, how would he know the location of the suspected brain tumor? In which side of the brain and in which lobe would it be? Explain the muscle weakness in terms of neuronal pathways from the brain to the periphery.

Hints: Remember the controlling and integrating function of the brain. Carefully study the information and accompanying figures concerning the structures and functions of the brain and the neuronal tracts.

FIGURE: Improvements in radiographic imaging have greatly enhanced the visualization of anatomical structures, and are indispensable aids to diagnostic medicine.

ORGANIZATION AND FUNCTIONS OF THE NERVOUS SYSTEM

The central nervous system and the peripheral nervous system are structural components of the nervous system, whereas the autonomic nervous system is a functional component. Together they orient the body, coordinate body activities, permit the assimilation of experiences, and program instinctual behavior.

Objective 1 Describe the divisions of the nervous system.

Objective 2 Define *neurology;* define *neuron.*

Objective 3 List the functions of the nervous system.

The immensely complex brain and its myriad of connecting pathways constitute the nervous system. The nervous system, along with the endocrine system, regulates the functions of the other body systems. The brain, however, does much more than that—and its potential is perhaps greatly underestimated. It is incomprehensible that one's personality, thoughts, and aspirations result from the functioning of a body organ. Plato referred to the brain as "the divinest part of us." The thought processes of this organ have devised the technology for launching rockets into space, curing diseases, mapping the human genome, and splitting atoms. But with all of these achievements, the brain still remains largely ignorant of its own workings.

Neurology, the study of the nervous system, has been referred to as the last frontier of functional anatomy. Basic questions concerning the functioning of the nervous system remain unanswered: How do nerve cells store and retrieve memory?

neurology: Gk. *neuron,* nerve, L. *logus,* study of

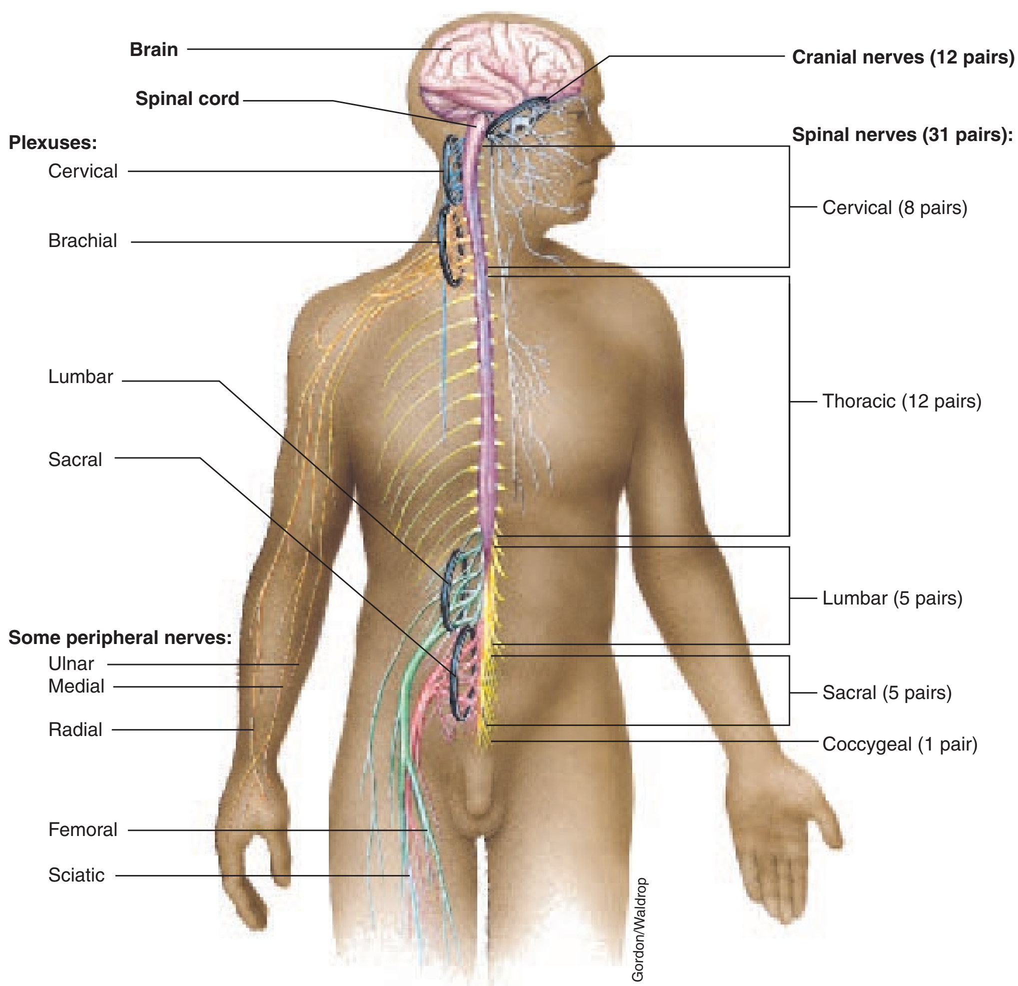

FIGURE 11.1 The nervous system. The central nervous system (CNS) consists of the brain and spinal cord. The peripheral nervous system (PNS) consists of cranial nerves and spinal nerves. Also part of the PNS are the plexuses and additional nerves that arise from the cranial and spinal nerves. The autonomic nervous system (ANS) is a functional subdivision of the nervous system.

TABLE 11.1 Selected Structures of the Nervous System and Their Definitions

Structure	Definition
Central nervous system (CNS)	Composed of brain and spinal cord; contains gray and white matter and covered by bone and meninges
Peripheral nervous system (PNS)	Composed of nerves, ganglia, and nerve plexuses
Autonomic nervous system (ANS)	Sympathetic and parasympathetic portions of the nervous system that control the actions of the visceral organs and skin.
Meninges (singular, *meninx*)	Group of three fibrous membranes covering the CNS, composed of the dura mater, arachnoid, and pia mater
Cerebrospinal fluid (CSF)	Clear, watery medium that buoys and maintains homeostasis in the brain and spinal cord
Neuron	Structural and functional cell of the nervous system; also called a nerve cell
Motor (afferent) neuron	Nerve cell that transmits action potentials from the CNS to an effector organ, such as a muscle or gland
Sensory (efferent) neuron	Nerve cell that transmits action potentials from an effector organ to the CNS
Nerve	Bundle of nerve fibers (elongated portions of neurons)
Nerve plexus	Convergence or network of nerves
Somatic motor nerve	Nerve that innervates skeletal muscle; conveys impulses causing muscle contraction
Autonomic motor nerve	Nerve that innervates smooth muscle, cardiac muscle, and glands; conveys impulses causing contraction (or inhibiting contraction) of smooth muscle and cardiac muscle and secretion of glands
Ganglion	Cluster of neuron cell bodies outside the CNS
Nucleus	Cluster of neuron cell bodies within the CNS
Tract	Bundle of nerve fibers interconnecting regions of the CNS

What are the roles of the many chemical compounds within the brain? What causes mental illness or senility? Scientists are still developing the technology and skills necessary to understand the functional complexity of the nervous system. The next few decades will undoubtedly witness major progress toward the achievement of research goals in this field of study.

Organization of the Nervous System

The nervous system is divided into the **central nervous system (CNS),** which includes the brain and spinal cord, and the **peripheral nervous system (PNS),** which includes the *cranial nerves* arising from the brain and the *spinal nerves* arising from the spinal cord (fig. 11.1 and table 11.1).

The **autonomic nervous system (ANS)** is a functional subdivision of the nervous system. The controlling centers of the ANS are located within the brain and are considered part of the CNS; the peripheral portions of the ANS are subdivided into the **sympathetic** and **parasympathetic divisions.**

Functions of the Nervous System

The nervous system is specialized for perceiving and responding to events in our internal and external environments. An awareness of one's environment is made possible by **neurons** (nerve cells), which are highly specialized with respect to excitability and conductivity. The nervous system functions throughout the body in conjunction with the endocrine system (see chapter 14) to closely coordinate the activities of the other body systems. In addition to integrating body activities, the nervous system has the ability to store experiences (*memory*) and to establish patterns of response on the basis of prior experiences (*learning*).

The functions of the nervous system include

1. orientation of the body to internal and external environments;
2. coordination and control of body activities;
3. assimilation of experiences requisite to memory, learning, and intelligence; and
4. programming of instinctual behavior (apparently more important in vertebrates other than humans).

These four functions depend on the ability of the nervous system to monitor changes, or *stimuli*, from both inside and outside the body; to interpret the changes in a process called *integration;* and to effect responses by activating muscles or glands. Thus, broadly speaking, the nervous system has *sensory*, *integrative*, and *motor functions*, all of which work together to maintain the internal constancy, or homeostasis, of the body.

An instinct also may be called a *fixed action pattern;* typically, it is genetically specified with little environmental modification. It is triggered only by a specific stimulus. Some of the basic instincts in humans include survival, feeding, drinking, voiding, and specific vocalization. Some ethologists (scientists who study animal behavior) believe that reproduction becomes an instinctive behavior following puberty.

Knowledge Check

1. Distinguish between the CNS and PNS. What are the subdivisions of the peripheral portions of the ANS?
2. Explain why neurology is considered a dynamic science.

Developmental Exposition

The Brain

EXPLANATION

The first indication of nervous tissue development occurs about 17 days following conception, when a thickening appears along the entire dorsal length of the embryo. This thickening, called the **neural plate** (exhibit I), differentiates and eventually gives rise to all of the **neurons** and to most of the **neuroglia** that support the neurons. As development progresses, the midline of the neural plate invaginates to become the **neural groove.** At the same time, there is a proliferation of cells along the lateral margins of the neural plate, which become the thickened **neural folds.** The neural groove continues to deepen as the neural folds elevate. By day 20, the neural folds have met and fused at the midline, and the neural groove has become a

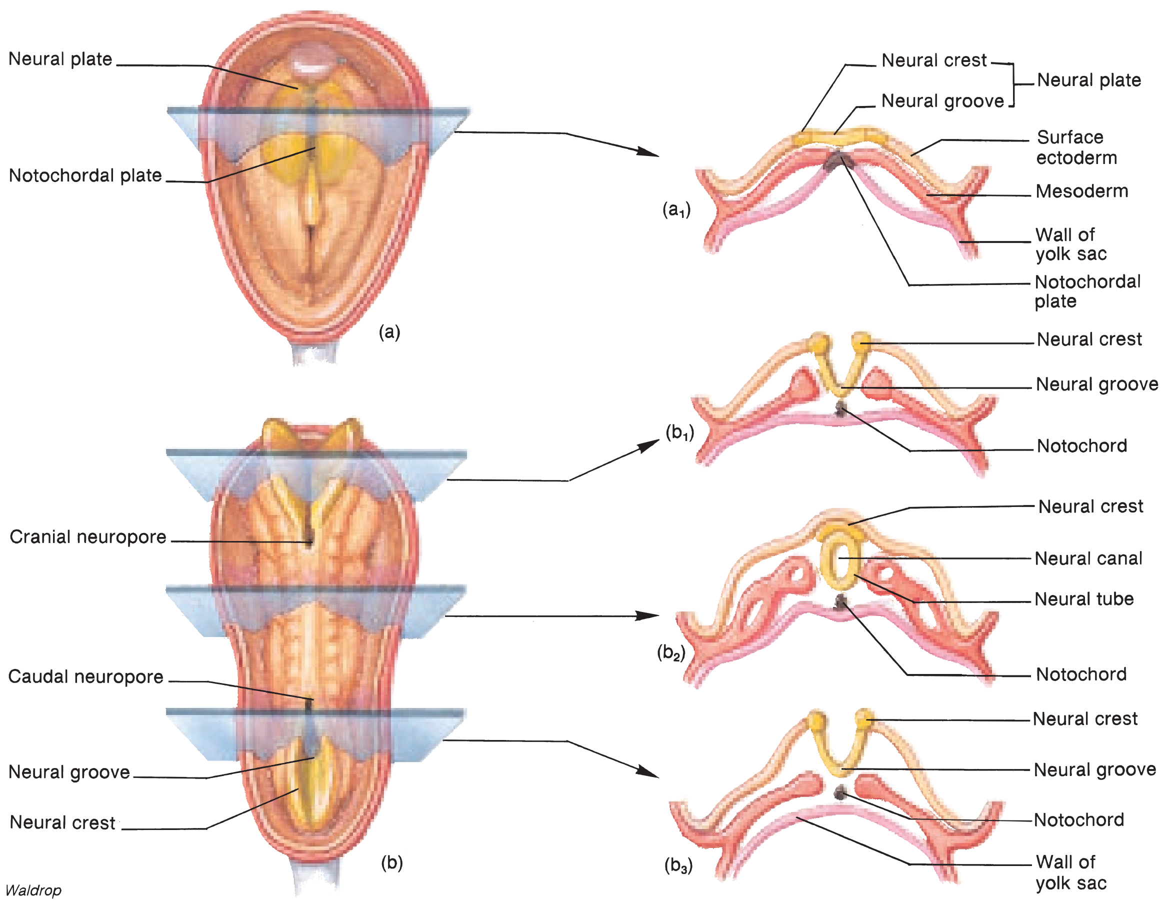

EXHIBIT I The early development of the nervous system from embryonic ectoderm. (*a*) A dorsal view of an 18-day-old embryo showing the formation of the neural plate and the position of a transverse cut indicated in (a_1). (*b*) A dorsal view of a 22-day-old embryo showing cranial and caudal neuropores and the positions of three transverse cuts indicated in (b_1–b_3). (Note the amount of fusion of the neural tube at the various levels of the 22-day-old embryo. Note also the relationship of the notochord to the neural tube.)

neural tube. For a short time, the neural tube is open both cranially and caudally. These openings, called **neuropores,** close during the fourth week. Once formed, the neural tube separates from the surface ectoderm and eventually develops into the central nervous system (brain and spinal cord). The **neural crest** forms from the neural folds as they fuse longitudinally along the dorsal midline. Most of the peripheral nervous system (cranial and spinal nerves) forms from the neural crest. Some neural crest cells break away from the main tissue mass and migrate to other locations, where they differentiate into motor nerve cells of the sympathetic nervous system or into *neurolemmocytes* (Schwann cells), which are a type of neuroglial cell important in the peripheral nervous system.

The brain begins its embryonic development as the cephalic end of the neural tube starts to grow rapidly and differentiate (exhibit II). By the middle of the fourth week, three distinct swellings are evident: the **prosencephalon** (*pros''en-sef'ă-lon*) (forebrain), the **mesencephalon** (midbrain), and the **rhombencephalon** (hindbrain). Further development during the fifth week results in the formation of five specific regions. The **telencephalon** and the **diencephalon** (*di''en-sef-ā-lon*) derive from the forebrain, the mesencephalon remains unchanged, and the **metencephalon** and **myelencephalon** form from the hindbrain. The caudal portion of the myelencephalon is continuous with and resembles the spinal cord.

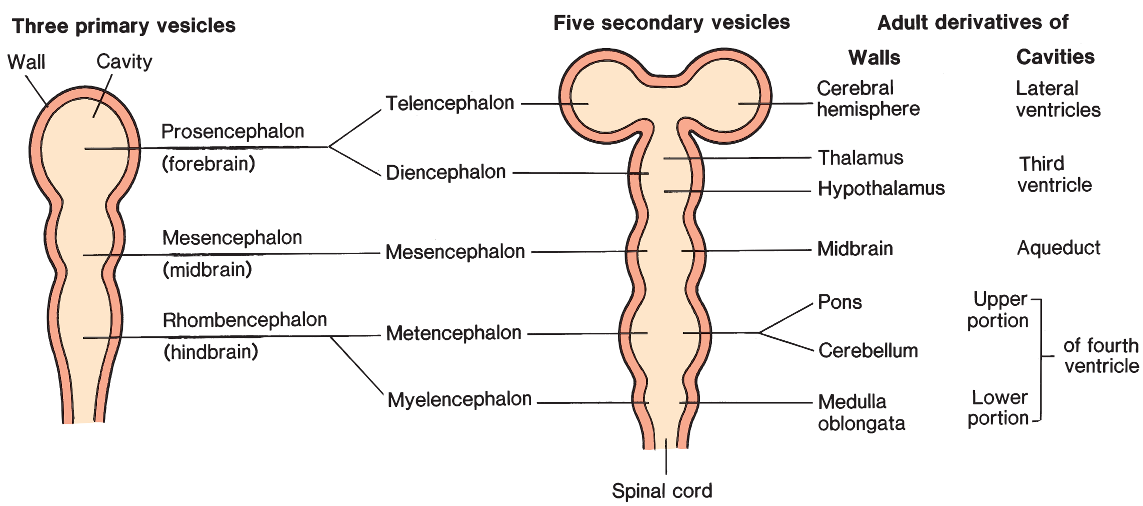

EXHIBIT II The developmental sequence of the brain. During the fourth week, the three principal regions of the brain are formed. During the fifth week, a five-regioned brain develops and specific structures begin to form.

NEURONS AND NEUROGLIA

Neurons come in many forms, but all contain dendrites for reception and an axon for the conduction of nerve impulses. The various types of neurons may be classified on the basis of structure or function. Different types of neuroglia support the neurons, both structurally and functionally.

Objective 4 Describe the microscopic structure of a neuron.

Objective 5 Describe how a neurolemmal sheath and a myelin sheath are formed.

Objective 6 List the types of neuroglia and describe their functions.

Objective 7 Describe the functions and locations of sensory and motor nerve fibers.

The highly specialized and complex nervous system is composed of only two principal categories of cells—neurons and neuroglia. **Neurons** are the basic structural and functional units of the nervous system. They are specialized to respond to physical and chemical stimuli, conduct impulses, and release specific chemical regulators. Through these activities, neurons perform such functions as storing memory, thinking, and regulating other organs and glands. Neurons cannot divide mitotically, although some neurons can regenerate a severed portion or sprout small new branches under certain conditions.

Mitotic activity of neurons is completed during prenatal development. However, recent evidence indicates that under certain conditions there may be limited mitotic activity of neurons in isolated areas of the midbrain through adulthood. For the most part, a person is born with all the neurons he or she is capable of producing. However, neurons continue to grow and specialize after a person is born, particularly in the first several years of postnatal life.

Neuroglia, or **glial cells,** are supportive cells in the nervous system that aid the function of neurons. Neuroglia are about 5 times as abundant as neurons and have limited mitotic abilities.

Neurons

Although **neurons** vary considerably in size and shape, they all have three principal components: (1) a cell body, (2) dendrites, and (3) an axon (figs. 11.2 and 11.3).

The **cell body** is the enlarged portion of the neuron that more closely resembles other cells. It contains a nucleus with a prominent nucleolus and the bulk of the cytoplasm. Besides containing organelles typically found in cells, the cytoplasm of neurons is characterized by the presence of **chromatophilic substances** (Nissl bodies) and filamentous strands of protein called **neurofibrils** (*noor''ŏ-fi'brilz*). Chromatophilic substances are specialized layers of granular (rough) endoplasmic reticulum, whose function is protein synthesis, and minute **microtubules,** which appear to be involved in transporting material within the cell. The cell bodies within the CNS are frequently clustered into regions called **nuclei** (not to be confused with the nucleus of a cell). Cell bodies in the PNS generally occur in clusters called **ganglia** (*gang'gle-ă*).

Dendrites (*den'drīts*) are branched processes that extend from the cytoplasm of the cell body. Dendrites respond to specific stimuli and conduct impulses to the cell body. Some dendrites are covered with minute **dendritic spinules** that greatly increase their surface area and provide contact points for other neurons. The area occupied by dendrites is referred to as the **dendritic zone** of a neuron.

The **axon** (*ak'son*) is the second type of cytoplasmic extension from the cell body. The term *nerve fiber* is commonly used in reference to either an axon or an elongated dendrite. An axon is a relatively long, cylindrical process that conducts impulses away from the cell body. Axons vary in length from a few millimeters in the CNS to over a meter between the distal portions of the extremities and the spinal cord. Side branches called **collateral branches** extend a short distance from the axon. The cytoplasm of an axon contains many mitochondria, microtubules, and neurofibrils.

Proteins and other molecules are transported rapidly through the axon by two different mechanisms: axoplasmic flow and axonal transport. *Axoplasmic flow,* the slower of the two, results from rhythmic waves of contraction that push cytoplasmic contents from the axon hillock, where the axon originates, to the nerve fiber endings. *Axonal transport,* which is more rapid and more selective, may occur in a retrograde as well as a forward direction. Indeed, such retrograde transport may be responsible for the movement of herpes virus, rabies virus, and tetanus toxin from nerve terminals into cell bodies.

Neuroglia

Unlike other organs that are packaged in connective tissue derived from mesoderm, all but one type of the supporting **neuroglia (glial cells)** (fig. 11.4) are derived from the same ectoderm that produces neurons. There are six categories of neuroglia: (1) **neurolemmocytes** (Schwann cells), which form myelin layers around axons in the PNS; (2) **oligodendrocytes** (*ol''ĭgo-den'drŏ-sīts*), which form myelin layers around axons in the CNS; (3) **microglia** (*mi-krog'le-ă*), which are derived from mesoderm and migrate through the CNS, removing foreign and degenerated

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Nissl body: from Franz Nissl, German neuroanatomist, 1860–1919

ganglion: Gk. *ganglion,* swelling
dendrite: Gk. *dendron,* tree branch
axon: Gk. *axon,* axis
neuroglia: Gk. *neuron,* nerve; *glia,* glue
Schwann cell: from Theodor Schwann, German histologist, 1810–82
oligodendrocyte: Gk. *oligos,* few; L. *dens,* tooth; Gk. *kytos,* hollow (cell)
microglia: Gk. *mikros,* small; *glia,* glue

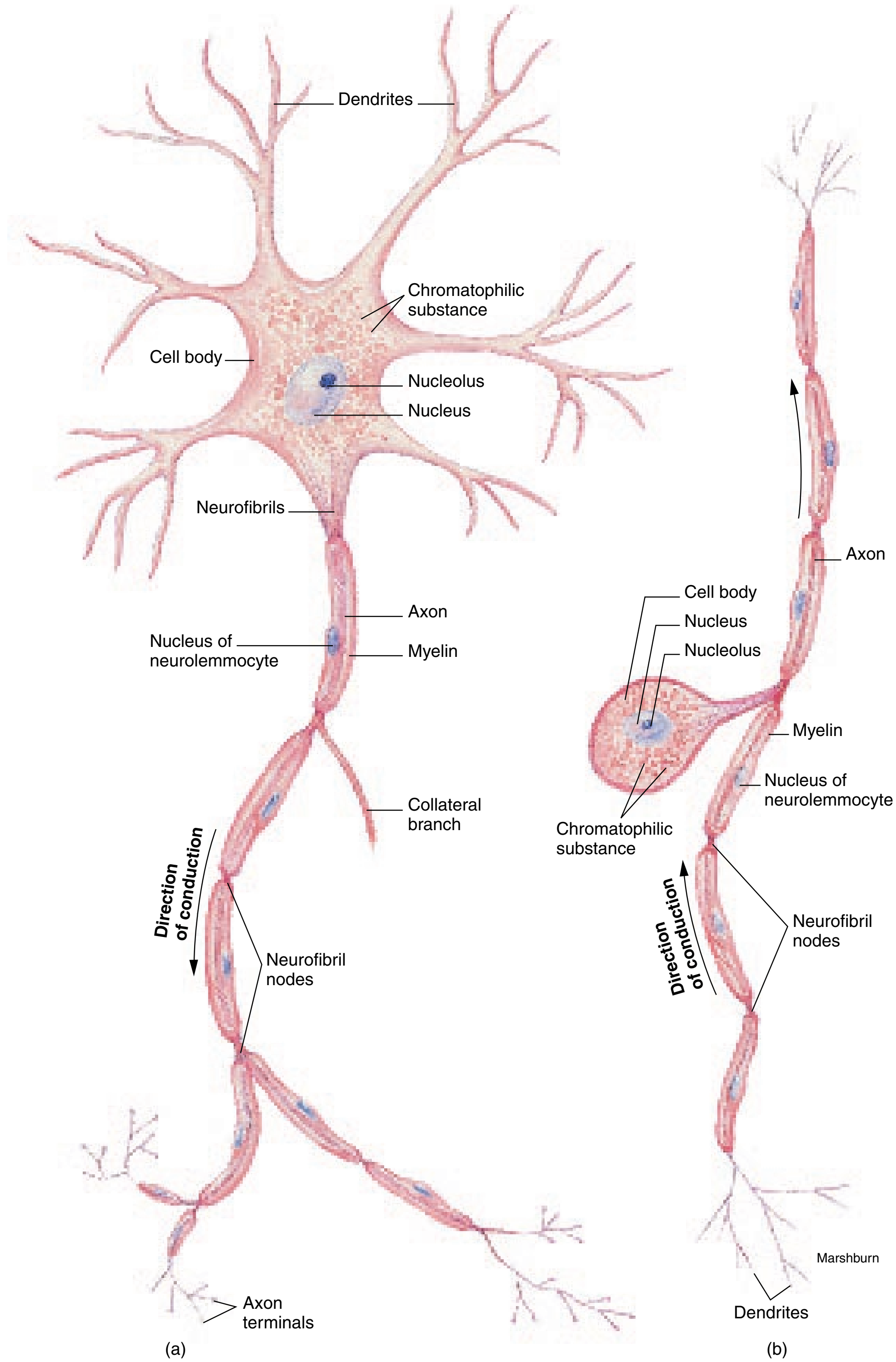

FIGURE 11.2 (*a*) A motor neuron conducts impulses away from the CNS and (*b*) a sensory neuron conducts nerve impulses toward the CNS.

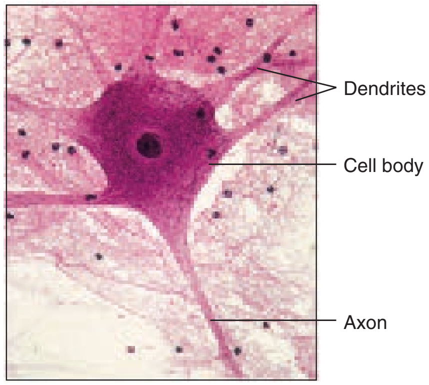

FIGURE 11.3 The neuron as seen in a photomicrograph of nervous tissue.

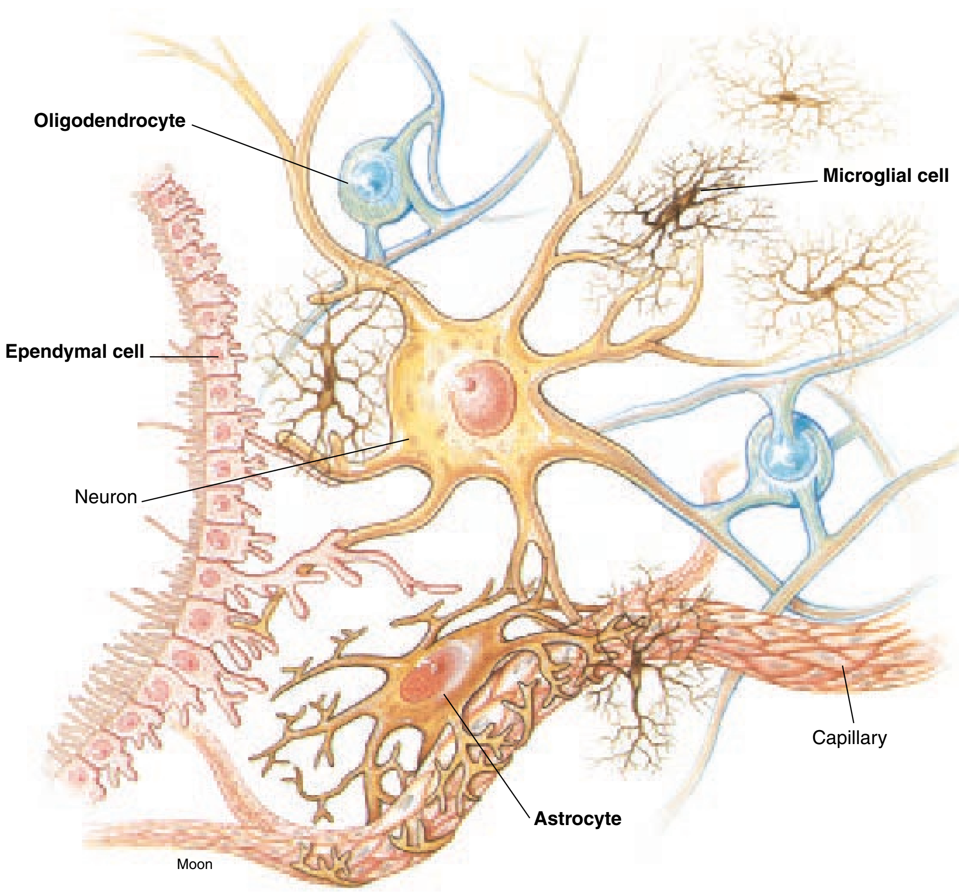

FIGURE 11.4 The four types of neuroglia found within the central nervous system.

TABLE 11.2 Neuroglia

Type	Structure	Function/Location	Type	Structure	Function/Location
Astrocytes	Stellate with numerous processes	Form structural support between capillaries and neurons of the CNS; contribute to blood-brain barrier	Ependymal cells	Columnar cells, some of which have ciliated free surfaces	Line ventricles and the central canal of the CNS, where cerebrospinal fluid is circulated by ciliary motion
Oligodendrocytes	Similar to astrocytes, but with shorter and fewer processes	Form myelin in the CNS; guide development of neurons in the CNS	Ganglionic gliocytes	Small, flattened cells	Support ganglia in the PNS
Microglia	Minute cells with few short processes	Phagocytize pathogens and cellular debris within the CNS	Neurolemmocytes (Schwann cells)	Flattened cells arranged in series around axons or dendrites	Form myelin in the PNS

material; (4) **astrocytes,** which help to regulate the passage of molecules from the blood to the brain; (5) **ependymal** (*ē-pen'dĭ-mal*) **cells,** which line the ventricles of the brain and the central canal of the spinal cord; and (6) **ganglionic gliocytes,** which support neuron cell bodies within the ganglia of the PNS. The six types of neuroglia are summarized in table 11.2.

Myelination

Neurons are either *myelinated* or *unmyelinated*. **Myelination** (*mi''ĕ-lĭ-na'shun*) is the process in which a neurolemmocyte or oligodendrocyte surrounds a portion of the axon or dendrite to provide support and aid in the conduction of impulses (figs. 11.5 and 11.6). The neuroglia that participate in the myelination process contain a white lipid-protein substance called **myelin** (*mi'ĕ-lin*). As several neuroglia are positioned in sequence, a **myelin layer** that encloses the axon or dendrite is formed. Myelinated neurons occur both in the CNS and the PNS. Myelin is responsible for the color of the *white matter* of the brain and spinal cord and the white coloration of nerves.

Myelination in the PNS occurs as neurolemmocytes grow and wrap around an axon or dendrite (figs. 11.2, 11.5, and 11.6). The outer surface of the myelin sheath is encased in a glycoprotein **neurolemmal sheath** that promotes neuron regeneration in the event that the neuron is injured. Each neurolemmocyte wraps only about 1 mm of axon, leaving gaps of exposed axon between adjacent neurolemmocytes. These gaps in the myelin sheath and neurolemmal sheath are known as the **neurofibril nodes** (nodes of Ranvier [*ron've-a; ran'vĕr*]). It is at the neurofibril nodes that a nerve impulse is propagated along a neuron.

The myelin sheaths of the CNS are formed by **oligodendrocytes.** Unlike a neurolemmocyte, which forms a portion of the myelin sheath around only one axon, each oligodendrocyte has extensions that form myelin sheaths around several axons.

astrocyte: Gk. *aster*, star; *kytos*, hollow (cell)
ependyma: Gk. *ependyma*, upper garment
myelin: Gk. *myelos*, marrow
nodes of Ranvier: from Louis A. Ranvier, French pathologist, 1835–1922

Regeneration of a Cut Axon

When an axon in a myelinated peripheral nerve is cut, the distal region of the axon that was severed from the cell body degenerates and is phagocytosed by neurolemmocytes. The neurolemmocytes then form a *regeneration tube* (fig. 11.7), as the part of the axon that is connected to the cell body begins to grow and exhibit ameboid movement. The neurolemmocytes of the regeneration tube are believed to secrete chemicals that attract the growing axon tip, and the tube helps guide the regenerating axon to its proper destination. Even a severed major nerve may be surgically reconnected and the function of the nerve reestablished if the surgery is performed before tissue death. The CNS lacks neurolemmocytes, and central axons are generally believed to have a much more limited ability to regenerate than peripheral axons.

Astrocytes and the Blood-Brain Barrier

Astrocytes are large, stellate cells with numerous cytoplasmic processes that radiate outward. These are the most abundant neuroglia in the CNS, and in some locations in the brain they constitute 90% of the nervous tissue.

Capillaries in the brain, unlike those of most other organs, do not have pores between adjacent endothelial cells. Molecules within these capillaries must thus be moved through the endothelial cells by active transport, endocytosis, and exocytosis. Astrocytes within the brain have numerous extensions called **vascular processes** that surround most of the outer surface of the brain capillaries (fig. 11.8). Before molecules in the blood can enter neurons in the CNS, they may have to pass through both the endothelial cells and the astrocytes. Astrocytes, therefore, contribute to the **blood-brain barrier,** which is highly selective; some molecules are permitted to pass, whereas closely related molecules may not be allowed to cross the barrier.

The blood-brain barrier presents difficulties in the chemotherapy of brain diseases because drugs that could enter other organs may not be able to enter the brain. In the treatment of *Parkinson's disease,* for example, patients who need a chemical called dopamine in the brain must be given a precursor molecule called levodopa (L-dopa). This is because dopamine cannot cross the blood-brain barrier, whereas L-dopa can enter neurons and be converted to dopamine in the brain.

CHAPTER 11

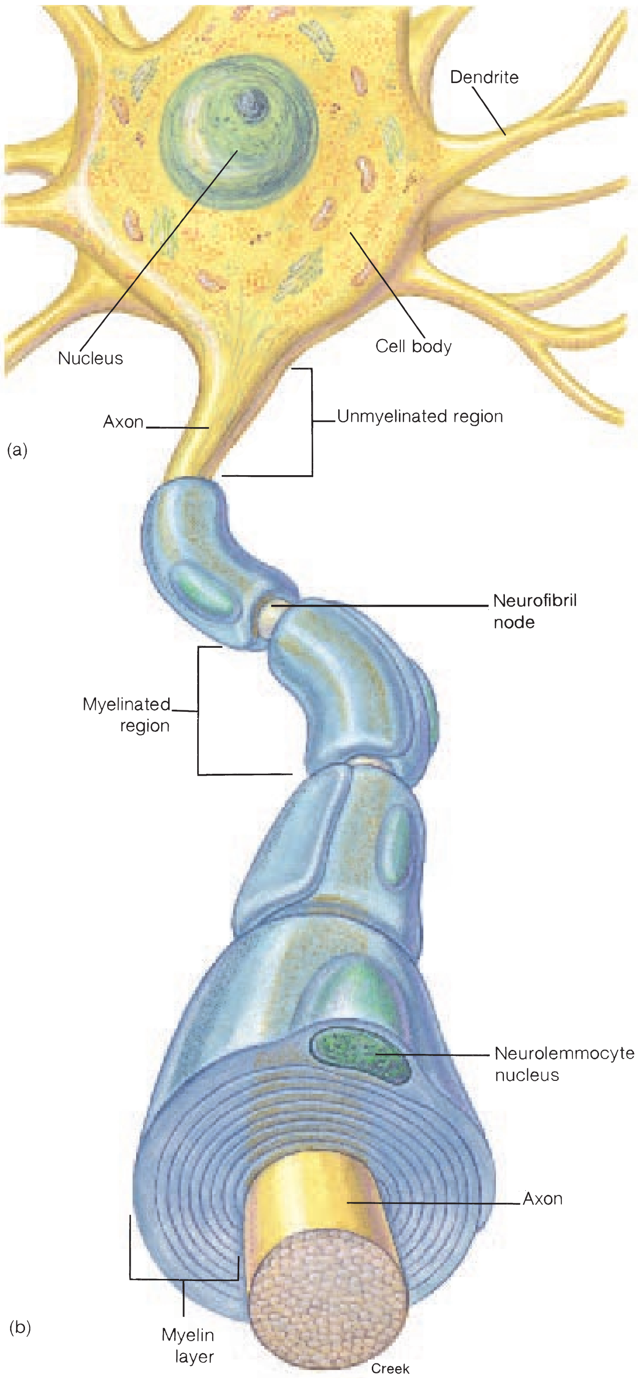

FIGURE 11.5 A myelinated neuron. A myelin layer is formed by the wrapping of neurolemmocytes around the axon of a neuron.

Classification of Neurons and Nerves

Neurons may be classified according to structure or function. The functional classification is based on the direction of conducted impulses. Sensory impulses originate in sensory receptors and are conducted by **sensory,** or **afferent, neurons** to the CNS. Motor impulses originate in the CNS and are conducted by **motor,** or **efferent, neurons** to a muscle or gland (fig. 11.9). Motor neurons may be *somatic* (nonvisceral) or *autonomic* (visceral). **Association neurons,** or **interneurons,** are located between sensory and motor neurons and are found within the spinal cord and brain.

The structural classification of neurons is based on the number of processes that extend from the cell body of the neuron (fig. 11.10). The spindle-shaped **bipolar neuron** has a process at both ends; this type occurs in the retina of the eye. **Pseudounipolar neurons** have a single process that divides into two. They are called pseudounipolar (*pseudo* = false) because they originate as bipolar neurons, but then their two processes converge and partially fuse during early embryonic development. Most sensory neurons are pseudounipolar and have their cell bodies located in sensory ganglia of spinal and cranial nerves. **Multipolar neurons** are the most common type and are characterized by several dendrites and one axon extending from the cell body. Motor neurons are a good example of this type.

A **nerve** is a collection of nerve fibers outside the CNS. Fibers within a nerve are held together and strengthened by loose connective tissue (fig. 11.11). Each individual nerve fiber is enclosed in a connective tissue sheath called the **endoneurium** (*en''do-nyoo're-um*). A group of fibers, called a **fasciculus** (*fă-sik'yŭ-lus*) is surrounded by a connective tissue sheath called a **perineurium.** The entire nerve is surrounded and supported by connective tissue called the **epineurium,** which contains tiny blood vessels and, often, adipose cells. Perhaps less than a quarter of the bulk of a nerve consists of nerve fibers. More than half is associated connective tissue, and approximately a quarter is the myelin that surrounds the nerve fibers.

Most nerves are composed of both motor and sensory fibers, and thus are called **mixed nerves.** Some of the cranial nerves, however, are composed either of sensory neurons only (**sensory nerves**) or of motor neurons only (**motor nerves**). Sensory nerves serve the special senses, such as taste, smell, sight, and hearing. Motor nerves conduct impulses to muscles, causing them to contract, or to glands, causing them to secrete.

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fasciculus: L. diminutive of *fascis,* bundle

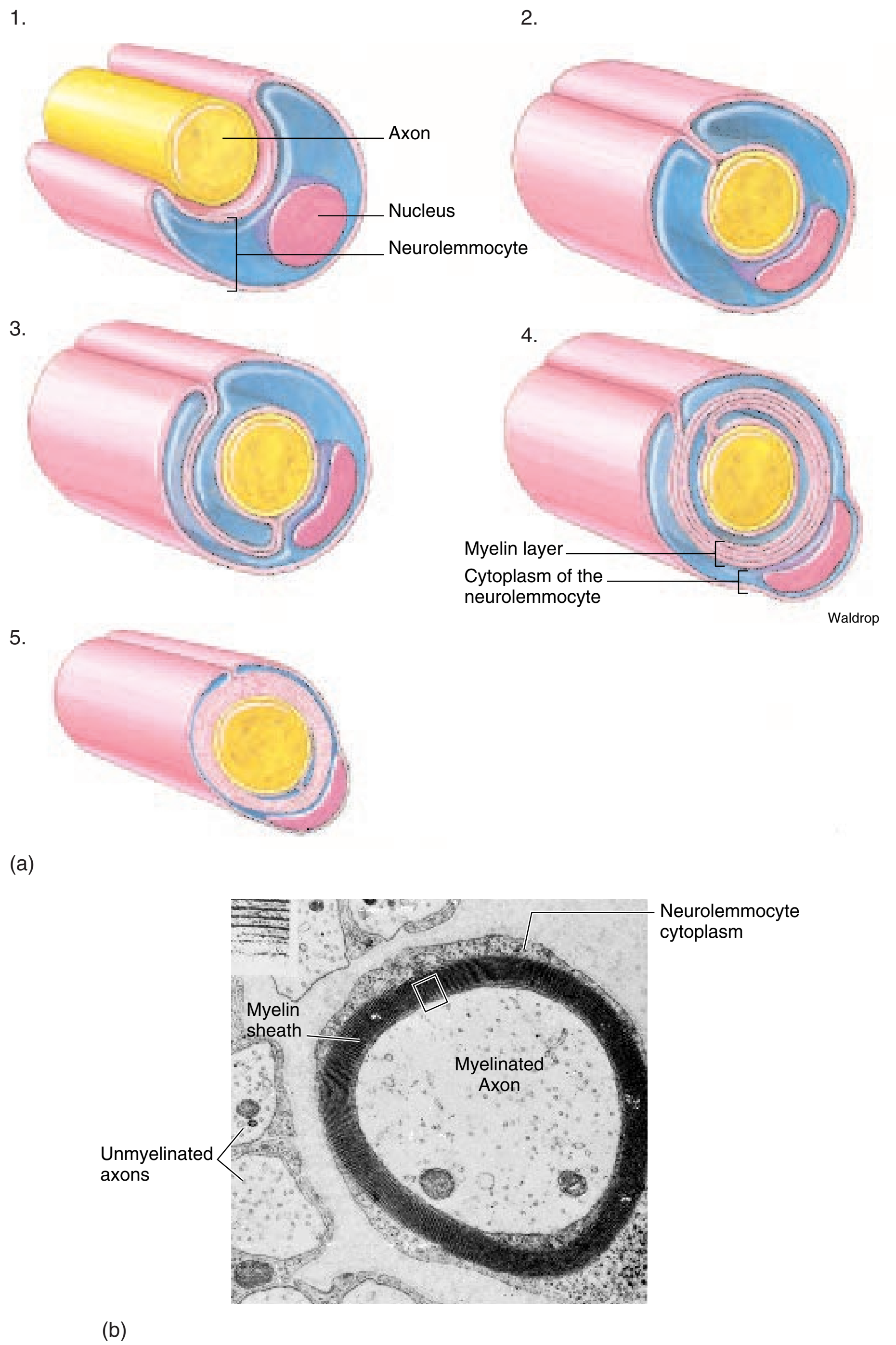


FIGURE 11.6 The process of myelination. (*a*) An axon of a peripheral neuron becomes myelinated as neurolemmocytes wrap around it to form a myelin layer. (*b*) A photomicrograph of a myelinated axon in cross section.

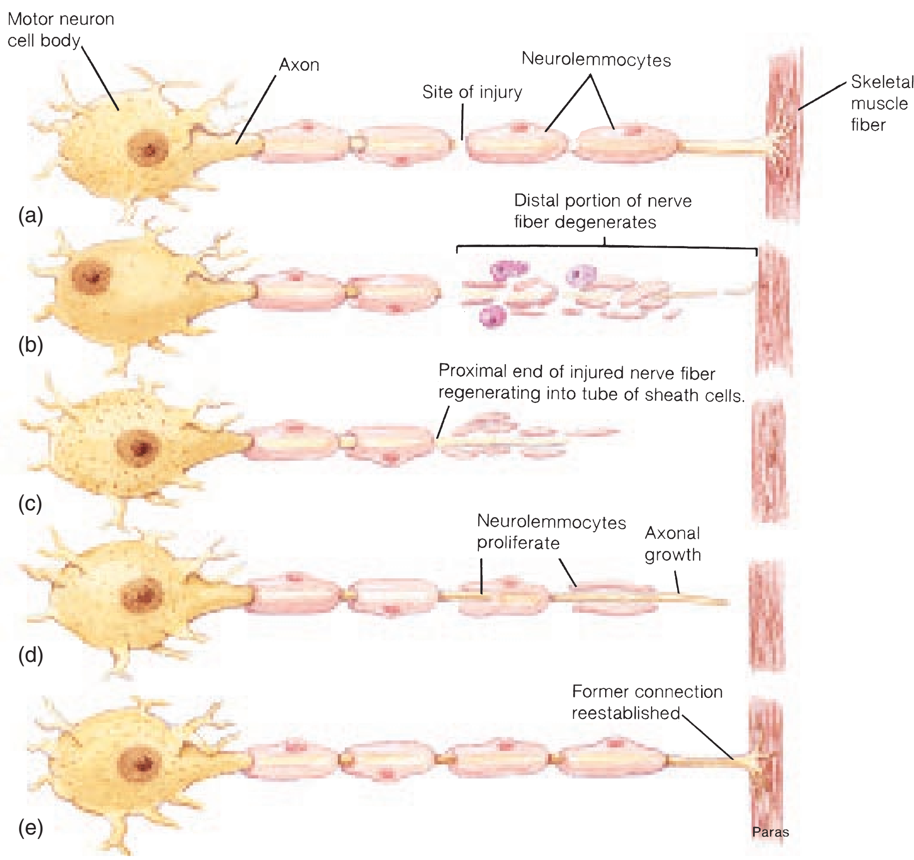


FIGURE 11.7 Neuron regeneration. (*a*) If a neuron is severed through a myelinated axon, the proximal portion may survive but (*b*) the distal portion will degenerate through phagocytosis. (*c*–*d*) The myelin layer provides a pathway for regeneration of the axon, and (*e*) innervation is restored.

Neurons and their fibers within nerves may be classified according to the area of innervation into the following scheme (fig. 11.12):

1. **Somatic sensory.** Sensory receptors within the skin, bones, muscles, and joints receive stimuli and convey nerve impulses through somatic sensory (afferent) fibers to the CNS for integration. Sensory receptors within the eyes and ears are also somatic sensory.
2. **Somatic motor.** Impulses from the CNS travel through somatic motor (efferent) fibers and cause the contraction of skeletal muscles.
3. **Visceral sensory.** Visceral sensory (afferent) fibers convey impulses from visceral organs and blood vessels to the CNS for integration. Sensory receptors within the tongue (taste) and nasal epithelium (smell) are also visceral sensory.
4. **Visceral motor.** Visceral motor (efferent) fibers, also called **autonomic motor fibers,** are part of the autonomic nervous system. They originate in the CNS and innervate cardiac muscle, glands, and smooth muscle within the visceral organs.

Knowledge Check

3. Briefly describe the functions of dendrites, cell bodies, and axons and distinguish between bipolar, pseudounipolar, and multipolar neurons.
4. Distinguish between myelinated and unmyelinated axons.
5. Discuss specific ways in which neuroglia aid neurons.
6. Explain the nature of the blood-brain barrier and describe its structure.
7. Contrast neurons, nerve fibers, and nerves, and describe how nerves are classified.

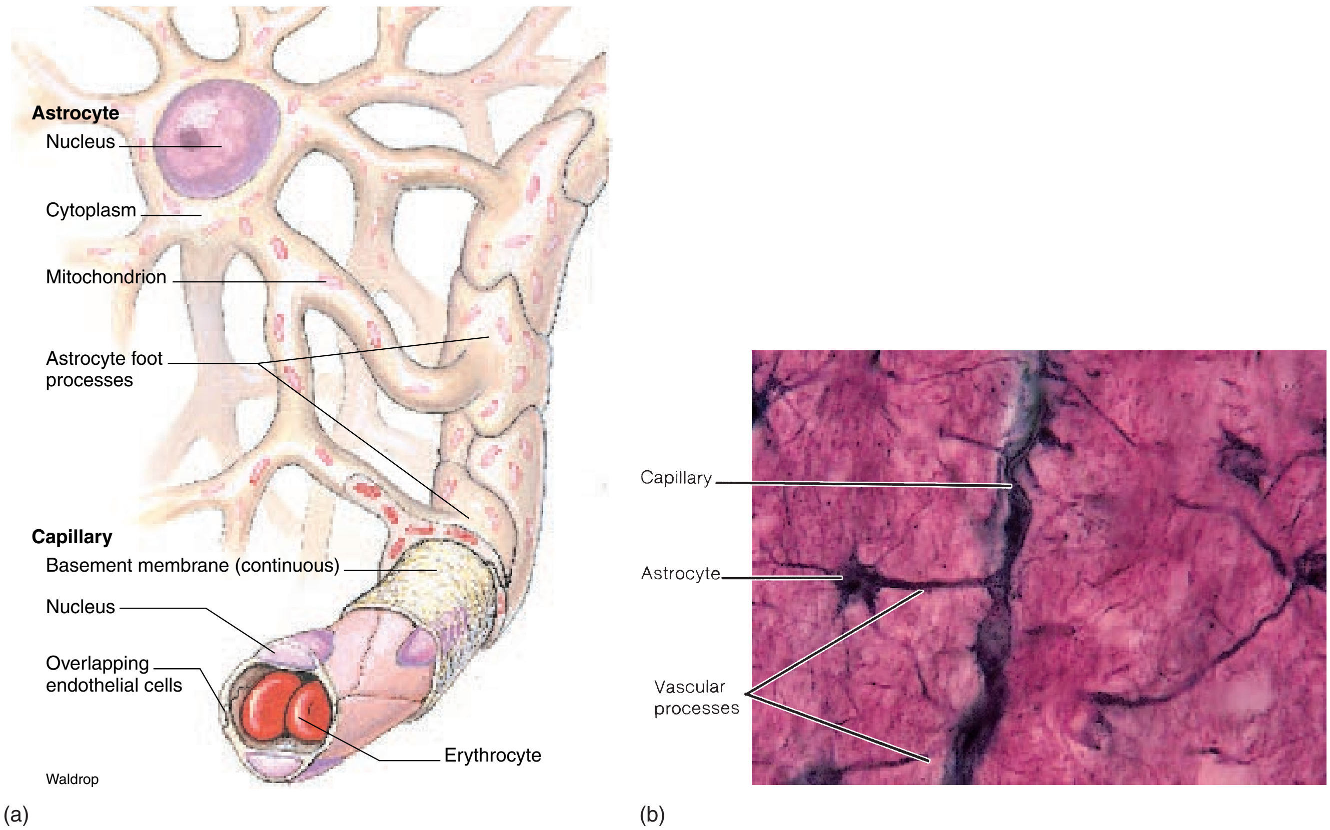


FIGURE 11.8 The blood-brain barrier maintains homeostasis within the CNS. (*a*) A diagram showing the relationship between astrocytes and a brain capillary. (*b*) A photomicrograph showing the vascular processes of astrocytes.

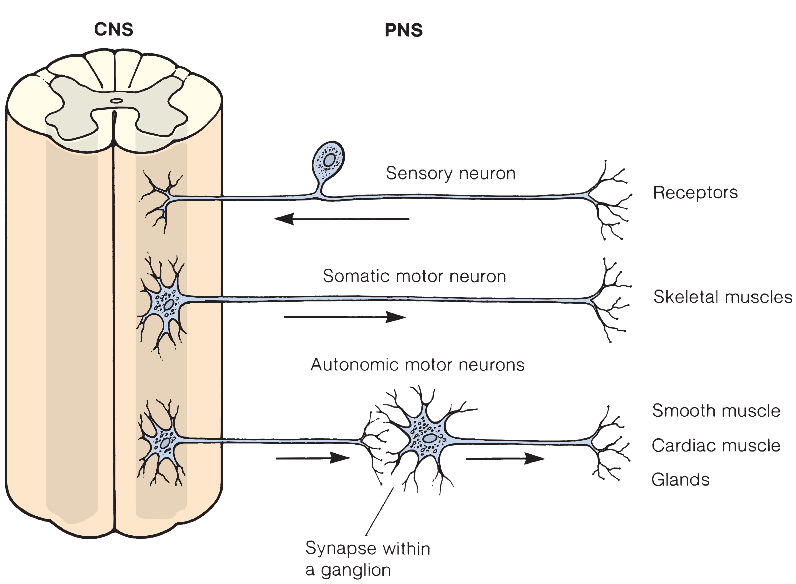


FIGURE 11.9 The relationship between sensory and motor fibers of the peripheral nervous system (PNS) and the central nervous system (CNS).

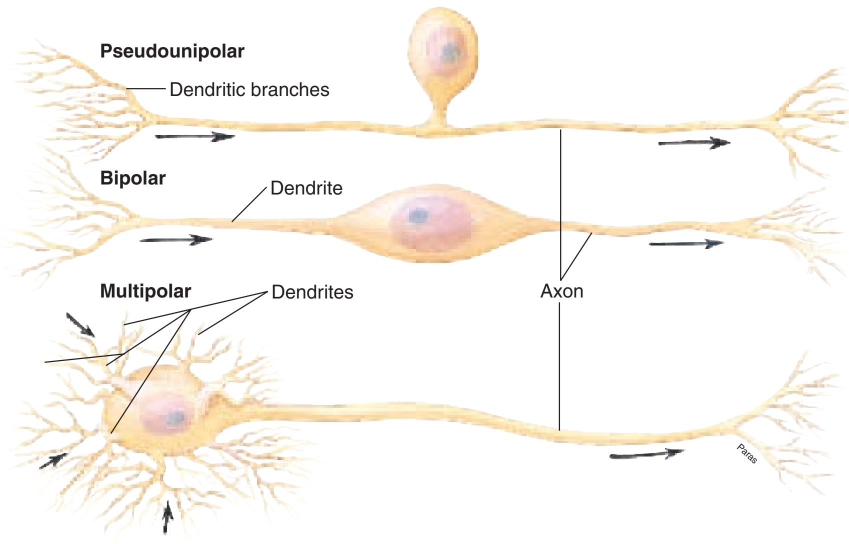


FIGURE 11.10 Three different types of neurons. Pseudounipolar neurons have one process, which splits; bipolar neurons have two processes; and multipolar neurons have many processes (one axon and many dendrites).

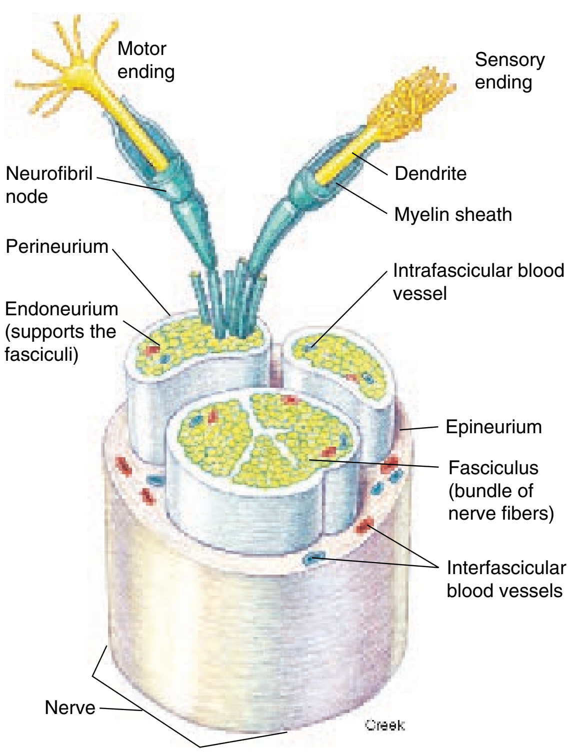


FIGURE 11.11 The structure of a nerve.

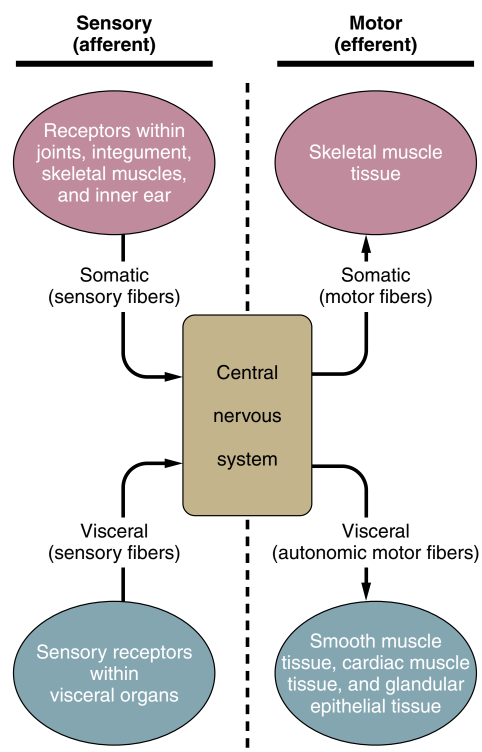


FIGURE 11.12 The classification of nerve fibers by origin and function.

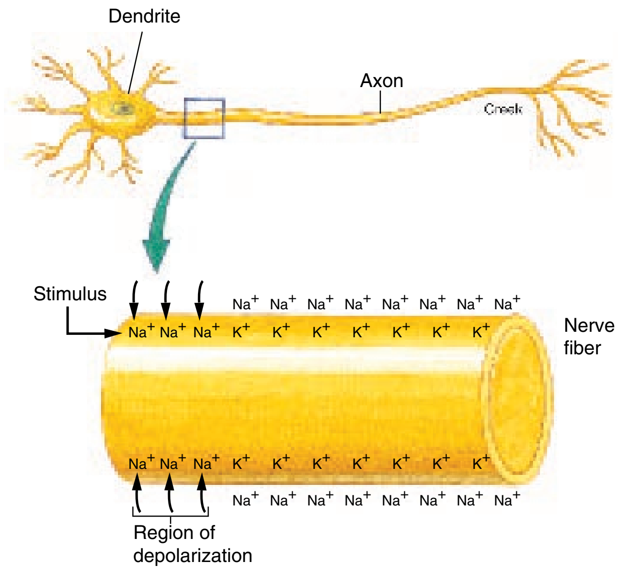


FIGURE 11.13 An action potential, or nerve impulse, is initiated if a sufficient stimulus occurs at the receptor site, causing movement of ions across the membrane of the nerve fiber.

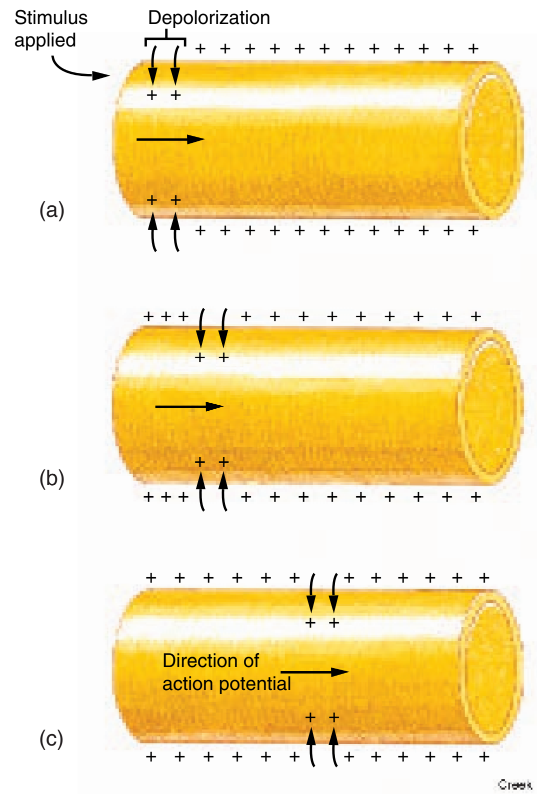


FIGURE 11.14 (*a–c*) Depolarization occurs in a sequential pattern along a nerve fiber as sodium ions diffuse inward and an action potential moves in one direction along the fiber.

TRANSMISSION OF IMPULSES

Movements of sodium and potassium ions across the axon membrane trigger impulses that travel through the neuron toward a synapse. Synaptic transmission is facilitated by the secretion of a neurotransmitter chemical.

Objective 8 Explain how a nerve fiber first becomes depolarized and then repolarized.

Objective 9 Describe the structure of a presynaptic nerve fiber ending and explain how neurotransmitters are released.

Action Potential

Two functional properties of neurons are irritability and conductivity, both of which are involved in the transmission of a nerve impulse. *Irritability* is the ability of dendrites and cell bodies to respond to a stimulus and convert it into an impulse. *Conductivity* is the transmission of an impulse along the axon or a dendrite of a neuron. An *action potential (nerve impulse)* is the actual movement, or exchange, of sodium (Na^+) and potassium (K^+) ions along the length of a nerve fiber, resulting in the creation of a stimulus that activates another neuron or another tissue.

Before a nerve fiber can respond to a stimulus, it must be *polarized*. A polarized nerve fiber has an abundance of sodium ions on the outside of the axon membrane, which produces a difference in electrical charge called the *resting potential*. When a stimulus of sufficient strength arrives at the receptor portion of the neuron, the polarized nerve fiber becomes *depolarized*, and an action potential is initiated (fig. 11.13). Once depolarization has started, a sequence of ionic exchange occurs along the axon, and the action potential is transmitted (fig. 11.14). After the axon membrane has reached maximum depolarization, the original concentrations of sodium and potassium ions are reestablished in a process called *repolarization*. This restores the resting potential, and the nerve fiber is now ready to send another impulse.

An action potential travels in one direction only and is an *all-or-none* response. This means that if an impulse is initiated, it will invariably travel the length of the nerve fiber and proceed without a loss in voltage. The speed of an action potential is determined by the diameter of the nerve fiber, its type (myelinated or unmyelinated), and the general physiological condition of the neuron. For example, unmyelinated nerve fibers with small diameters conduct impulses at the rate of about 0.5 m/sec; myelinated neurons conduct impulses at speeds up to 130 m/sec.

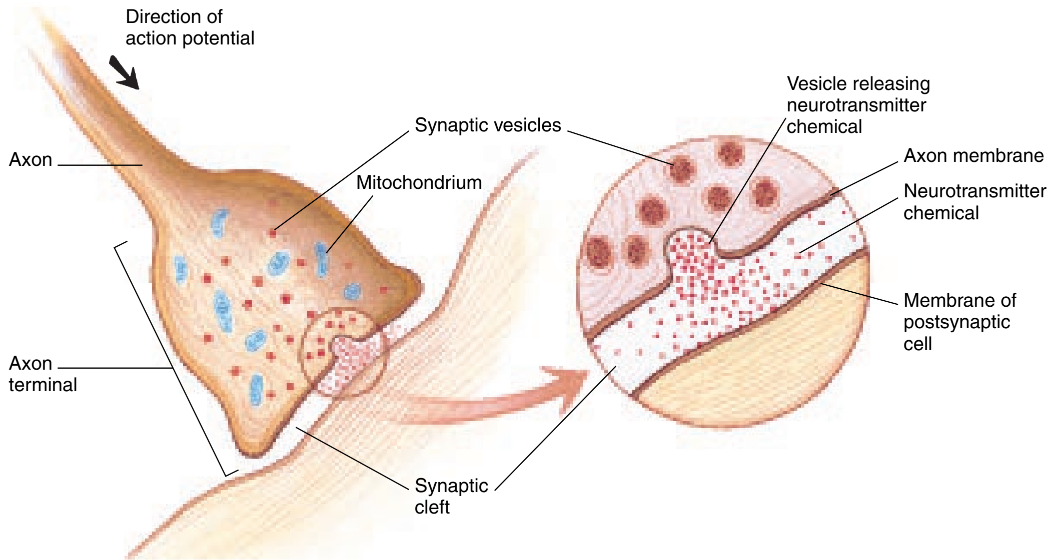


FIGURE 11.15 Synaptic transmission. When an action potential reaches the axon terminal, neurotransmitter chemicals are released into the synaptic cleft. Synaptic transmission occurs if sufficient amounts of the neurotransmitter chemicals are released.

Synapse

A **synapse** (*sin'aps*) is the functional connection between the axon terminal of a **presynaptic neuron** and a dendrite of a **postsynaptic neuron** (fig. 11.15). The **axon terminal** (synaptic knob), is the distal portion of the presynaptic neuron at the end of the axon; it is characterized by the presence of numerous mitochondria and **synaptic vesicles.** Synaptic vesicles contain a neurotransmitter chemical, the most common of which is *acetylcholine* (*ă-set''l-ko'lēn*). When an action potential reaches the axon terminal, some of the vesicles respond by releasing their neurotransmitter into the **synaptic cleft,** a tiny gap separating the presynaptic and postsynaptic membranes. If a sufficient number of nerve impulses occur in a short time interval, enough neurotransmitter will accumulate within the synaptic cleft to stimulate the postsynaptic neuron to depolarize.

Neurotransmitters are decomposed by enzymes present in the synaptic cleft. *Cholinesterase* (*ko''lĭ-nes'tĭ-rās*) is the enzyme that decomposes acetylcholine and prepares the synapse to receive additional neurotransmitter with the next impulse.

Synaptic transmission may be affected by various drugs or diseases. *Caffeine* is a stimulant that increases the rate of transmission across the synapse. *Aspirin* causes a moderate decrease in the transmission rate. The drug *strychnine* profoundly reduces synaptic transmission; it affects breathing and paralyzes respiratory structures, causing death. In *Parkinson's disease,* there is a deterioration of neurons within the brain that synthesize the neurotransmitter dopamine.

synapse Gk. *syn*, together; *haptein*, to fasten

Knowledge Check

8. Define the terms *depolarization* and *repolarization* and illustrate these processes graphically.
9. Describe the mechanism by which a neurotransmitter affects impulse conduction across a synapse.

GENERAL FEATURES OF THE BRAIN

The brain is enclosed by the cranium and meninges and is bathed in cerebrospinal fluid. The tremendous metabolic rate of the brain makes it highly susceptible to oxygen deprivation.

Objective 10 Describe the general features of the brain.

Objective 11 Comment on the importance of neuropeptides.

Objective 12 List the metabolic needs of the brain.

The entire delicate CNS is protected by a fixed bony encasement—the cranium (figs. 11.16 and 11.17*d*) surrounding the brain and a flexible vertebral column surrounding the spinal cord. The **meninges** (*mĕ-nin'jēz*) are connective tissue encasements that form a protective membrane between the bone and the soft tissue of the CNS. The CNS is bathed in **cerebrospinal** (*ser''ĕ-bro-spi'nal*) **fluid** that circulates within the hollow **ventricles** of the brain, the **central canal** of the spinal cord, and the **subarachnoid** (*sub''ă-rak'noid*) **space** surrounding the entire CNS (see figs. 11.34 and 11.35).

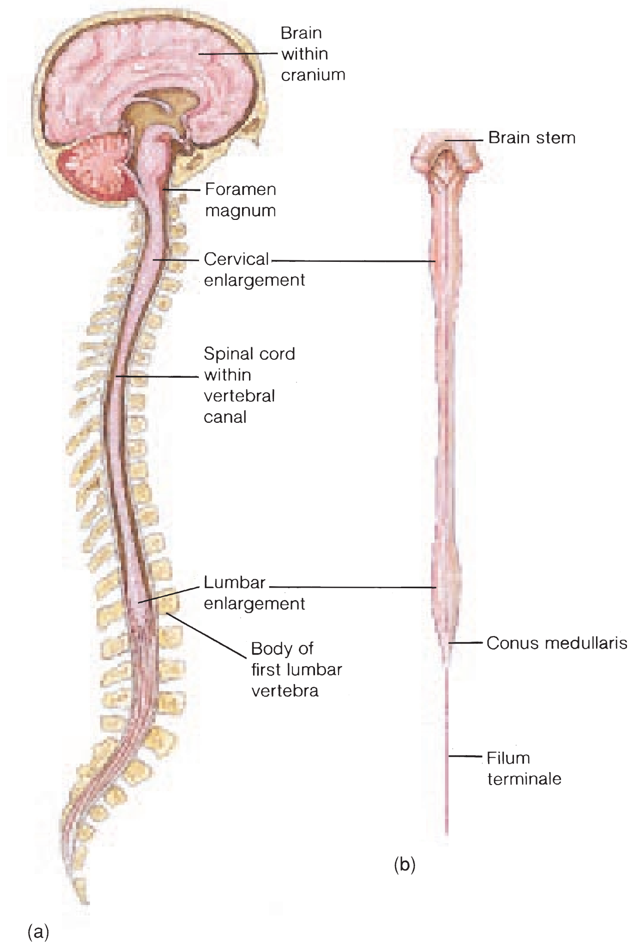


FIGURE 11.16 The central nervous system consists of the brain and the spinal cord, both of which are covered with meninges and bathed in cerebrospinal fluid. (*a*) A sagittal section showing the brain within the cranium of the skull and the spinal cord within the vertebral canal. (*b*) The spinal cord, shown in a posterior view, extends from the level of the foramen magnum to the first lumbar vertebra (L1).

The CNS is composed of gray and white matter. **Gray matter** consists of either nerve cell bodies and dendrites or bundles of unmyelinated axons and neuroglia. The gray matter of the brain exists as the outer convoluted **cortex layer** of the cerebrum and cerebellum. In addition, specialized gray matter clusters of nerve cells called **nuclei** are found deep within the white matter. **White matter** forms the tracts within the CNS. It consists of aggregations of dendrites and myelinated axons, along with associated neuroglia.

The brain of an adult weighs nearly 1.5 kg (3–3.5 lb) and is composed of an estimated 100 billion (10^{11}) neurons. As described in the previous section, neurons communicate with one another by means of innumerable synapses between the axons and dendrites within the brain. Neurotransmission within the brain is regulated by specialized neurotransmitter chemicals called *neuropeptides*. These specialized chemical protein messengers are thought to account for specific mental functions.

Over 200 neuropeptides have been identified within the brain, yet most of their functions are not well understood. Two groups of neuropeptides that have received considerable attention are *enkephalins* and *endorphins*. These classes of substances numb the brain to pain, functioning in a manner similar to morphine. They are released in response to stress or pain in a traumatized person.

The brain has a tremendous metabolic rate and therefore needs a continuous supply of oxygen and nutrients. Although it accounts for only 2% of a person's body weight, the brain receives approximately 20% of the total resting cardiac output. This amounts to a flow of about 750 ml of blood per minute. The volume remains relatively constant even with changes in physical or mental activity. This continuous flow is so crucial that a failure of cerebral circulation for as short an interval as 10 seconds causes unconsciousness.

The brain is composed of perhaps the most sensitive tissue of the body. Because of its high metabolic rate, it not only requires continuous oxygen, but also a continuous nutrient supply and the rapid removal of wastes. It is also very sensitive to certain toxins and drugs. The cerebrospinal fluid aids the metabolic needs of the brain by serving as a medium for exchange of nutrients and waste products between the blood and nervous tissue. Cerebrospinal fluid also maintains a protective homeostatic environment within the brain. The blood-brain barrier and the secretory activities of neural tissue also help maintain homeostasis. The brain has an extensive vascular supply through the paired internal carotid and vertebral arteries that unite at the cerebral arterial circle (circle of Willis) (see chapter 16 and fig. 16.24).

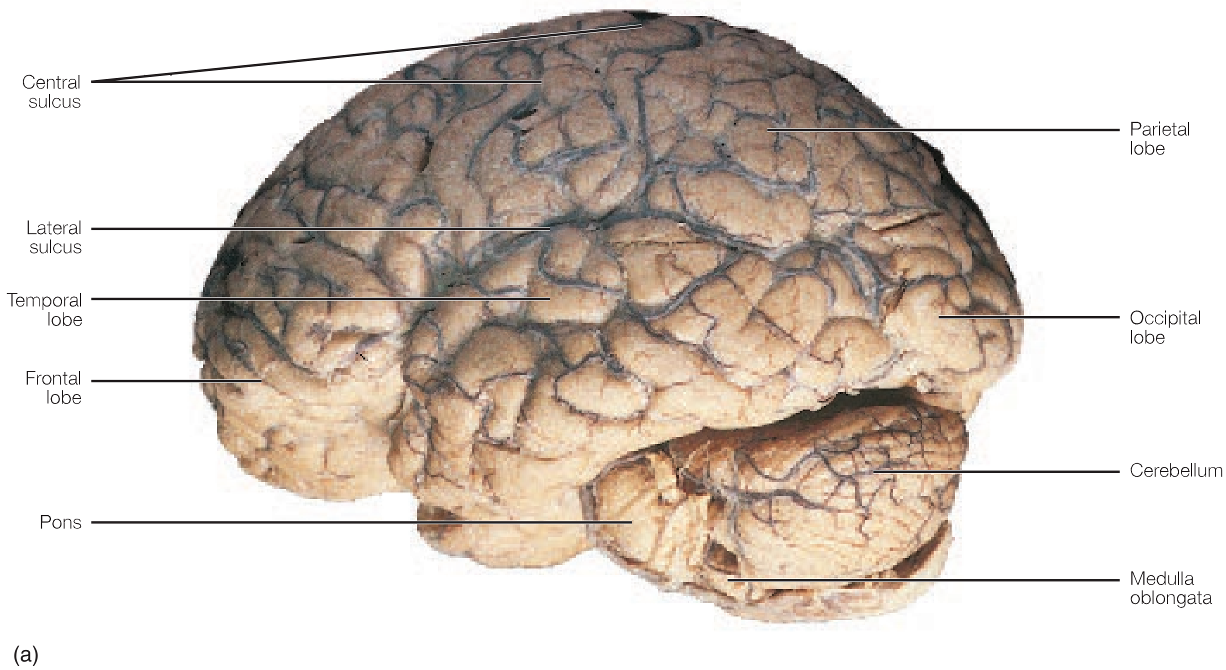
The brain of a newborn is especially sensitive to oxygen deprivation or to excessive oxygen. If complications arise during childbirth and the oxygen supply from the mother's blood to the baby is interrupted while it is still in the birth canal, the infant may be stillborn or suffer brain damage that can result in cerebral palsy, epilepsy, paralysis, or mental retardation. Excessive oxygen administered to a newborn may cause blindness.

Measurable increases in regional blood flow and in glucose and oxygen metabolism within the brain accompany mental functions, including perception and emotion. These metabolic changes can be assessed through the use of *positron emission tomography (PET)*. The technique of a PET scan (fig. 11.18) is based on injecting radioactive tracer molecules labeled with carbon-11, fluorine-18, and oxygen-15 into the bloodstream and photographing the gamma rays that are subsequently emitted from the patient's brain through the skull. PET scans are of value in studying neurotransmitters and neuroreceptors, as well as the substrate metabolism of the brain.

The development of the five basic regions of the brain, was described earlier in this chapter. From each of these regions, distinct functional structures are formed. These structures are summarized in table 11.3 and will be discussed in greater detail in the following sections.

Knowledge Check

10. What characteristics do the brain and spinal cord have in common? Describe the general features of each.
11. Explain how the study of neuropeptides can enhance understanding of brain function.
12. Using specific examples, describe the metabolic requirements of the brain.



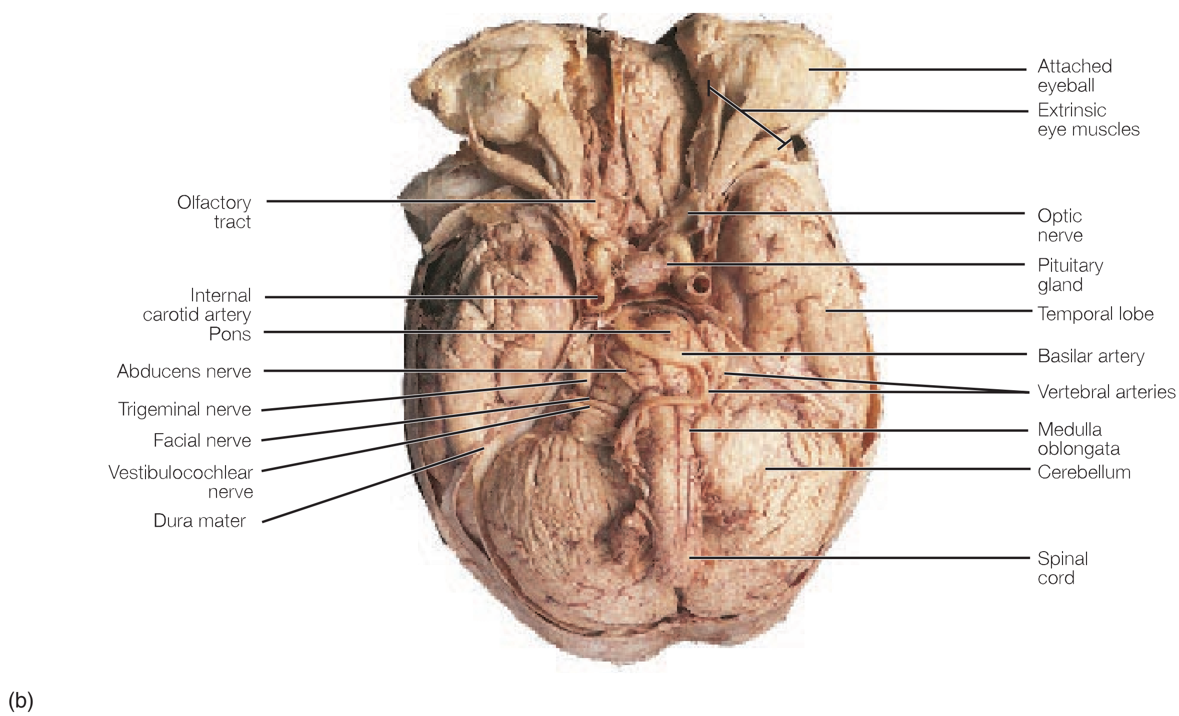
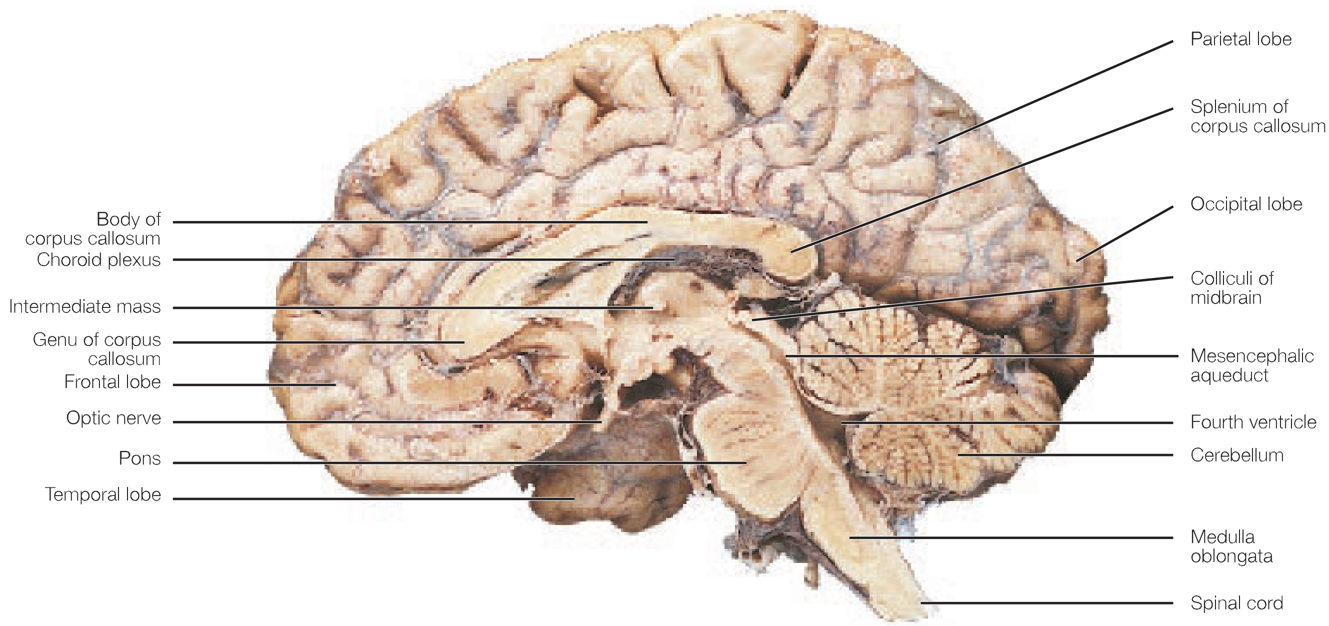
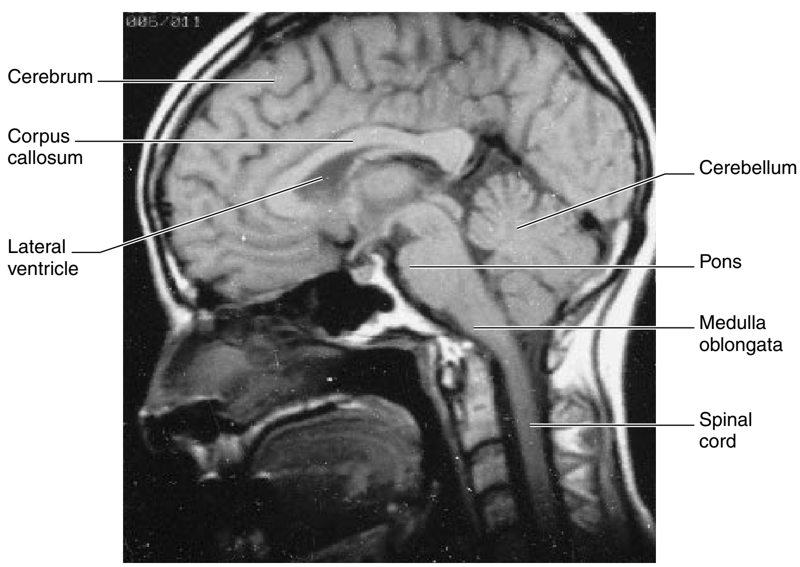


FIGURE 11.17 The brain: (*a*) a lateral view, (*b*) an inferior view, and (*c*) a sagittal view. (*d*) A left/right magnetic resonance image (MRI) of the skull, brain, and cervical portion of the spinal cord.

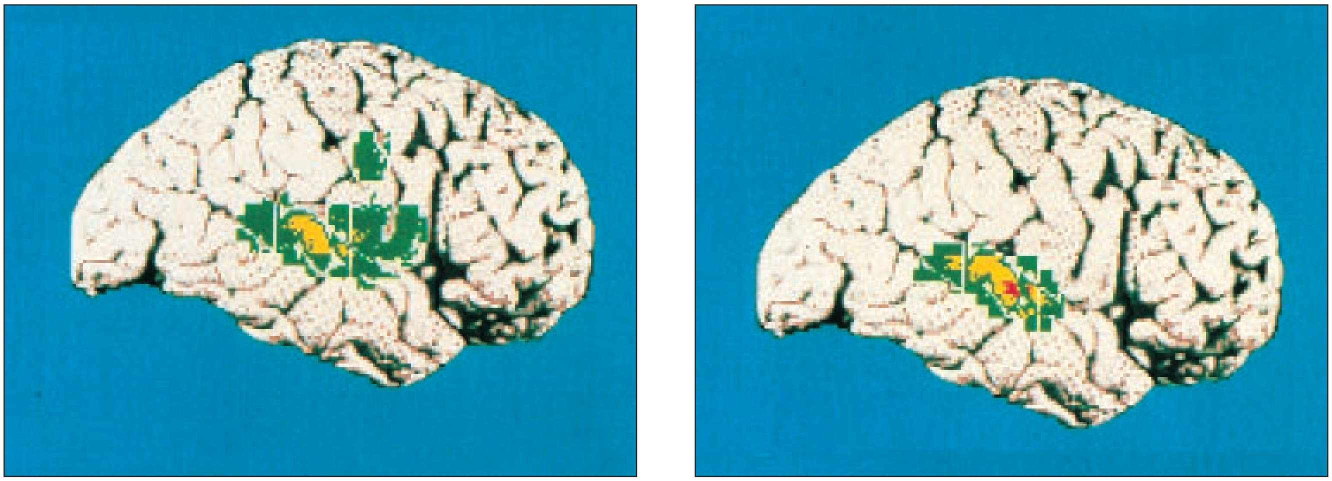


(c)



(d)

FIGURE 11.17 *Continued*



(a) (b)

FIGURE 11.18 Positron emission tomographic (PET) scans of the cerebrum showing language responses. (*a*) The response in the temporal lobe while the subject is listening to words only, and (*b*) the temporal lobe while repeating the words as they are presented.

TABLE 11.3 Derivation and Functions of the Major Brain Structures

Developmental Region	Adult Region	Structure	Function
Prosencephalon (forebrain)	Telencephalon	Cerebrum	Control of most sensory and motor activities; reasoning, memory, intelligence, etc.; instinctual and limbic functions
	Diencephalon	Thalamus	Relay center; all impulses (except olfactory) going into the cerebrum synapse here; some sensory interpretation; initial autonomic response to pain
		Hypothalamus	Regulation of food and water intake, body temperature, heartbeat, etc.; control of secretory activity in anterior pituitary gland; instinctual and limbic functions
		Pituitary gland	Regulation of other endocrine glands
Mesencephalon (midbrain)	Mesencephalon	Superior colliculi	Visual reflexes (eye-hand coordination)
		Inferior colliculi	Auditory reflexes
		Cerebral peduncles	Reflex coordination; contain many motor fibers
Rhombencephalon (hindbrain)	Metencephalon	Cerebellum	Balance and motor coordination
		Pons	Relay center; contains nuclei (pontine nuclei)
	Myelencephalon	Medulla oblongata	Relay center; contains many nuclei; visceral autonomic center (e.g., respiration, heart rate, vasoconstriction)

CEREBRUM

The cerebrum, consisting of five paired lobes within two convoluted hemispheres, is concerned with higher brain functions, including the perception of sensory impulses, the instigation of voluntary movement, the storage of memory, thought processes, and reasoning ability. The cerebrum is also concerned with instinctual and limbic (emotional) functions.

Objective 13 Describe the structure of the cerebrum and list the functions of the cerebral lobes.

Objective 14 Define the term *electroencephalogram* and discuss the clinical importance of the EEG.

Objective 15 Describe the fiber tracts within the cerebrum.

Structure of the Cerebrum

The **cerebrum** (*ser'ĕ-brum*), located in the region of the telencephalon, is the largest and most obvious portion of the brain. It accounts for about 80% of the mass of the brain and is responsible for the higher mental functions, including memory and reason. The cerebrum consists of the **right** and **left hemispheres,** which are incompletely separated by a **longitudinal cerebral fissure** (fig. 11.19). Portions of the two hemispheres are connected internally by the **corpus callosum** (*kă-lo'sum*), a large tract of white matter (see fig. 11.17*c*,*d*). A portion of the meninges called the **falx** (*falks*) **cerebri** extends into the longitudinal fissure. Each cerebral hemisphere contains a central cavity, the **lateral ventricle** (fig. 11.20), which is lined with ependymal cells and filled with cerebrospinal fluid.

The two cerebral hemispheres carry out different functions. In most people, the left hemisphere controls analytical and verbal skills, such as reading (see fig. 11.18), writing, and mathematics. The right hemisphere is the source of spatial and artistic kinds of intelligence. The corpus callosum unifies attention and awareness between the two hemispheres and permits a sharing of learning and memory.

Severing the corpus callosum is a radical treatment for controlling severe epileptic seizures. Although this surgery has proven successful, it results in the cerebral hemispheres functioning as separate structures, each with its own information, competing for control. A more recent and effective technique of controlling epileptic seizures is a precise laser treatment of the corpus callosum.

The cerebrum consists of two layers. The surface layer, referred to as the **cerebral cortex,** is composed of gray matter that is 2–4 mm (0.08–0.16 in.) thick (fig. 11.20). Beneath the cerebral cortex is the thick **white matter** of the cerebrum, which constitutes the second layer. The cerebral cortex is characterized by numerous folds and grooves called **convolutions.** Convolutions form during early fetal development, when brain size increases rapidly and the cortex enlarges out of proportion to the underlying white matter. The elevated folds of the convolutions are the **cerebral gyri** (*jī'ri'*—singular, *gyrus*), and the depressed grooves are the **cerebral sulci** (*sul'si*—singular, *sulcus*). The convolutions effectively triple the area of the gray matter, which is composed of nerve cell bodies.

Recent studies indicate that increased learning is accompanied by an increase in the number of synapses between neurons within the cerebrum. Although the number of neurons is established during prenatal development, the number of synapses is variable depending upon the learning process. The number of cytoplasmic extensions from the cell body of a neuron determines the extent of action potential conduction and the associations that can be made to cerebral areas already containing stored information.

Lobes of the Cerebrum

Each cerebral hemisphere is subdivided into five lobes by deep sulci or fissures. Four of these lobes appear on the surface of the cerebrum and are named according to the overlying cranial bones (fig. 11.21). The reasons for the separate cerebral lobes, as well as two cerebral hemispheres, have to do with specificity of function (table 11.4).

Frontal Lobe

The frontal lobe forms the anterior portion of each cerebral hemisphere (fig. 11.21). A prominent deep furrow called the **central sulcus** (fissure of Rolando) separates the frontal lobe from the parietal lobe. The central sulcus extends at right angles from the longitudinal fissure to the lateral sulcus. The **lateral sulcus** (fissure of Sylvius) extends laterally from the inferior surface of the cerebrum to separate the frontal and temporal lobes. The **precentral gyrus** (see figs. 11.19 and 11.21), an important motor area, is positioned immediately in front of the central sulcus. The frontal lobe's functions include initiating voluntary motor impulses for the movement of skeletal muscles, analyzing sensory experiences, and providing responses relating to personality. The frontal lobes also mediate responses related to memory, emotions, reasoning, judgment, planning, and verbal communication.

Parietal Lobe

The parietal lobe lies posterior to the central sulcus of the frontal lobe. An important sensory area called the **postcentral gyrus** (see figs. 11.19 and 11.21) is positioned immediately behind the central sulcus. The postcentral gyrus is designated as a somatesthetic area because it responds to stimuli from cutaneous and muscular receptors throughout the body.

cerebrum: L. *cerebrum*, brain

gyrus: Gk. *gyros*, circle

sulcus: L. *sulcus*, a furrow or ditch

fissure of Rolando: from Luigi Rolando, Italian anatomist, 1773–1831

fissure of Sylvius: from Franciscus Sylvius del la Boë, Dutch anatomist, 1614–72

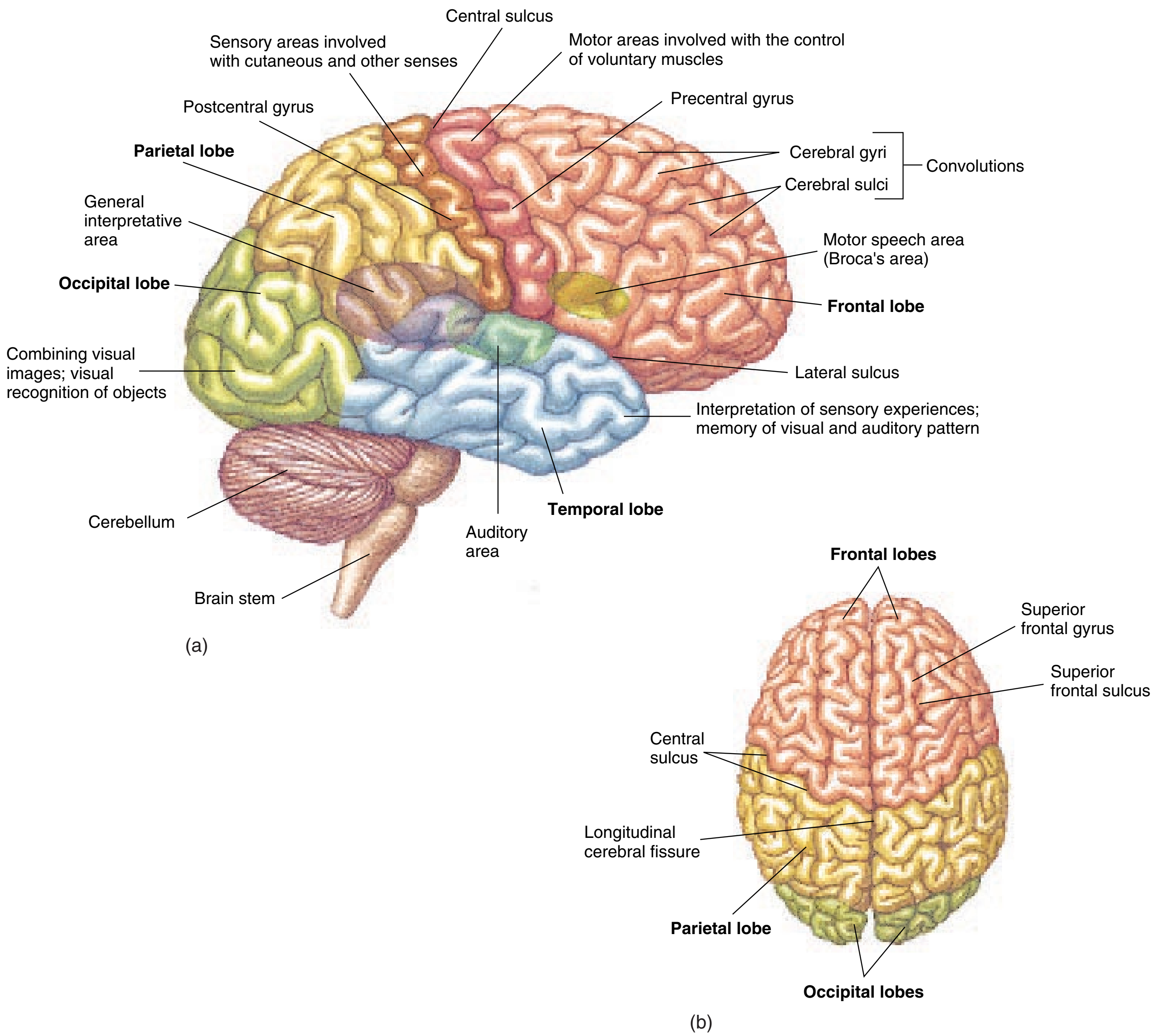


FIGURE 11.19 The cerebrum. (*a*) A lateral view and (*b*) a superior view. (The cerebral lobes are color-coded and labeled in boldface type.)

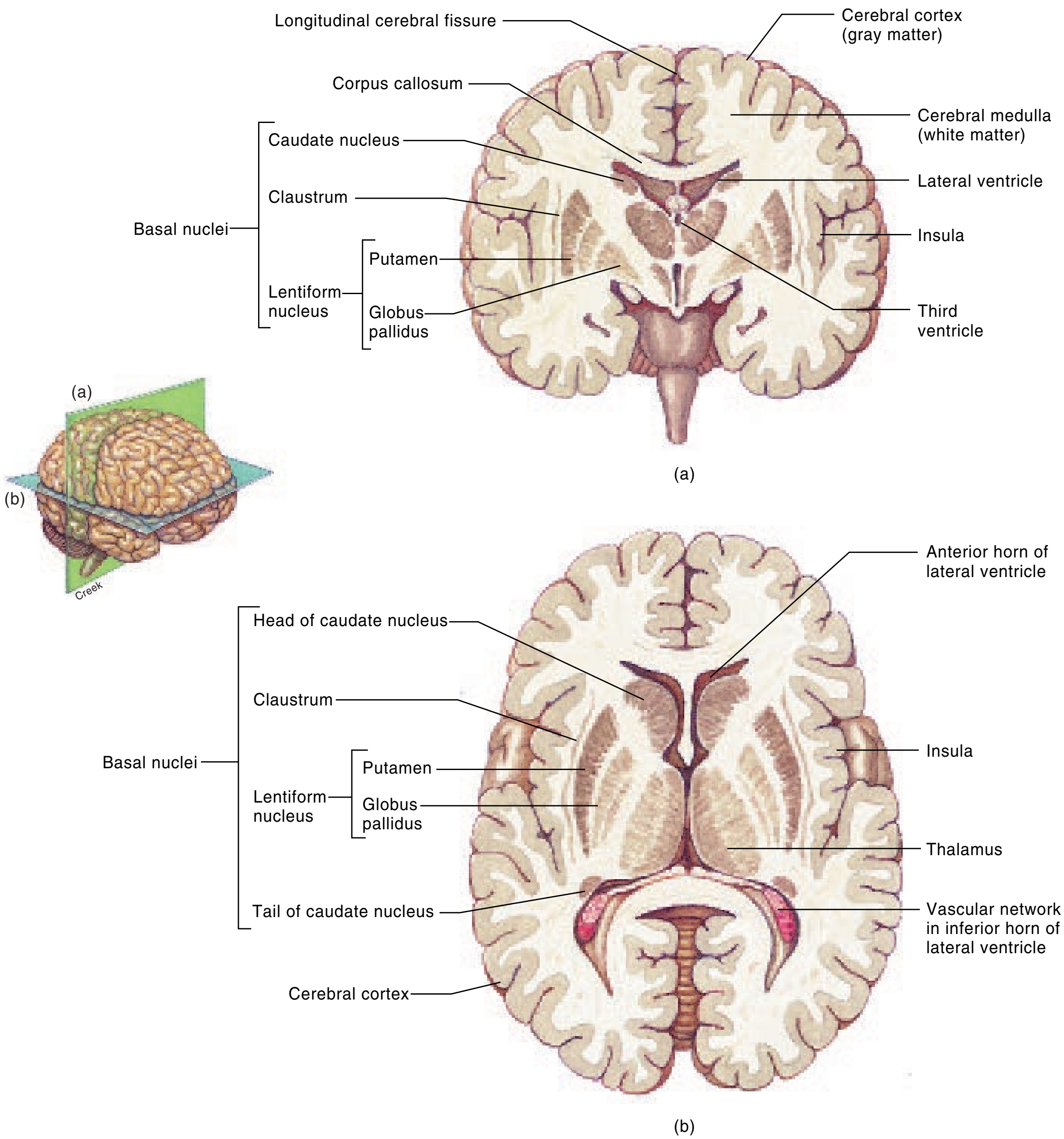


FIGURE 11.20 Sections through the cerebrum and diencephalon. (*a*) A coronal view and (*b*) a cross section.

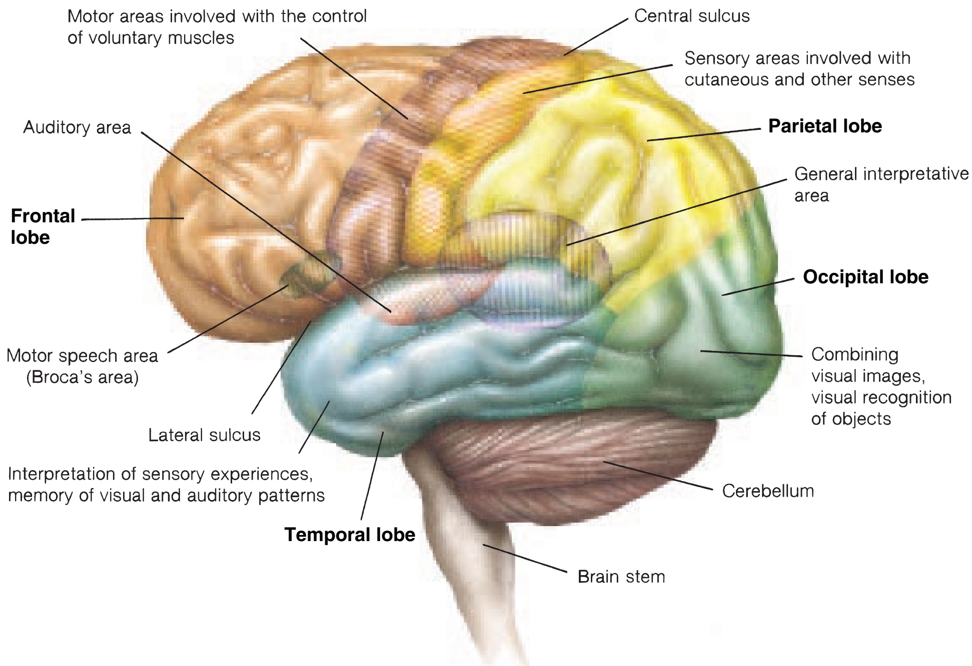


FIGURE 11.21 The lobes of the left cerebral hemisphere showing the principal motor and sensory areas of the cerebral cortex.

TABLE 11.4 Functions of the Cerebral Lobes

Lobe	Functions	Lobe	Functions
Frontal	Voluntary motor control of skeletal muscles; personality; higher intellectual processes (e.g., concentration, planning, and decision making); verbal communication	Temporal	Interpretation of auditory sensations; storage (memory) of auditory and visual experiences
Parietal	Somatesthetic interpretation (e.g., cutaneous and muscular sensations); understanding speech and formulating words to express thoughts and emotions; interpretation of textures and shapes	Occipital	Integration of movements in focusing the eye; correlation of visual images with previous visual experiences and other sensory stimuli; conscious perception of vision
		Insula	Memory; integration of other cerebral activities

Portions of the precentral gyrus responsible for motor movement and portions of the postcentral gyrus that respond to sensory stimuli do not correspond in size to the part of the body being served, but rather to the number of motor units activated or to the density of receptors (fig. 11.22). For example, because the hand has many motor units and sensory receptors, larger portions of the precentral and postcentral gyri serve it than serve the thorax, even though the thorax is much larger.

In addition to responding to somatesthetic stimuli, the parietal lobe functions in understanding speech and in articulating thoughts and emotions. The parietal lobe also interprets the textures and shapes of objects as they are handled.

Temporal Lobe

The temporal lobe is located below the parietal lobe and the posterior portion of the frontal lobe. It is separated from both by the lateral sulcus (see fig. 11.21). The temporal lobe contains auditory centers that receive sensory fibers from the cochlea of the ear. This lobe also interprets some sensory experiences and stores memories of both auditory and visual experiences.

Occipital Lobe

The occipital lobe forms the posterior portion of the cerebrum and is not distinctly separated from the temporal and parietal lobes (see fig. 11.21). It lies superior to the cerebellum and is sep-

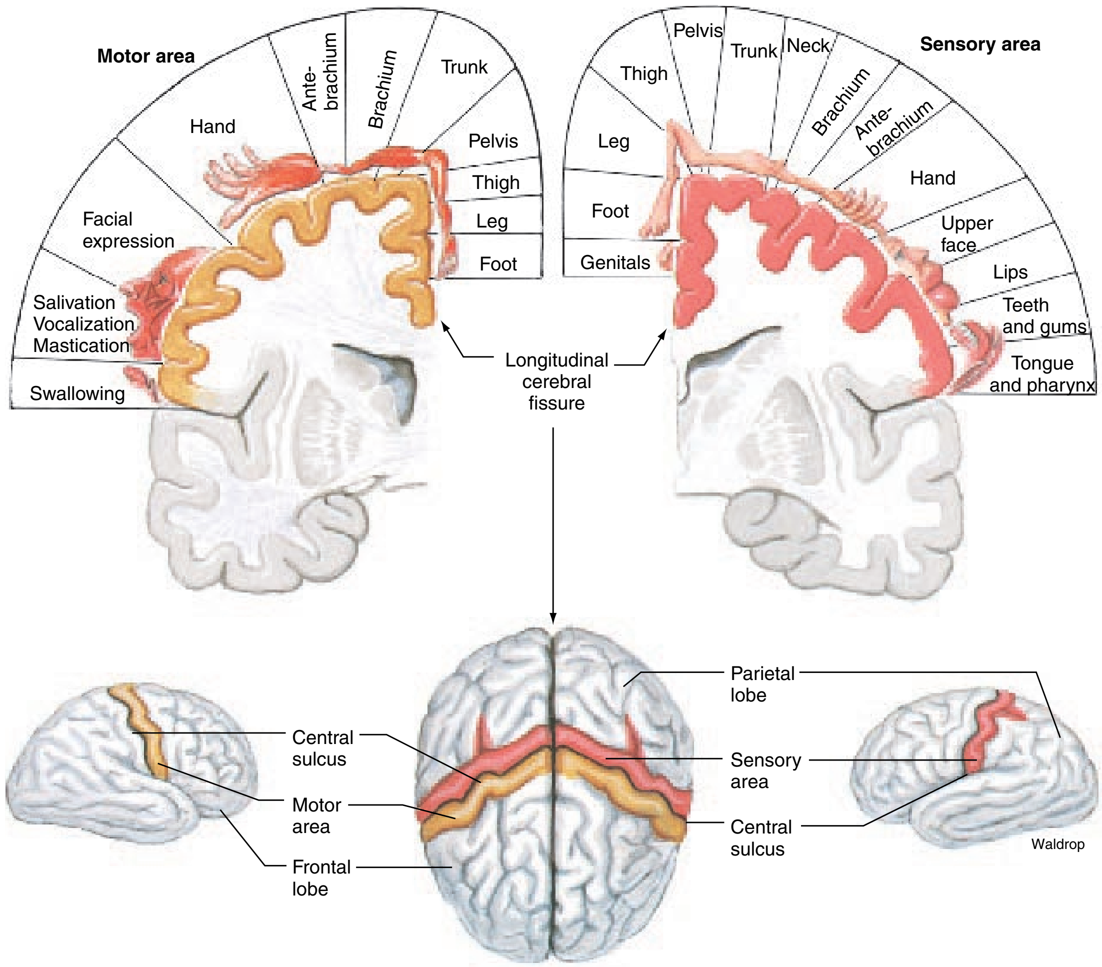


FIGURE 11.22 Motor and sensory areas of the cerebral cortex. Motor areas control skeletal muscles and sensory areas receive somatesthetic sensations.

arated from it by an infolding of the meningeal layer called the **tentorium cerebelli** (*ten-to're-um ser''ĕ-bel'i*). The principal functions of the occipital lobe concern vision. It integrates eye movements by directing and focusing the eye. It is also responsible for visual association—correlating visual images with previous visual experiences and other sensory stimuli.

Insula

The insula is a deep lobe of the cerebrum that cannot be viewed on the surface (see fig. 11.20). It lies deep to the lateral sulcus and is covered by portions of the frontal, parietal, and temporal lobes. Little is known of the function of the insula except that it integrates other cerebral activities. It is also thought to have some function in memory.

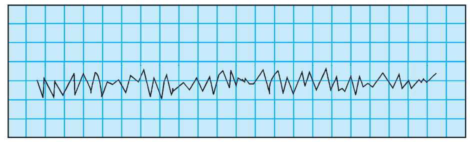
Because of its size and position, portions of the cerebrum frequently suffer brain trauma. A concussion to the brain may cause a temporary or permanent impairment of cerebral functions. Much of what is known about cerebral function comes from observing body dysfunctions when specific regions of the cerebrum are traumatized.

Brain Waves

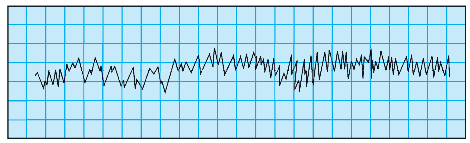
Neurons within the cerebral cortex continuously generate electrical activity. This activity can be recorded by electrodes attached to precise locations on the scalp, producing an **electroencephalogram** (*ĕ-lek''tro-en-sef'ă-lŏ-gram*) (**EEG**). An EEG pattern, commonly called *brain waves,* is the collective expression of millions of action potentials from cerebral neurons.

TABLE 11.5 EEG Patterns

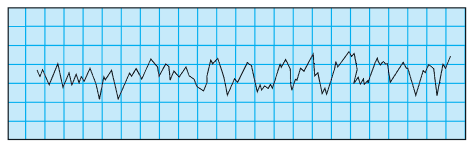
Alpha waves—recorded on the scalp over the parietal and occipital regions while a person is awake and relaxed, but with the eyes closed; rhythmic oscillation at about 10 to 12 cycles/sec; in a child under the age of 8, at 4 to 7 cycles/sec.



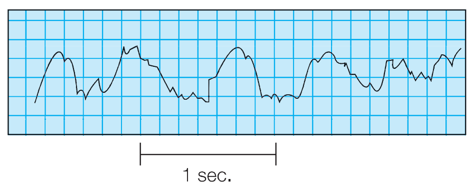
Beta waves—recorded on the scalp over the precentral gyrus of the frontal region while a person is experiencing visual and mental activity; rhythmic oscillation at about 13 to 25 cycles/sec.



Theta waves—recorded on the scalp over the temporal and occipital lobes while a person is awake and relaxed; rhythmic oscillation at about 5 to 8 cycles/sec; typical in newborns, but its presence in an adult generally indicates severe emotional stress and can be a forewarning of a nervous breakdown.



Delta waves—recorded on the scalp over all the cerebral lobes while a person is asleep; rhythmic oscillation at about 1 to 5 cycles/sec; typical in an awake infant, but its presence in an awake adult indicates brain damage.



Brain waves are first emitted from a developing brain during early fetal development and continue throughout a person's life. The cessation of brain-wave patterns (a "flat EEG") may be a decisive factor in the legal determination of death.

Certain distinct EEG patterns signify healthy mental functions. Deviations from these patterns are of clinical significance in diagnosing trauma, mental depression, hematomas, tumors, infections, and epileptic lesions. Normally, there are four kinds of EEG patterns (Table 11.5).

White Matter of the Cerebrum

The thick white matter of the cerebrum is deep to the cerebral cortex (see fig. 11.20) and consists of dendrites, myelinated axons, and associated neuroglia. These fibers form the billions of connections within the brain by which information is transmitted to the appropriate places in the form of electrical impulses. The three types of fiber tracts within the white matter are named according to location and the direction in which they conduct impulses (fig. 11.23).

1. **Association fibers** are confined to a given cerebral hemisphere and conduct impulses between neurons within that hemisphere.
2. **Commissural** (*kă-mĭ-shur'al*) **fibers** connect the neurons and gyri of one hemisphere with those of the other. The **corpus callosum** and **anterior commissure** (fig. 11.24) are composed of commissural fibers.
3. **Projection fibers** form the ascending and descending tracts that transmit impulses from the cerebrum to other parts of the brain and spinal cord and from the spinal cord and other parts of the brain to the cerebrum.

Basal Nuclei

The **basal nuclei** are specialized paired masses of gray matter located deep within the white matter of the cerebrum (figs. 11.20 and 11.25). The most prominent of the basal nuclei is the **corpus striatum** (*stri-a'tum*), so named because of its striped appearance. The corpus striatum is composed of several masses of nuclei. The **caudate nucleus** is the upper mass. A thick band of white matter lies between the caudate nucleus and the next two masses underneath, collectively called the **lentiform nucleus.** The lentiform nucleus consists of a lateral

corpus striatum: L. *corpus*, body; *striare*, striped

lentiform: L. *lentis*, elongated

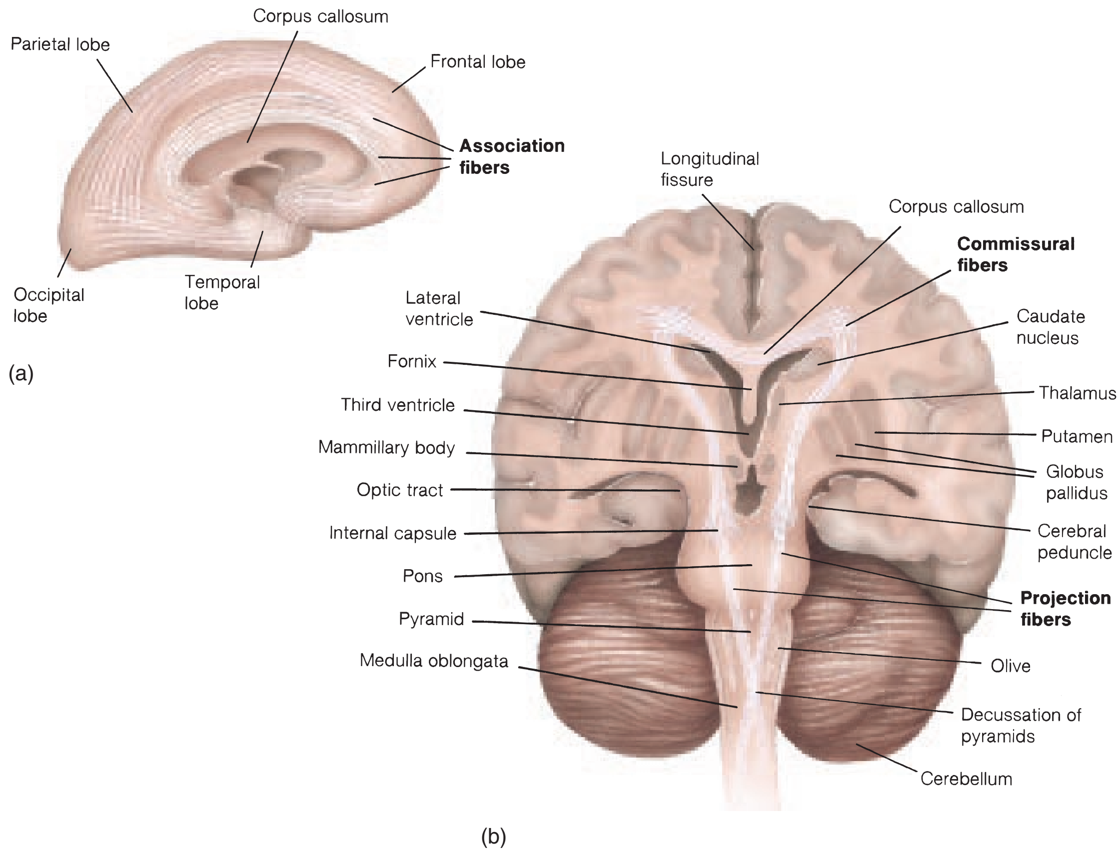


FIGURE 11.23 Types of fiber tracts within the white matter associated with the cerebrum. (*a*) Association fibers of a given hemisphere and (*b*) commissural fibers connecting the hemispheres and projection fibers connecting the cerebral hemispheres with other structures of the CNS. (Note the decussation [crossing-over] of projection fibers within the medulla oblongata.)

portion, called the **putamen** (*pyoo-ta'men*), and a medial portion, called the **globus pallidus** (fig. 11.25). The **claustrum** (*klos'trum*) is another portion of the basal nuclei. It is a thin layer of gray matter, lying just deep to the cerebral cortex of the insula.

The basal nuclei are associated with other structures of the brain, particularly within the mesencephalon. The caudate nucleus and putamen of the basal nuclei control unconscious contractions of certain skeletal muscles, such as those of the upper extremities involved in involuntary arm movements during walking. The globus pallidus regulates the muscle tone necessary for specific intentional body movements. Neural diseases or physical trauma to the basal nuclei generally cause a variety of motor movement dysfunctions, including rigidity, tremor, and rapid and aimless movements.

Language

Knowledge of the brain regions involved in language has been gained primarily by the study of *aphasias*—speech and language disorders caused by damage to specific language areas of the brain. These areas (fig. 11.26) are generally located in the cerebral cortex of the left hemisphere in both right-handed and left-handed people.

The **motor speech area** (Broca's area) is located in the left inferior gyrus of the frontal lobe. Neural activity in the motor speech area causes selective stimulation of motor impulses in motor centers elsewhere in the frontal lobe, which in turn causes coordinated skeletal muscle movement in the pharynx and larynx. At the same time, motor impulses are sent to

putamen: L. *putare*, to cut, prune
globus pallidus: L. *globus*, sphere; *pallidus*, pale

aphasia: L. *a*, without; Gk. *phasis*, speech
Broca's area: from Pierre P. Broca, French neurologist, 1824–80

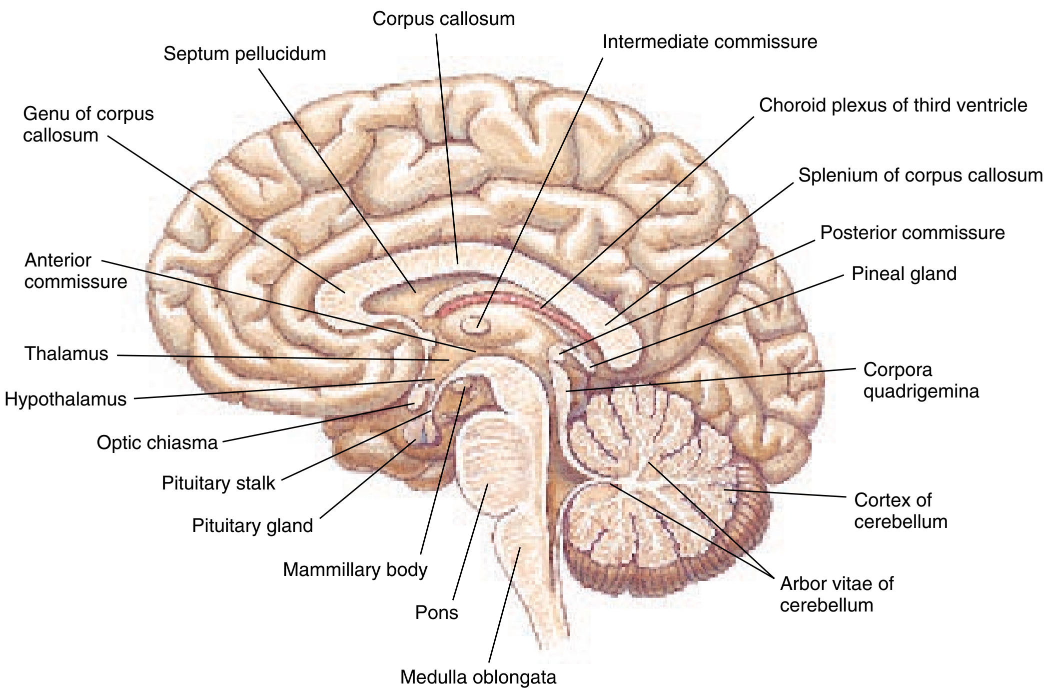


FIGURE 11.24 A midsagittal section through the brain.

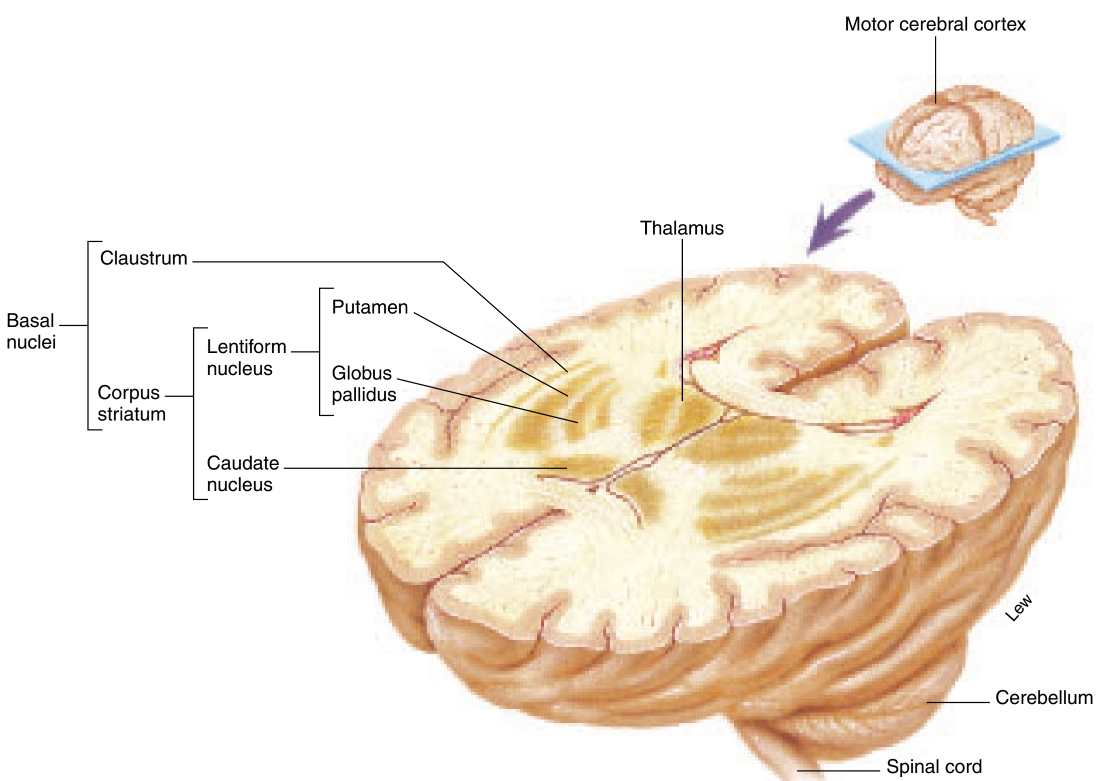


FIGURE 11.25 Structures of the cerebrum containing nuclei involved in the control of skeletal muscles. The thalamus is a relay center between the motor cerebral cortex and the other brain areas.

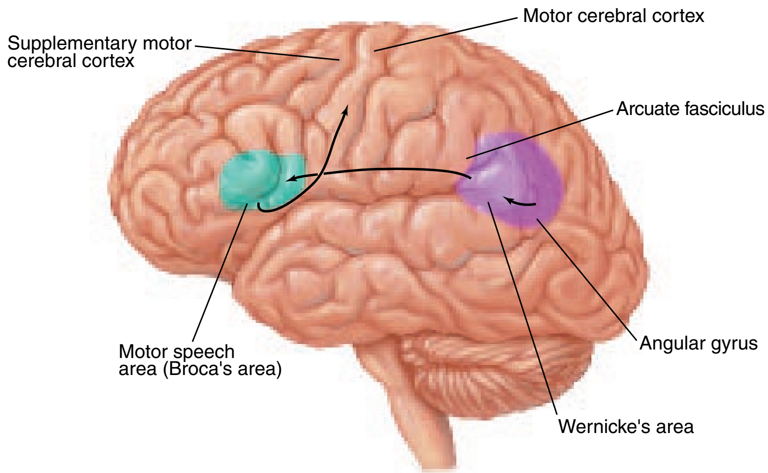


FIGURE 11.26 Brain areas involved in the control of speech. Arrows indicate the direct communication between these areas.

the respiratory muscles to regulate air movement across the vocal folds. The combined muscular stimulation translates thought patterns into speech.

Wernicke's (*ver'nĭ-kēz*) **area** is located in the superior gyrus of the temporal lobe and is directly connected to the motor speech area by a fiber tract called the **arcuate fasciculus.** People with *Wernicke's aphasia* produce speech that has been described as a "word salad." The words used may be real words that are randomly mixed together, or they may be made-up words. Language comprehension has been destroyed in people with Wernicke's aphasia; they cannot understand either spoken or written language.

It appears that the concept of words to be spoken originates in Wernicke's area and is then communicated to the motor speech area through the arcuate fasciculus. Damage to the arcuate fasciculus produces *conduction aphasia,* which is fluent but nonsensical speech as in Wernicke's aphasia, even though both the motor speech area and Wernicke's area are intact.

The **angular gyrus,** located at the junction of the parietal, temporal, and occipital lobes, is believed to be a center for the integration of auditory, visual, and somatesthetic information. Damage to the angular gyrus produces aphasias, which suggests that this area projects to Wernicke's area. Some patients with damage to the left angular gyrus can speak and understand spoken language but cannot read or write. Other patients can write a sentence but cannot read it, presumably because of damage to the projections from the occipital lobe (involved in vision) to the angular gyrus.

Recovery of language ability, by transfer to the right hemisphere after damage to the left hemisphere, is very good in children but decreases after adolescence. Recovery is reported to be faster in left-handed people, possibly because language ability is more evenly divided between the two hemispheres in left-handed people. Some recovery usually occurs after damage to the motor speech area, but damage to Wernicke's area produces more severe and permanent aphasias.

Knowledge Check

13. Diagram a lateral view of the cerebrum and label the four superficial lobes and the fissures that separate them.
14. List the functions of each of the paired cerebral lobes.
15. What is a brain-wave pattern? How are these patterns monitored clinically?
16. Describe the arrangement of the fiber tracts within the cerebrum.
17. Name and describe the basal nuclei and list their functions.
18. Describe the aphasias that result from damage to the motor speech area and Wernicke's area from damage to the arcuate fasciculus and from damage to the angular gyrus. Explain how these areas may interact in the production of speech.

Wernicke's area: from Karl Wernicke, German neurologist, 1848–1905

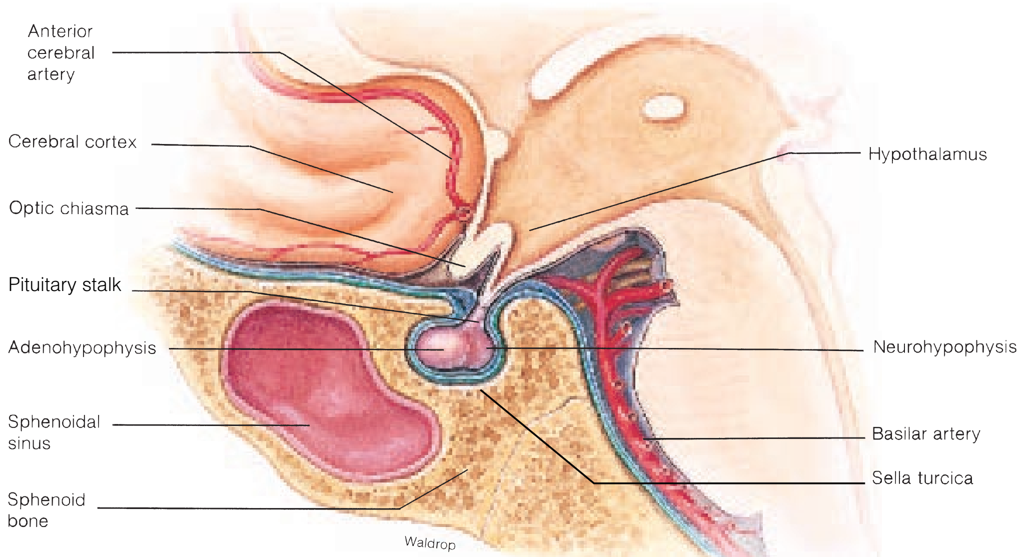


FIGURE 11.27 The pituitary gland is positioned within the sella turcica of the sphenoid bone and is attached to the brain by the pituitary stalk.

DIENCEPHALON

The diencephalon is a major autonomic region of the brain that consists of such vital structures as the thalamus, hypothalamus, epithalamus, and pituitary gland.

Objective 16 List the autonomic functions of the thalamus and the hypothalamus.

Objective 17 Describe the location and structure of the pituitary gland.

The **diencephalon** (*di''en-sef'ă-lon*) is the second subdivision of the forebrain and is almost completely surrounded by the cerebral hemispheres of the telencephalon. The third ventricle (see fig. 11.36) is a narrow midline cavity within the diencephalon. The most important structures of the diencephalon are the *thalamus*, *hypothalamus*, *epithalamus*, and *pituitary gland*.

Thalamus

The **thalamus** (*thal'ă-mus*) is a large oval mass of gray matter, constituting nearly four-fifths of the diencephalon. It is actually a paired organ, with each portion positioned immediately below the lateral ventricle of its respective cerebral hemisphere (see figs. 11.24 and 11.25). The principal function of the thalamus is to act as a relay center for all sensory impulses, except smell, to the cerebral cortex. Specialized masses of nuclei relay the incoming impulses to precise locations within the cerebral lobes for interpretation.

The thalamus also performs some sensory interpretation. The cerebral cortex discriminates pain and other tactile stimuli, but the thalamus responds to general sensory stimuli and provides crude awareness. The thalamus probably plays a role in the initial autonomic response of the body to intense pain, and is therefore partially responsible for the physiological shock that frequently follows serious trauma.

Hypothalamus

The **hypothalamus** (*hi''po-thal'ă-mus*), named for its position below the thalamus, is the most inferior portion of the diencephalon. It forms the floor and part of the lateral walls of the third ventricle (figs. 11.24 and 11.27) and contains several masses of nuclei that are interconnected with other parts of the nervous system. Despite its small size, the hypothalamus performs numerous vital functions, most of which relate directly or indirectly to the regulation of visceral activities. It also has emotional and instinctual functions (see also fig. 14.12).

The hypothalamus acts as an autonomic nervous center in accelerating or decelerating certain body functions. It secretes several hormones, including two released from the posterior pituitary. These hormones and their functions are discussed in chapter 14. The principal autonomic and limbic (emotional) functions of the hypothalamus are as follows:

1. **Cardiovascular regulation.** Although the heart has an innate pattern of contraction, impulses from the hypothalamus cause autonomic acceleration or deceleration of the heart rate. Impulses from the posterior hypothalamus produce a rise in arterial blood pressure and an increase of the heart rate. Impulses from the anterior portion have the op-

thalamus: L. *thalamus*, inner room

posite effect. Rather than traveling directly to the heart, impulses from these regions pass first to the cardiovascular centers of the medulla oblongata.

2. **Body-temperature regulation.** Specialized nuclei within the anterior portion of the hypothalamus are sensitive to changes in body temperature. If the arterial blood flowing through this portion of the hypothalamus is above normal temperature, the hypothalamus initiates impulses that cause heat loss through sweating and vasodilation of cutaneous vessels of the skin. A below-normal blood temperature causes the hypothalamus to relay impulses that result in heat production and retention through shivering, contraction of cutaneous blood vessels, and cessation of sweating (see fig. 5.9).
3. **Regulation of water and electrolyte balance.** Specialized *osmoreceptors* in the hypothalamus continuously monitor the osmotic concentration of the blood. An increased osmotic concentration resulting from lack of water causes the production of antidiuretic hormone (ADH) by the hypothalamus and its release from the posterior pituitary. At the same time, a *thirst center* within the hypothalamus produces feelings of thirst.
4. **Regulation of hunger and control of gastrointestinal activity.** The *feeding center* is a specialized portion of the lateral hypothalamus that monitors blood glucose, fatty acid, and amino acid levels. Low levels of these substances in the blood are partially responsible for a sensation of hunger elicited from the hypothalamus. When enough food has been eaten, the *satiety (să-ti′ĭ-te) center* in the midportion of the hypothalamus inhibits the feeding center. The hypothalamus also receives sensory impulses from the abdominal viscera and regulates glandular secretions and the peristaltic movements of the GI tract.
5. **Regulation of sleeping and wakefulness.** The hypothalamus has both a *sleep center* and a *wakefulness center* that function with other parts of the brain to determine the level of conscious alertness.
6. **Sexual response.** Specialized *sexual center* nuclei within the superior portion of the hypothalamus respond to sexual stimulation of the tactile receptors within the genital organs. The experience of orgasm involves neural activity within the sexual center of the hypothalamus.
7. **Emotions.** A number of nuclei within the hypothalamus are associated with specific emotional responses, including anger, fear, pain, and pleasure (see fig. 14.12).
8. **Control of endocrine functions.** The hypothalamus produces neurosecretory chemicals that stimulate the anterior and posterior pituitary to release various hormones.

The hypothalamus is a vital structure in maintaining overall body homeostasis. Dysfunction of the hypothalamus may seriously affect autonomic, somatic, or psychic body functions. Not surprisingly, this organ is implicated as a principal factor in *psychosomatic illness.* Insomnia, peptic ulcers, palpitation of the heart, diarrhea, and constipation are a few symptoms of psychophysiologic disorders.

Epithalamus

The **epithalamus** is the posterior portion of the diencephalon that forms a thin roof over the third ventricle. The inside lining of the roof consists of a vascular **choroid plexus,** where cerebrospinal fluid is produced (see fig. 11.24). A small mass of tissue called the **pineal** (*pin′e-al*) **gland,** named for its resemblance to a pine cone, extends outward from the posterior end of the epithalamus (see fig. 11.24). It is thought to have a neuroendocrine function. The **posterior commissure,** located inferior to the pineal gland, is a tract of commissural fibers that connects the right and left superior colliculi of the midbrain (see fig. 11.24).

Pituitary Gland

The rounded, pea-shaped **pituitary gland,** or **cerebral hypophysis** (*hi-pof′ĭ-sis*), is positioned on the inferior aspect of the diencephalon. It is attached to the hypothalamus by the funnel-shaped pituitary stalk and is supported by the sella turcica of the sphenoid bone (fig. 11.27). The pituitary, which has an endocrine function, is structurally and functionally divided into an anterior portion, called the **adenohypophysis** (*ad″ĕ-no-hi-pof′ĭ-sis*), and a posterior portion, called the **neurohypophysis** (see chapter 14).

Knowledge Check

19. What is meant by the statement that the thalamus is the pain center of the brain?
20. List the body systems and functions over which the hypothalamus has some control.
21. What are the components of the epithalamus?
22. Describe the location of the pituitary gland relative to the rest of the diencephalon and the rest of the brain. What are the two portions of the pituitary gland?

MESENCEPHALON

The mesencephalon contains the corpora quadrigemina, concerned with visual and auditory reflexes, and the cerebral peduncles, composed of fiber tracts. It also contains specialized nuclei that help control posture and movement.

Objective 18 List the structures of the mesencephalon and explain their functions.

The *brain stem* contains nuclei for autonomic functions of the body and their connecting tracts. It is that portion of the brain that attaches to the spinal cord and includes the midbrain, pons,

pineal: L. *pinea*, pine cone

pituitary: L. *pituita*, phlegm (this gland was originally thought to secrete mucus into nasal cavity)

adenohypophysis: Gk. *adeno*, gland; *hypo*, under; *physis*, a growing

CHAPTER 11

and medulla oblongata. The **mesencephalon** (*mes''en-sef'ă-lon*), or midbrain, is the short section of the brain stem between the diencephalon and the pons (see fig. 11.30). Within the midbrain is the **mesencephalic aqueduct** (aqueduct of Sylvius) (see figs. 11.36 and 11.38), which connects the third and fourth ventricles. The midbrain also contains the corpora quadrigemina (see fig. 11.24), the cerebral peduncles (see fig. 11.23), the *red nucleus*, and the *substantia nigra*.

The **corpora quadrigemina** (*kwad''rĭ-jem-ĭ-nă*) are the four rounded elevations on the posterior portion of the midbrain. The two upper eminences, the **superior colliculi** (*ko-lik'yŭ-li*), are concerned with visual reflexes. The two posterior eminences, the **inferior colliculi,** are responsible for auditory reflexes. The **cerebral peduncles** (*pĕ-dung'kulz*) are a pair of cylindrical structures composed of ascending and descending projection fiber tracts that support and connect the cerebrum to the other regions of the brain.

The **red nucleus** lies deep within the midbrain between the cerebral peduncle and the cerebral aqueduct. It connects the cerebral hemispheres and the cerebellum and functions in reflexes concerned with motor coordination and maintenance of posture. Its reddish color is due to its rich blood supply and an iron-containing pigment in the cell bodies of its neurons. Another nucleus, the **substantia nigra** (*ni'gră*), lies inferior to the red nucleus. The substantia nigra is thought to inhibit forced involuntary movements. Its dark color reflects its high content of melanin pigment.

CHAPTER 11

Knowledge Check

23. Describe symptoms that might indicate a tumor in the midbrain.
24. Which structures of the midbrain function with the cerebellum in controlling posture and movement?

METENCEPHALON

The metencephalon contains the pons, which relays impulses, and the cerebellum, which coordinates skeletal muscle contractions.

Objective 19 Describe the location and structure of the pons and cerebellum and list their functions.

The **metencephalon** (*met''en-sef'ă-lon*) is the most superior portion of the hindbrain. Two vital structures of the metencephalon are the *pons* and *cerebellum*. The mesencephalic aqueduct of the mesencephalon enlarges to become the **fourth ventricle** (see fig. 11.36) within the metencephalon and myelencephalon.

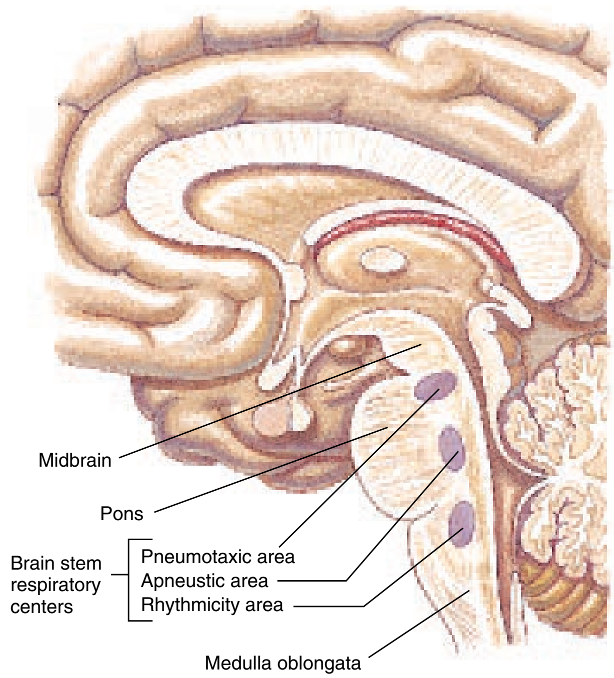


FIGURE 11.28 Nuclei within the pons and medulla oblongata that constitute the respiratory center.

Pons

The **pons** can be observed as a rounded bulge on the inferior surface of the brain, between the midbrain and the medulla oblongata (fig. 11.28). It consists of white fiber tracts that course in two principal directions. The surface fibers extend transversely to connect with the cerebellum through the middle cerebellar peduncles. The deeper longitudinal fibers are part of the motor and sensory tracts that connect the medulla oblongata with the tracts of the midbrain.

Scattered throughout the pons are several nuclei associated with specific cranial nerves. The cranial nerves that have nuclei within the pons include the trigeminal (V), which transmits impulses for chewing and sensory sensations from the head; the abducens (VI), which controls certain movements of the eyeball; the facial (VII), which transmits impulses for facial movements and sensory sensations from the taste buds; and the vestibular branches of the vestibulocochlear (VIII), which maintain equilibrium.

Other nuclei of the pons function with nuclei of the medulla oblongata to regulate the rate and depth of breathing. The two respiratory centers of the pons are called the **apneustic** and **pneumotaxic areas** (fig. 11.28).

aqueduct of Sylvius: from Jacobus Sylvius, French anatomist, 1478–1555
corpora quadrigemina: L. *corpus*, body; *quadri*, four; *geminus*, twin
colliculus: L. *colliculus*, small mound

pons: L. *pons*, bridge

Cerebellum

The **cerebellum** (*ser'ĕ-bel'um*) is the second largest structure of the brain. It is located in the metencephalon and occupies the inferior and posterior aspect of the cranial cavity. The cerebellum is separated from the overlying cerebrum by a **transverse fissure.** A portion of the meninges called the **tentorium cerebelli** extends into the transverse fissure. The cerebellum consists of two **hemispheres** and a central constricted area called the **vermis** (fig. 11.29). The **falx cerebelli** is the portion of the meninges that partially extends between the hemispheres.

Like the cerebrum, the cerebellum has a thin outer layer of gray matter, the **cerebellar cortex,** and a thick, deeper layer of white matter. The cerebellum is convoluted into a series of parallel slender **folia.** The tracts of white matter within the cerebellum have a distinctive branching pattern called the **arbor vitae** (*vi'te*) that can be seen in a sagittal view (fig. 11.29*c*).

Three paired bundles of nerve fibers called **cerebellar peduncles** support the cerebellum and provide it with tracts for communicating with the rest of the brain (fig. 11.30). Following is a description of the cerebellar peduncles.

1. **Superior cerebellar peduncles** connect the cerebellum with the midbrain. The fibers within these peduncles originate primarily from specialized **dentate nuclei** within the cerebellum and pass through the red nucleus to the thalamus, and then to the motor areas of the cerebral cortex. Impulses through the fibers of these peduncles provide feedback to the cerebrum.
2. **Middle cerebellar peduncles** convey impulses of voluntary movement from the cerebrum through the pons and to the cerebellum.
3. **Inferior cerebellar peduncles** connect the cerebellum with the medulla oblongata and the spinal cord. They contain both incoming vestibular and proprioceptive fibers and outgoing motor fibers.

The principal function of the cerebellum is coordinating skeletal muscle contractions by recruiting precise motor units within the muscles. Impulses for voluntary muscular movement originate in the cerebral cortex and are coordinated by the cerebellum. The cerebellum constantly initiates impulses to selective motor units for maintaining posture and muscle tone. The cerebellum also processes incoming impulses from **proprioceptors** (*pro''pre-o-sep'torz*) within muscles, tendons, joints, and special sense organs to refine learned movement patterns. A proprioceptor is a sensory nerve ending that is sensitive to changes in the tension of a muscle or tendon.

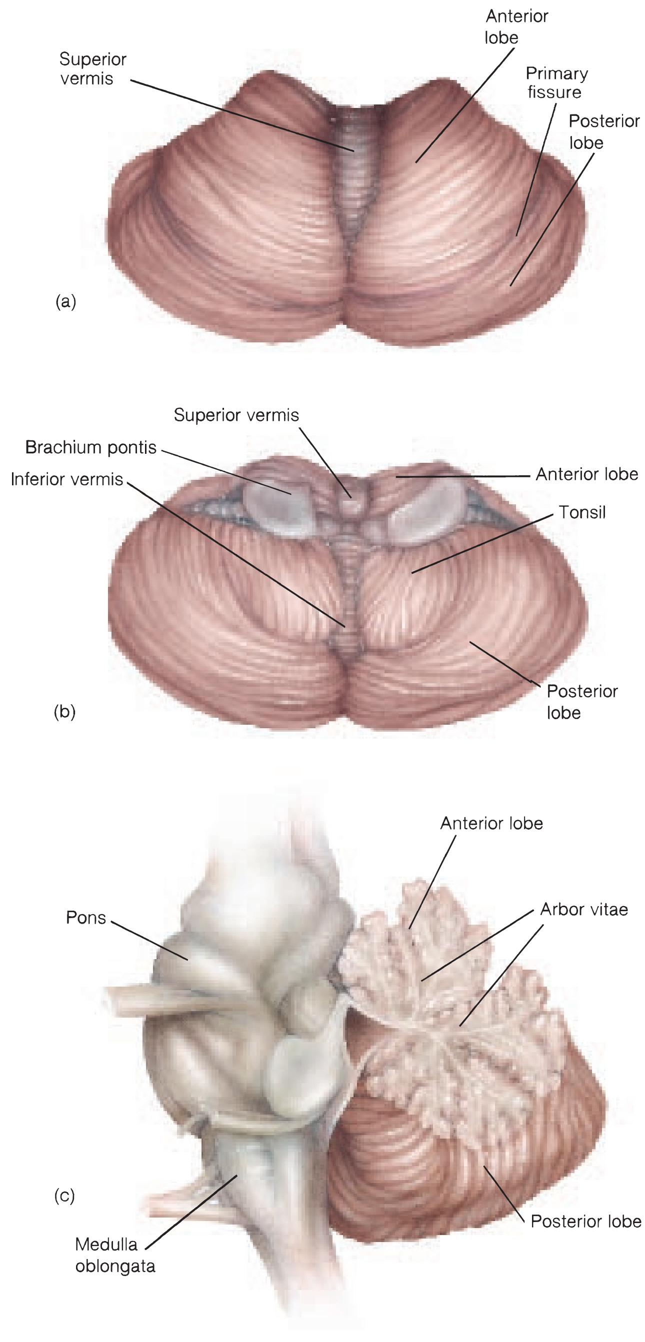


FIGURE 11.29 The structure of the cerebellum. (*a*) A superior view, (*b*) an inferior view, and (*c*) a sagittal view.

cerebellum: L. *cerebellum*, diminutive of *cerebrum*, brain
vermis: L. *vermis*, worm
arbor vitae: L. *arbor*, tree; *vitae*, life
peduncle: L. *peduncle*, diminutive of *pes*, foot

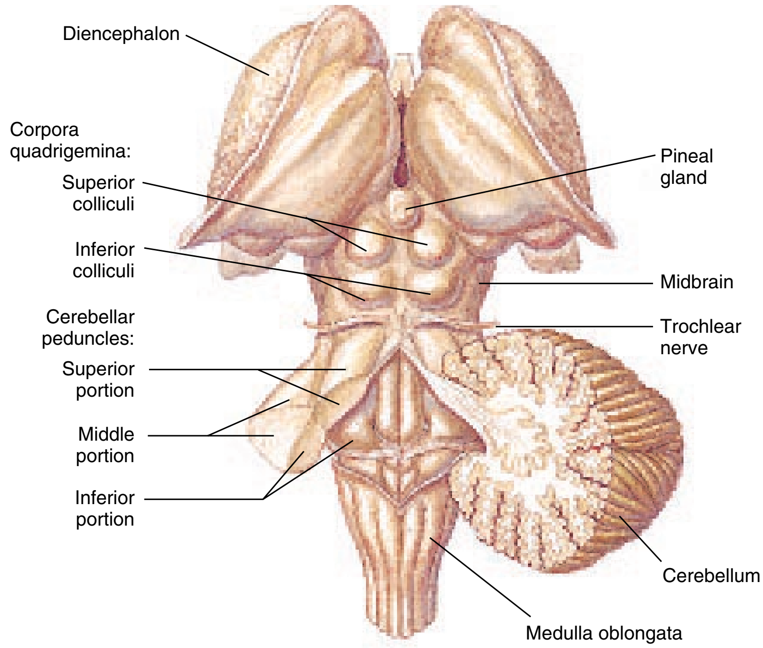


FIGURE 11.30 The cerebellar peduncles can be seen when the cerebellar hemisphere has been removed from its attachment to the brain stem.

Trauma or diseases of the cerebellum, such as a *stroke* or *cerebral palsy,* frequently cause an impairment of skeletal muscle function. Movements become jerky and uncoordinated in a condition known as *ataxia.* There is also a loss of equilibrium, resulting in a disturbance of gait. *Alcohol intoxication* causes similar uncoordinated body movements.

Knowledge Check

25. Describe the locations and relative sizes of the pons and the cerebellum.
26. Which cranial nerves have nuclei located within the pons?
27. Define the terms *tentorium cerebelli*, *vermis*, *arbor vitae*, and *cerebellar peduncles*.
28. List the functions of the pons and the cerebellum.

MYELENCEPHALON

The medulla oblongata, contained within the myelencephalon, connects to the spinal cord and contains nuclei for the cranial nerves and vital autonomic functions.

Objective 20 Describe the location, structure, and functions of the medulla oblongata.

Objective 21 Describe the location and primary functions of the reticular formation.

Medulla Oblongata

The **medulla oblongata** (*mĕ-dul'ă ob''long-gă'tă*) is a bulbous structure about 3 cm (1 in.) long, and it is the most inferior structure of the brain stem. It is continuous with the pons anteriorly and the spinal cord posteriorly at the level of the foramen magnum (see figs. 11.23 and 11.24). Externally, the medulla oblongata resembles the spinal cord, except for two triangular elevations called **pyramids** on the inferior side and an oval enlargement called the **olive** (see fig. 11.23) on each lateral surface. The **fourth ventricle,** the space within the medulla oblongata, is continuous posteriorly with the central canal of the spinal cord and anteriorly with the mesencephalic aqueduct (see figs. 11.36 and 11.38).

The medulla oblongata is composed of vital nuclei and white matter that form all the descending and ascending tracts communicating between the spinal cord and various parts of the brain. Most of the fibers within these tracts cross over to the opposite side through the pyramidal region of the medulla oblongata, permitting one side of the brain to receive information from and send information to the opposite side of the body (see fig. 11.23).

The gray matter of the medulla oblongata consists of several important nuclei for the cranial nerves and sensory relay (fig. 11.31). The **nucleus ambiguus** (*am-big'you-us*) and the **hypoglossal nucleus** are the centers from which arise the glossopharyngeal (IX), accessory (XI), and hypoglossal (XII) nerves. The vestibular nuclei are the center from which arise the

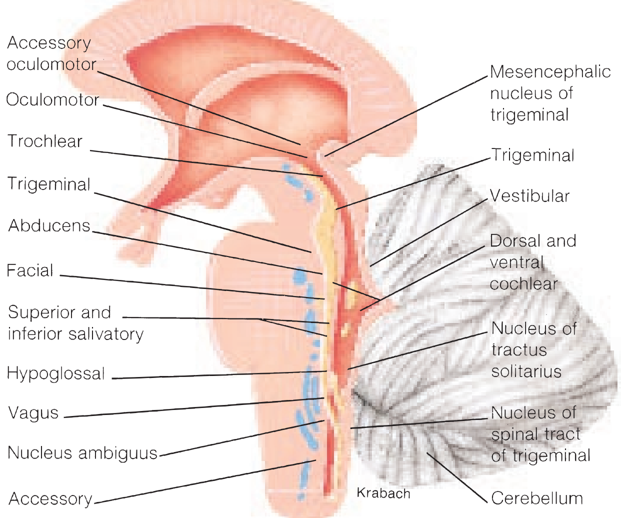


FIGURE 11.31 A sagittal section of the medulla oblongata and pons showing the cranial nuclei of gray matter.

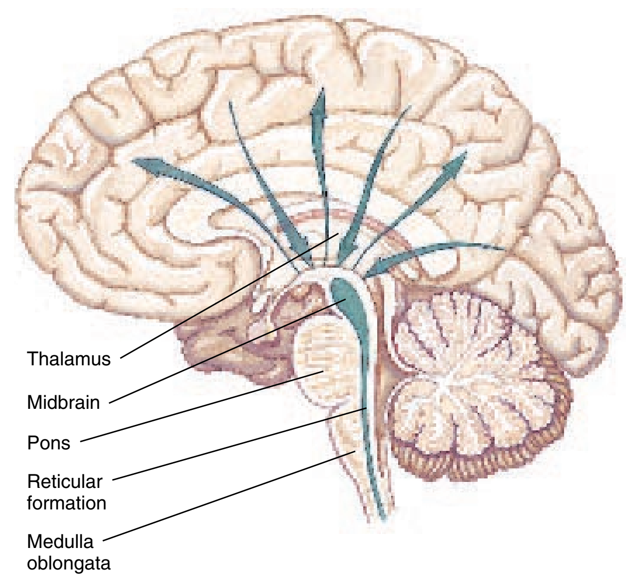


FIGURE 11.32 The reticular activating system. The arrows indicate the direction of impulses along nerve pathways that connect with the RAS.

vestibulocochlear (VIII) nerves. The vagus (X) nerves arise from **vagus nuclei,** one on each lateral side of the medulla oblongata, adjacent to the fourth ventricle. The **nucleus gracilis** (*gras'ĭ-lis*) and the **nucleus cuneatus** (*kyoo-ne-a'tus*) relay sensory information to the thalamus, and the impulses are then relayed to the cerebral cortex via the thalamic nuclei (not illustrated). The **inferior olivary nuclei** and the **accessory olivary nuclei** of the olive mediate impulses passing from the forebrain and midbrain through the inferior cerebellar peduncles to the cerebellum.

Three other nuclei within the medulla oblongata function as autonomic centers for controlling vital visceral functions.

1. **Cardiac center.** Both *inhibitory* and *accelerator fibers* arise from nuclei of the cardiac center. Inhibitory impulses constantly travel through the vagus nerves to slow the heartbeat. Accelerator impulses travel through the spinal cord and eventually innervate the heart through fibers within spinal nerves T1–T5.
2. **Vasomotor center.** Nuclei of the vasomotor center send impulses via the spinal cord and spinal nerves to the smooth muscles of arteriole walls, causing them to constrict and elevate arterial blood pressure.
3. **Respiratory center.** The respiratory center of the medulla oblongata controls the rate and depth of breathing and functions in conjunction with the respiratory nuclei of the pons (see fig. 11.28) to produce rhythmic breathing.

Other nuclei of the medulla oblongata function as centers for reflexes involved in sneezing, coughing, swallowing, and vomiting. Some of these activities (swallowing, for example) may be initiated voluntarily, but once they progress to a certain point they become involuntary and cannot be stopped.

Reticular Formation

The **reticular formation** is a complex network of nuclei and nerve fibers within the brain stem that functions as the *reticular activating system* (*RAS*) in arousing the cerebrum. Portions of the reticular formation are located in the spinal cord, pons, midbrain, and parts of the thalamus and hypothalamus (fig. 11.32). The reticular formation contains ascending and descending fibers from most of the structures within the brain.

Nuclei within the reticular formation generate a continuous flow of impulses unless they are inhibited by other parts of the brain. The principal functions of the RAS are to keep the cerebrum in a state of alert consciousness and to selectively monitor the sensory impulses perceived by the cerebrum. The RAS also helps the cerebellum activate selected motor units to maintain muscle tonus and produce smooth, coordinated contractions of skeletal muscles.

The RAS is sensitive to changes in and trauma to the brain. The sleep response is thought to occur because of a decrease in activity within the RAS, perhaps because of the secretion of specific neurotransmitters. A blow to the head or certain drugs and diseases may damage the RAS, causing unconsciousness. A *coma* is a state of unconsciousness and inactivity of the RAS that even the most powerful external stimuli cannot alter the person's mental state.

Knowledge Check

29. Describe the major reflex centers of the medulla oblongata that regulate autonomic functions.
30. Which cranial nerves arise from the medulla oblongata?
31. Explain the statement that the RAS is the brain's "chief watchguard."

CHAPTER 11

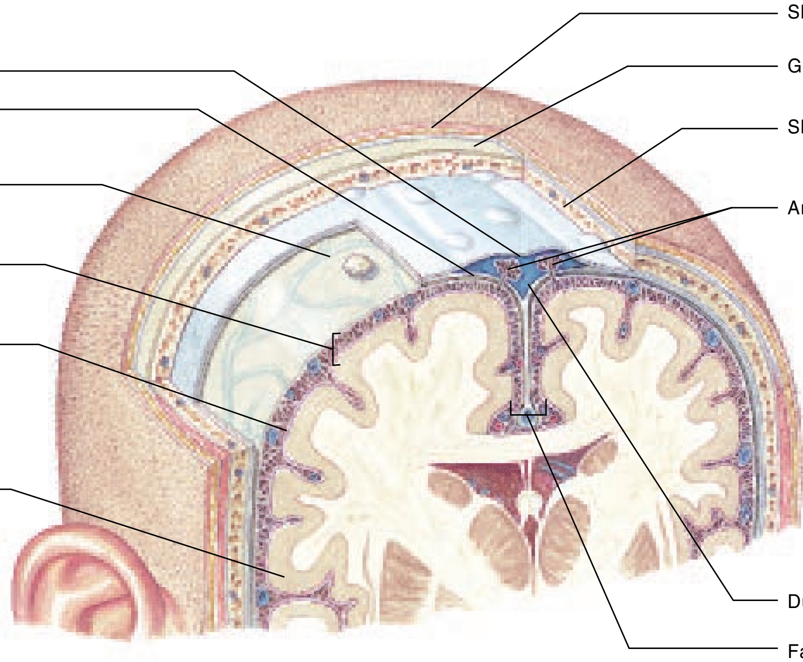


FIGURE 11.33 Meninges and associated structures surrounding the brain. (The meninges are labeled in boldface type.)

MENINGES

The CNS is covered by protective meninges; namely, the dura mater, the arachnoid, and the pia mater.

Objective 22 Describe the position of the meninges as they protect the CNS.

As mentioned previously in the discussion of the brain's general features, the entire delicate CNS is protected by a bony encasement—the cranium surrounding the brain and the vertebral column surrounding the spinal cord. It is also protected by three membranous connective tissue coverings called the **meninges** (figs. 11.33 and 11.34). Individually, from the outside in, they are known as the *dura mater*, the *arachnoid*, and the *pia mater*.

Dura Mater

The **dura mater** (*door'ă ma'ter*) is in contact with the bone and is composed primarily of dense connective tissue. The **cranial dura mater** is a double-layered structure. The outer **periosteal** (*per''e-os'te-al*) **layer** adheres lightly to the cranium, where it constitutes the periosteum (fig. 11.33). The inner **meningeal layer,** which is thinner, follows the general contour of the brain. The **spinal dura mater** is not double layered. It is similar to the meningeal layer of the cranial dura mater.

The two layers of the cranial dura mater are generally fused and cover most of the brain. In certain regions, however, the layers separate, enclosing **dural sinuses** (see fig. 11.33) that collect venous blood and drain it to the internal jugular veins of the neck.

meninges: L. plural form of *meninx*, membrane

dura mater: L. *dura*, hard; *mater*, mother

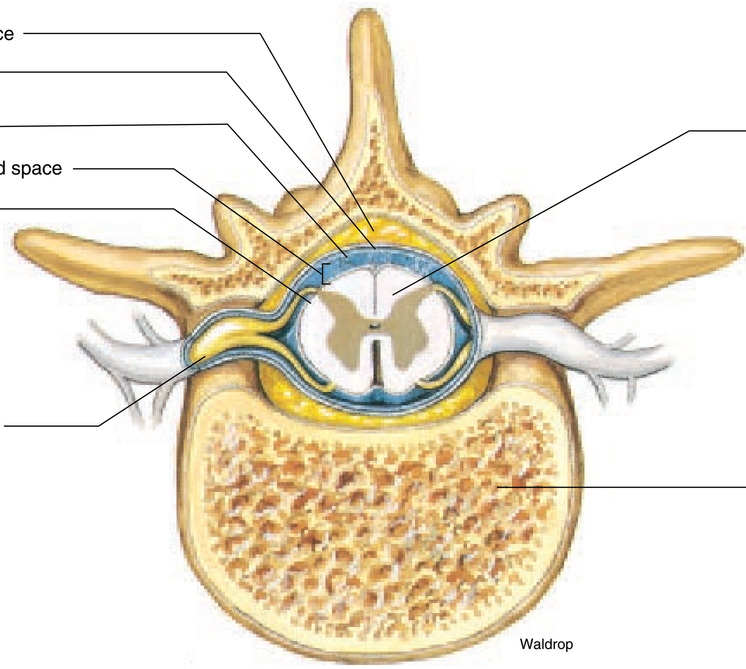


FIGURE 11.34 Meninges and associated structures surrounding the spinal cord. The epidural space in the lower lumbar region is of clinical importance as a site for an epidural block that may be administered to facilitate childbirth.

In four locations, the meningeal layer of the cranial dura mater forms distinct septa to partition major structures on the surface of the brain and anchor the brain to the inside of the cranial case. These septa were identified earlier and are reviewed in table 11.6.

The spinal dura mater (figs. 11.34 and 11.35) forms a tough, tubular **dural sheath** that continues into the vertebral canal and surrounds the spinal cord. There is no connection between the dural sheath and the vertebrae forming the vertebral canal, but instead there is a potential cavity called the **epidural space** (see fig. 11.34). The epidural space is highly vascular and contains loose fibrous and adipose connective tissues that form a protective pad around the spinal cord.

Arachnoid

The **arachnoid** (*ă rak′noid*) is the middle of the three meninges. This delicate, netlike membrane spreads over the CNS but generally does not extend into the sulci or fissures of the brain. The **subarachnoid space,** located between the arachnoid mater and the deepest meninx, the pia mater, contains cerebrospinal fluid. The subarachnoid space is maintained by weblike strands that connect the arachnoid and pia mater (see fig. 11.33).

Pia Mater

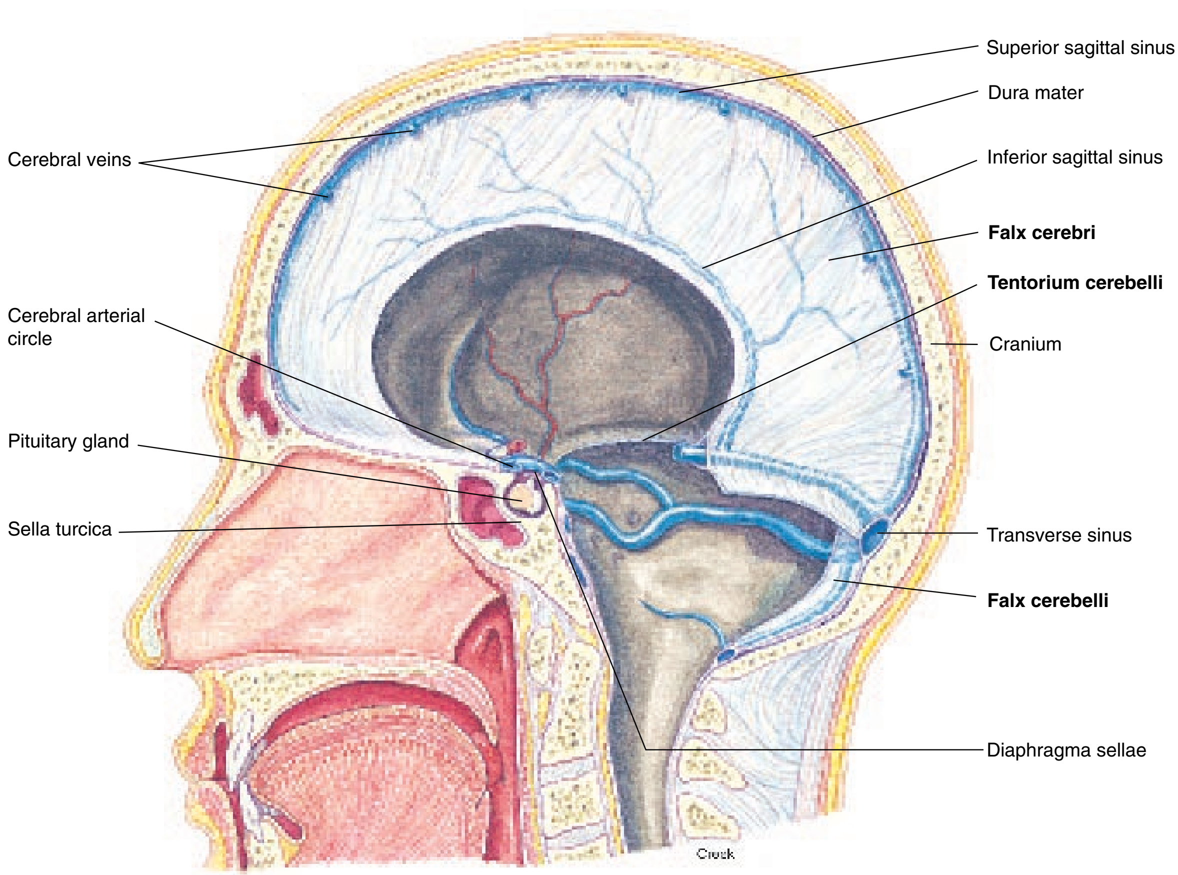
The thin **pia** (*pi′ă*) **mater** which is tightly bound to the convolutions of the brain and the irregular contours of the spinal cord, is composed of modified loose connective tissue. It is highly vascular and functions to support the vessels that nourish the underlying cells of the brain and spinal cord. The pia mater is specialized over the roofs of the ventricles, where it contributes to the formation of the choroid plexuses along with the arachnoid. Lateral extensions of the pia mater along the spinal cord form the **ligamentum denticulatum,** which attaches the spinal cord to the dura mater (fig. 11.35).

arachnoid: L. *arachnoides*, like a cobweb

pia mater: L. *pia*, soft or tender; *mater*, mother

TABLE 11.6 Septa of the Cranial Dura Mater

Septa	Location
Falx cerebri	Extends downward into the longitudinal fissure to partition the right and left cerebral hemispheres; anchored anteriorly to the crista galli of the ethmoid bone and posteriorly to the tentorium
Tentorium cerebelli	Separates the occipital and temporal lobes of the cerebrum from the cerebellum; anchored to the tentorium, petrous parts of the temporal bones, and occipital bone
Falx cerebelli	Partitions the right and left cerebellar hemispheres; anchored to the occipital crest
Diaphragma sellae	Forms the roof of the sella turcica



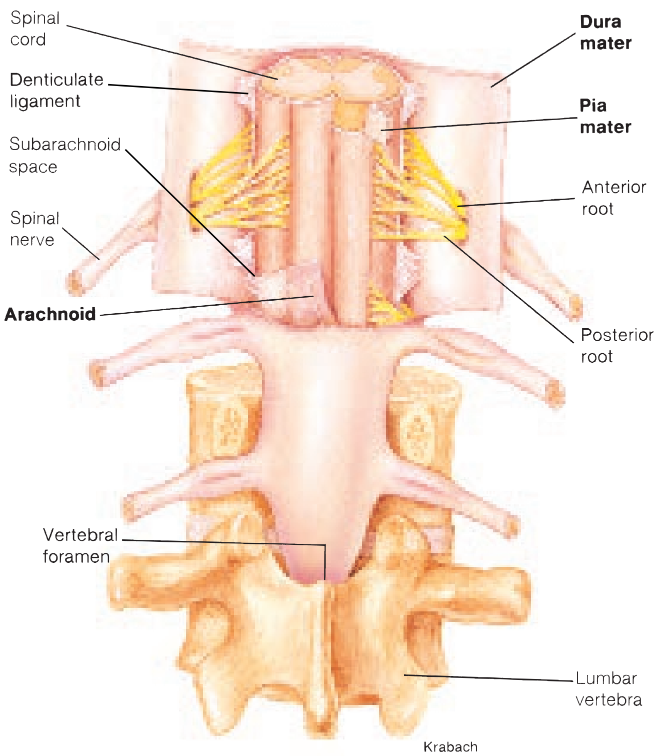


FIGURE 11.35 The spinal cord and spinal meninges.

Meningitis, an inflammation of the meninges, is usually caused by bacteria or viruses. The arachnoid and the pia mater are the two meninges most frequently affected. Meningitis is accompanied by high fever and severe headache. Complications may cause sensory impairment, paralysis, or mental retardation. Untreated meningitis generally results in coma and death.

Knowledge Check

32. Contrast the cranial dura mater and the spinal dura mater.
33. Explain how the meninges support and protect the CNS.
34. Describe the location of the dural sinuses and the epidural space.

VENTRICLES AND CEREBROSPINAL FLUID

The ventricles, central canal, and subarachnoid space contain cerebrospinal fluid, formed by the active transport of substances from blood plasma in the choroid plexuses.

Objective 23 Discuss the formation, function, and flow of cerebrospinal fluid.

Objective 24 Explain the importance of the blood-brain barrier in maintaining homeostasis within the brain.

Cerebrospinal fluid (CSF) is a clear, lymphlike fluid that forms a protective cushion around and within the CNS. The fluid also buoys the brain. CSF circulates through the various **ventricles** of the brain, the **central canal** of the spinal cord, and the **subarachnoid space** around the entire CNS. The cerebrospinal fluid returns to the circulatory system by draining through the walls of the **arachnoid villi,** which are venous capillaries.

Ventricles of the Brain

The ventricles of the brain are connected to one another and to the central canal of the spinal cord (figs. 11.36 and 11.37). Each of the two **lateral ventricles** (first and second ventricles) is located in one of the hemispheres of the cerebrum, inferior to the corpus callosum. The **third ventricle** is located in the diencephalon, between the thalami. Each lateral ventricle is connected to the third ventricle by a narrow, oval opening called the **interventricular foramen** (foramen of Monro). The **fourth ventricle** is located in the brain stem between the pons and cerebellum. The **mesencephalic aqueduct** (cerebral aqueduct) passes through the midbrain to link the third and fourth ventricles. The fourth ventricle also communicates posteriorly with the central canal of the spinal cord. Cerebrospinal fluid exits from the fourth ventricle into the subarachnoid space (fig. 11.38) through three foramina: the **median aperture** (foramen of Magendie), a medial opening, and two **lateral apertures,** foramina of Luschka (not illustrated). Cerebrospinal fluid returns to the venous blood through the arachnoid villi.

Internal hydrocephalus (hi''dro-sef''ă-lus) is a condition in which cerebrospinal fluid builds up within the ventricles of the brain (fig. 11.37*b*). It is more common in infants, whose cranial sutures have not yet strengthened or ossified, than in older individuals. If the pressure is excessive, the condition may have to be treated surgically.

External hydrocephalus, an accumulation of fluid within the subarachnoid space, usually results from an obstruction of drainage at the arachnoid villi. The external pressure compresses neural tissue and is likely to cause brain damage.

Cerebrospinal Fluid

Cerebrospinal fluid buoys the CNS and protects it from mechanical injury. The brain weighs about 1,500 grams, but suspended in CSF its buoyed weight is about 50 grams. This means that the brain has a near neutral buoyancy; at a true neutral buoyancy, an object does not float or sink but is suspended in its fluid environment.

In addition to buoying the CNS, CSF reduces the damaging effect of an impact to the head by spreading the force over a larger area. It also helps to remove metabolic wastes from nervous tissue. Because the CNS lacks lymphatic circulation, the CSF moves cellular wastes into the venous return at its places of drainage.

foramen of Monro: from Alexander Monro Jr., Scottish anatomist, 1733–1817
foramen of Magendie: from François Magendie, French physiologist, 1783–1855
foramen of Luschka: from Hubert Luschka, German anatomist, 1820–75

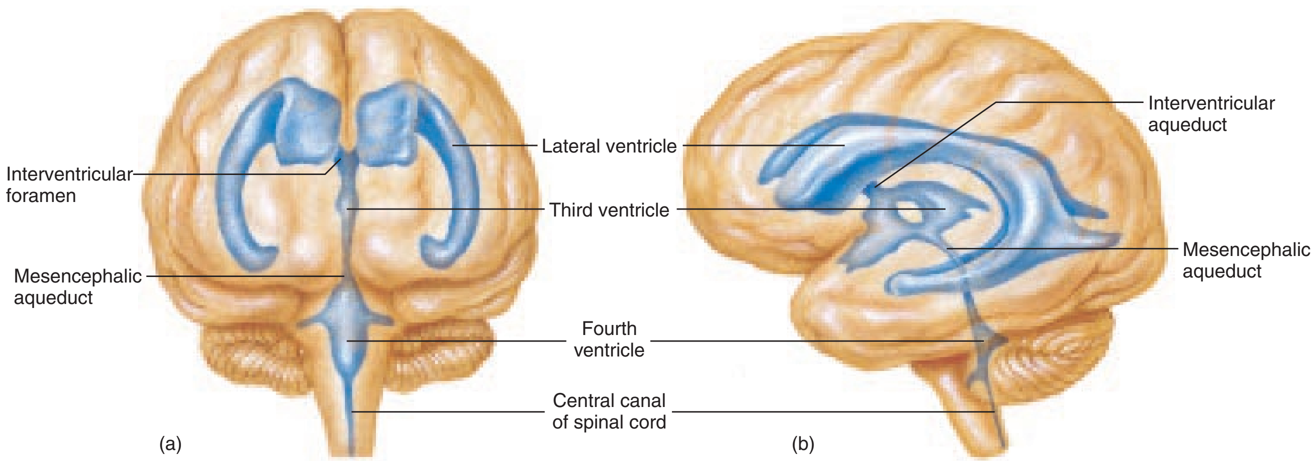


FIGURE 11.36 The ventricles of the brain. (*a*) An anterior view and (*b*) a lateral view.

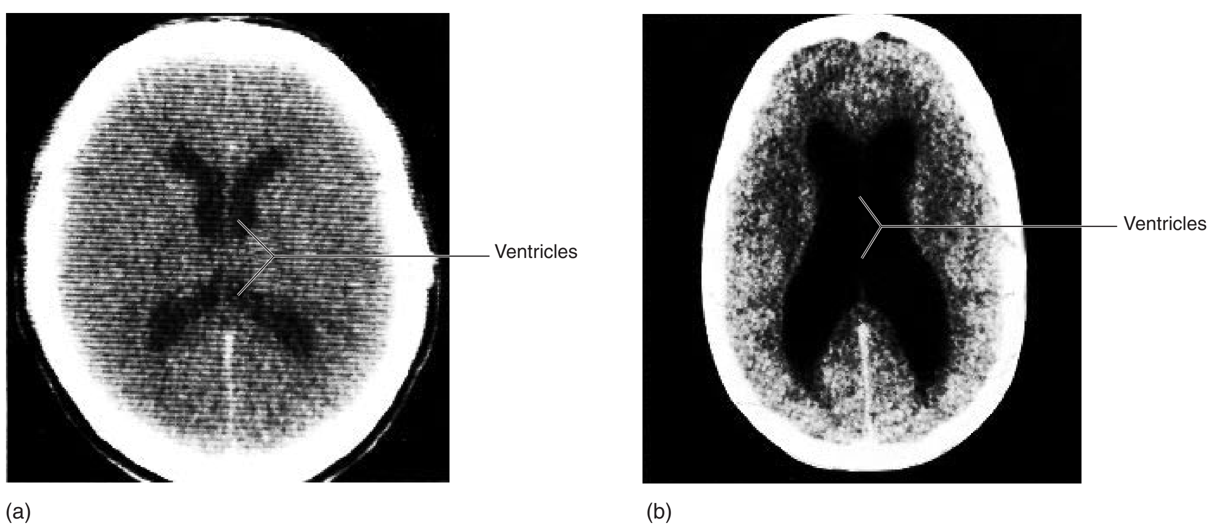


FIGURE 11.37 CT scans of the brain showing (*a*) a normal configuration of the ventricles and (*b*) an abnormal configuration of the ventricles as a result of hydrocephalism.

The clear, watery CSF is continuously produced by the filtration of blood plasma through masses of specialized capillaries called **choroid plexuses** and, to a lesser extent, by secretions of ependymal cells. The ciliated ependymal cells cover the choroid plexuses, as well as line the central canal, and presumably aid the movement of the CSF. The tight junctions between the ependymal cells also help to form a *blood–cerebrospinal fluid barrier* that prohibits certain potentially harmful substances in the blood from entering the CSF.

CSF is similar in composition to the blood plasma from which it is formed. Like blood plasma, it contains proteins, glucose, urea, and white blood cells. Comparing electrolytes, CSF contains more sodium, chloride, magnesium and hydrogen, and fewer calcium and potassium ions than does blood plasma.

Up to 800 ml of cerebrospinal fluid are produced each day, although only 140–200 ml are bathing the CNS at any given moment. A person lying in a horizontal position has a slow but continuous circulation of cerebrospinal fluid, with a fluid pressure of about 10 mmHg.

The homeostatic consistency of the CSF composition is critical, and a chemical imbalance may have marked effects on CNS functions. An increase in amino acid glycine concentration, for example, produces hypothermia and hypotension as temperature and blood pressure regulatory mechanisms are disrupted. A slight change in pH may affect the respiratory rate and depth.

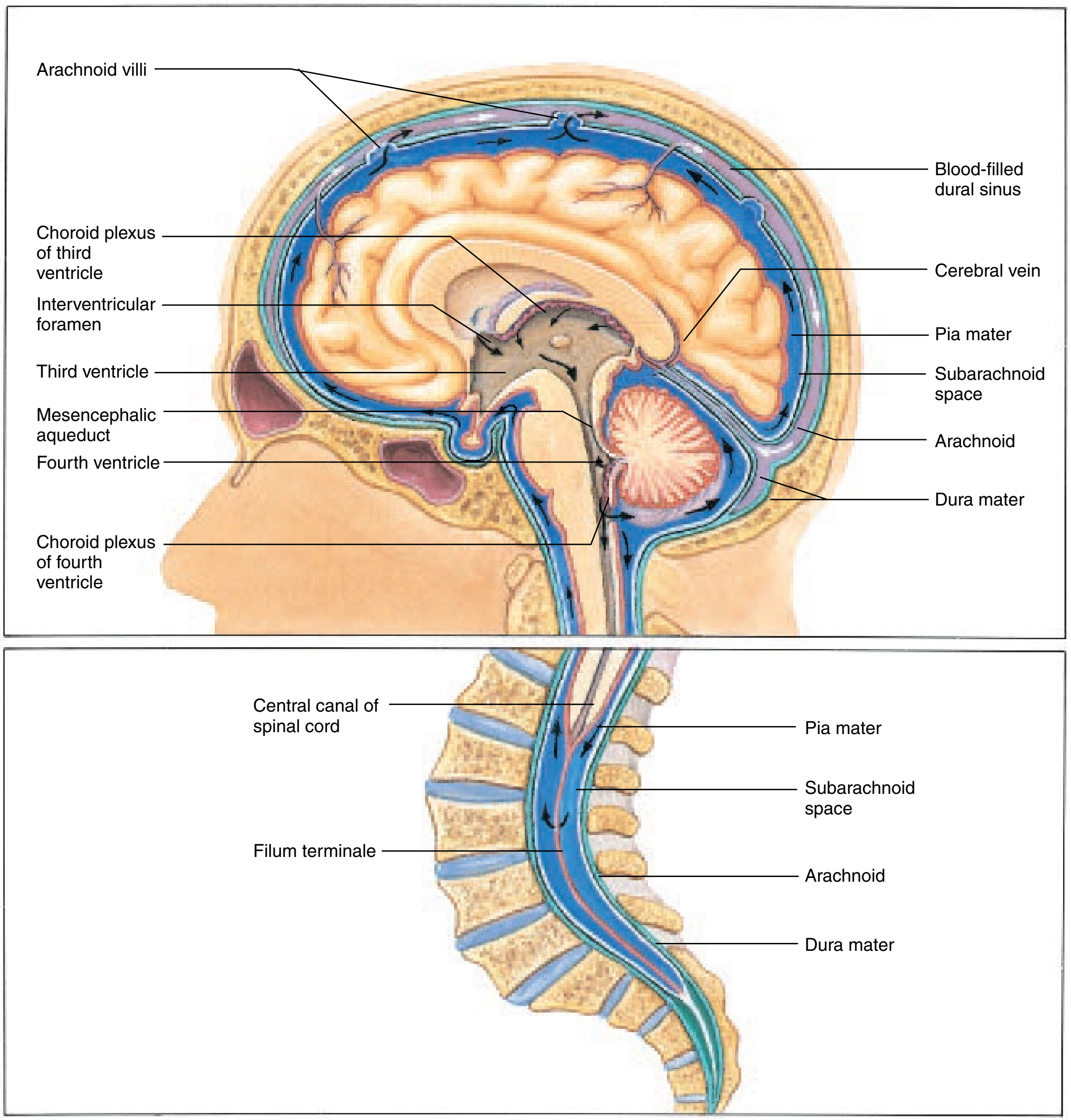


FIGURE 11.38 The flow of cerebrospinal fluid. Cerebrospinal fluid is secreted by choroid plexuses in the ventricular walls. The fluid circulates through the ventricles and central canal, enters the subarachnoid space, and is reabsorbed into the blood of the dural sinuses through the arachnoid villi.

Blood-Brain Barrier

The **blood-brain barrier (BBB)** is a structural arrangement of capillaries, surrounding connective tissue, and specialized neuroglia called astrocytes (see figs. 11.4 and 11.8) that selectively determine which substances can move from the plasma of the blood to the extracellular fluid of the brain. Certain substances such as water, oxygen, carbon dioxide, glucose, and lipid-soluble compounds (alcohol, for example) pass readily through the BBB. Certain inorganic ions (Ca^{+} and K^{+}) pass more slowly, so that the concentrations of these ions in the brain differ from those in the blood plasma. Other substances, such as proteins, lipids, creatine, urea, inulin, certain toxins, and most antibiotics, are restricted in passage. The BBB must be taken into account when planning drug therapy for neurological disorders.

Although the BBB is an important protective device, it is essential that the brain be able to monitor and respond to fluctuations in blood glucose, pH, salinity, osmolarity, and pressure. For this reason, the BBB is absent in limited brain areas, including portions of the hypothalamus.

Knowledge Check

35. Describe the location of the ventricles within the brain.
36. What are the functions of cerebrospinal fluid?
37. Where is cerebrospinal fluid produced and where does it drain?
38. Name some structures to which the BBB is highly permeable and some to which it is slightly permeable. What substances are prevented from crossing?

SPINAL CORD

The spinal cord consists of centrally located gray matter, involved in reflexes, and peripherally located ascending and descending tracts of white matter that conduct impulses to and from the brain.

Objective 25 Describe the structure of the spinal cord.

Objective 26 Describe the arrangement of ascending and descending tracts within the spinal cord.

The **spinal cord** is the portion of the CNS that extends through the vertebral canal of the vertebral column (fig. 11.39). It is continuous with the brain through the foramen magnum of the skull. The spinal cord has two principal functions.

1. **Impulse conduction.** It provides a means of neural communication to and from the brain through tracts of white matter. **Ascending tracts** conduct impulses from the peripheral sensory receptors of the body to the brain. **Descending tracts** conduct motor impulses from the brain to the muscles and glands.
2. **Reflex integration.** It serves as a center for spinal reflexes. Specific nerve pathways allow for reflexive movements rather than those initiated voluntarily by the brain. Movements of this type are not confined to skeletal muscles; reflexive movements of cardiac and smooth muscles control heart rate, breathing rate, blood pressure, and digestive activities. Spinal nerve pathways are also involved in swallowing, coughing, sneezing, and vomiting.

Structure of the Spinal Cord

The spinal cord extends inferiorly from the position of the foramen magnum of the occipital bone to the level of the first lumbar vertebra (L1). It is somewhat flattened posteroventrally, making it oval in cross section. Two prominent enlargements can be seen in a posterior view (fig. 11.39). The **cervical enlargement** is located between the third cervical and the second thoracic vertebrae. Nerves emerging from this region serve the upper extremities. The **lumbar enlargement** lies between the ninth and twelfth thoracic vertebrae. Nerves from the lumbar enlargement supply the lower extremities.

The embryonic spinal cord develops more slowly than the associated vertebral column; thus, in the adult, the cord does not extend beyond L1. The tapering, terminal portion of the spinal cord is called the **conus medullaris** (*med-yoo-lar'is*) The **filum terminale** (*fi'lum ter-mĭ-nal'e*), a fibrous strand composed mostly of pia mater, extends inferiorly from the conus medullaris at the level of L1 to the coccyx. Nerve roots also radiate inferiorly from the conus medullaris through the vertebral canal. These nerve roots are collectively referred to as the **cauda equina** (*kaw'dă e'qui'nă*) because they resemble a horse's tail.

The spinal cord develops as 31 segments, each of which gives rise to a pair of **spinal nerves** that emerge from the spinal cord through the intervertebral foramina. Two grooves, an **anterior median fissure** and a **posterior median sulcus,** extend the length of the spinal cord and partially divide it into right and left portions. Like the brain, the spinal cord is protected by three distinct meninges and is cushioned by cerebrospinal fluid. The pia mater contains an extensive vascular network.

The **gray matter** of the spinal cord is centrally located and surrounded by white matter. It is composed of nerve cell bodies, neuroglia, and unmyelinated association neurons (interneurons). The **white matter** consists of bundles, or tracts, of myelinated fibers of sensory and motor neurons.

The relative size and shape of the gray and white matter varies throughout the spinal cord. The amount of white matter increases toward the brain as the nerve tracts become thicker. More gray matter is found in the cervical and lumbar enlargements where innervations from the upper and lower extremities, respectively, make connections.

The core of gray matter roughly resembles the letter H (fig. 11.40). Projections of the gray matter within the spinal cord are called *horns*, and are named according to the direction in which they project. The paired **posterior horns** extend posteriorly and the paired **anterior horns** project anteriorly. Between the posterior and anterior horns, the short paired **lateral horns** extend to the sides. Lateral horns are prominent only in the thoracic and upper lumbar regions. The transverse bar of gray matter that connects the paired horns across the center of the spinal cord is called the **gray commissure.** Within the gray commissure is the **central canal.** It is continuous with the ventricles of the brain and is filled with cerebrospinal fluid.

Spinal Cord Tracts

Impulses are conducted through the ascending and descending tracts of the spinal cord within the columns of white matter.

filum terminale: L. *filum*, filament; *terminus*, end
cauda equina: L. *cauda*, tail; *equus*, horse
commissure: L. *commissura*, a joining

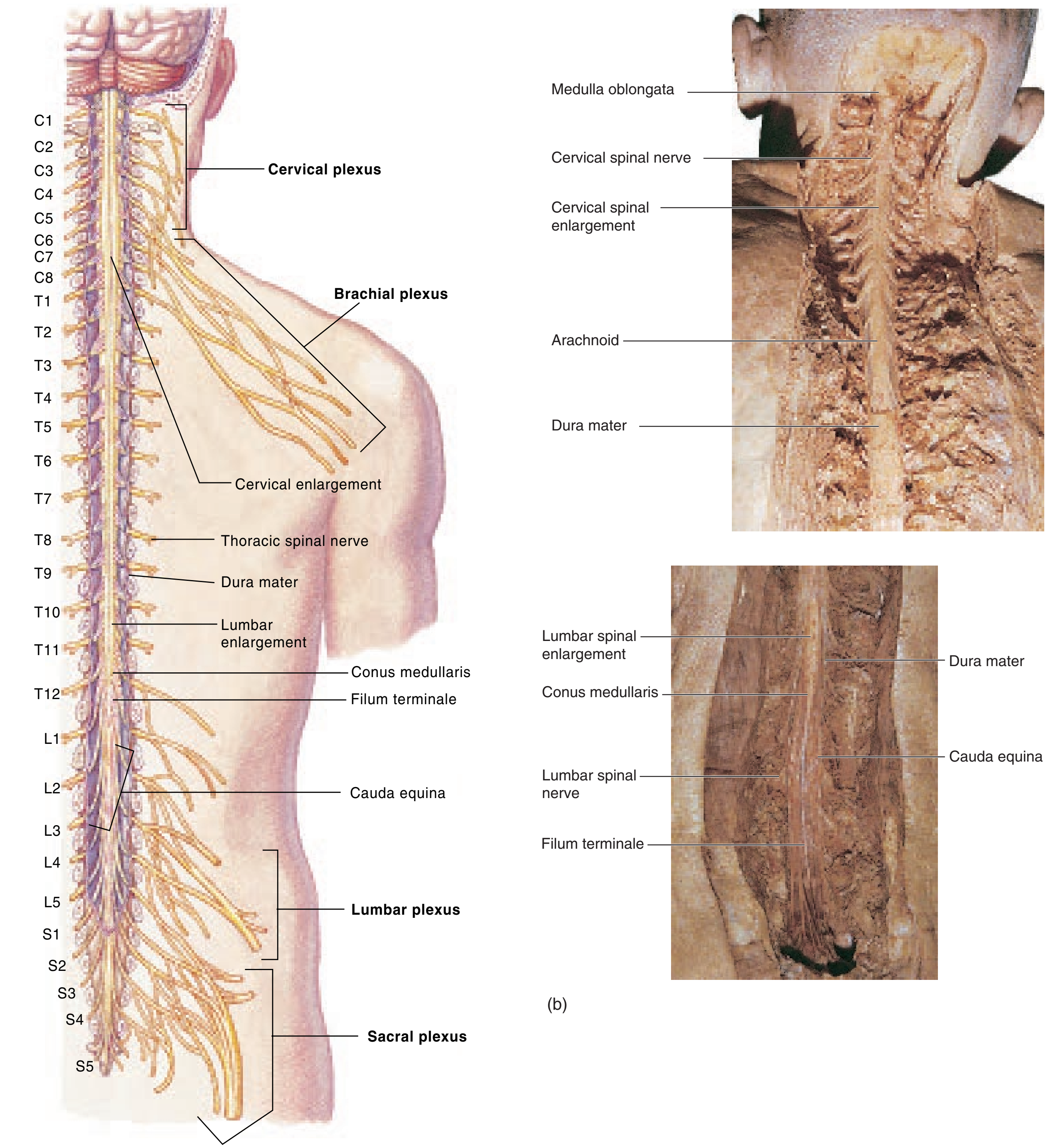
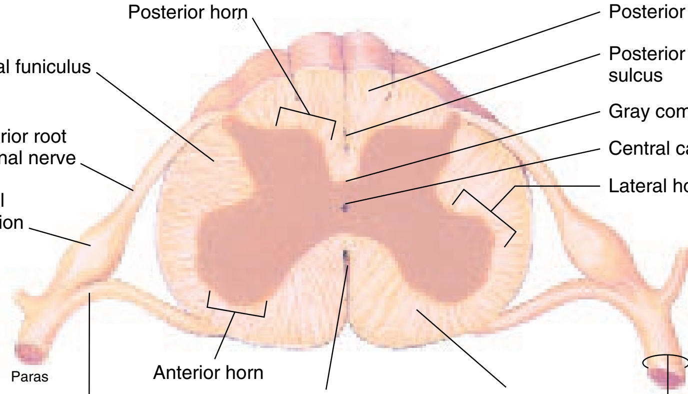


FIGURE 11.39 The spinal cord and plexuses. (*a*) An illustration depicting the spinal nerves and plexuses. (The plexuses are indicated in boldface type.) (*b*) A dissected spinal cord and roots of the spinal nerves.



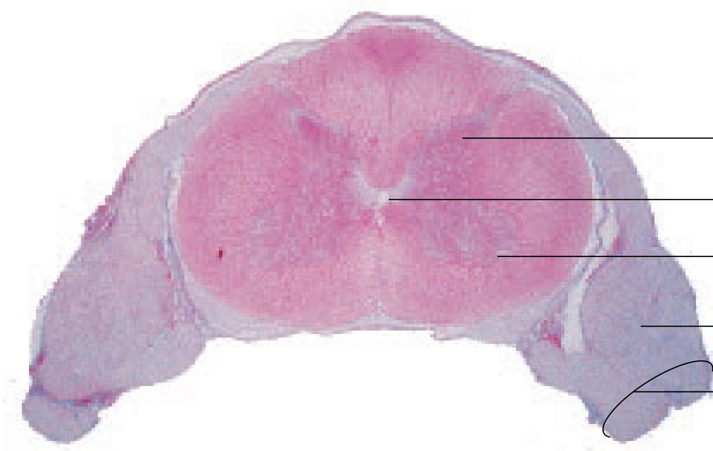


FIGURE 11.40 The spinal cord in cross section. (*a*) A diagram and (*b*) a photomicrograph.

The spinal cord has six columns of white matter called **funiculi** (*fyoo-nik'yŭ-li*), which are named according to their relative position within the spinal cord. The two **anterior funiculi** are located between the two anterior horns of gray matter, to either side of the anterior median fissure (fig. 11.40). The two **posterior funiculi** are located between the two posterior horns of gray matter, to either side of the posterior median sulcus. Two **lateral funiculi** are located between the anterior and posterior horns of gray matter.

Each funiculus consists of both ascending and descending tracts. The nerve fibers within the tracts are generally myelinated and are named according to their origin and termination. The fibers of the tracts either remain on the same side of the brain and spinal cord or cross over within the medulla oblongata or the spinal cord. The crossing over of nerve tracts is referred to as *decussation* (*de''kus-a'shun*). Illustrated in figures 11.41 and 11.42 are descending and ascending tracts, respectively, that decussate within the medulla oblongata.

The principal ascending and descending tracts within the funiculi are summarized in table 11.7 and illustrated in figure 11.43.

Descending tracts are grouped according to place of origin as either corticospinal or extrapyramidal. **Corticospinal (pyramidal) tracts** descend directly, without synaptic interruption, from the cerebral cortex to the lower motor neurons. The cell bodies of the neurons that contribute fibers to these tracts are located primarily

funiculus: L. diminutive of *funis*, cord or rope

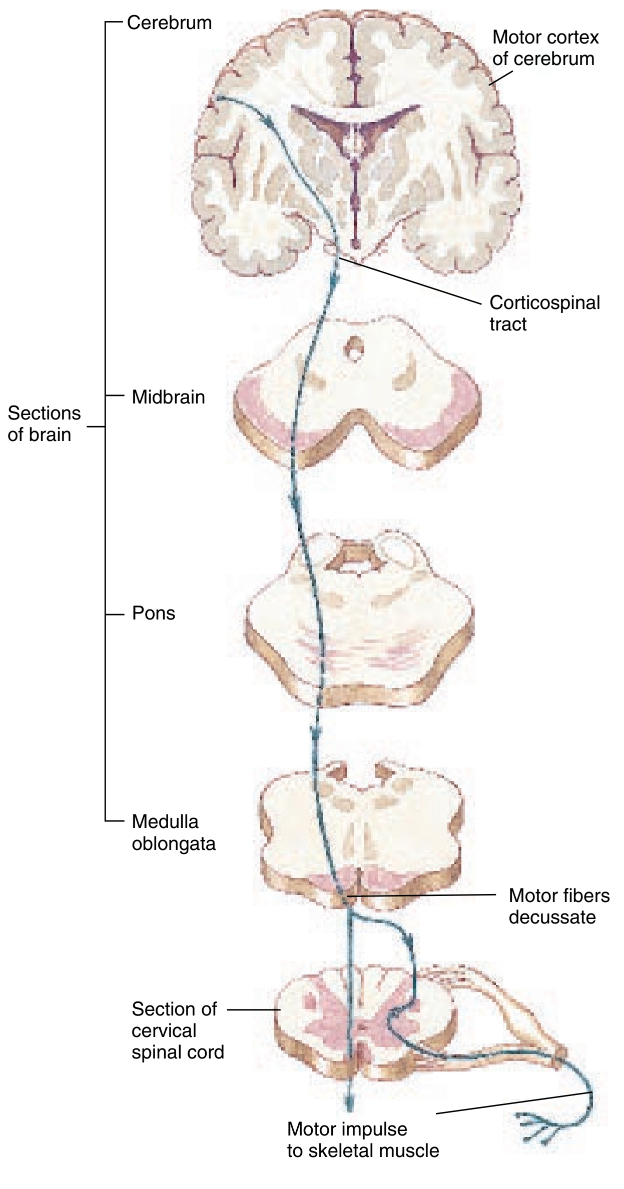


FIGURE 11.41 A descending corticospinal tract composed of motor fibers that decussate in the medulla oblongata of the brain stem.

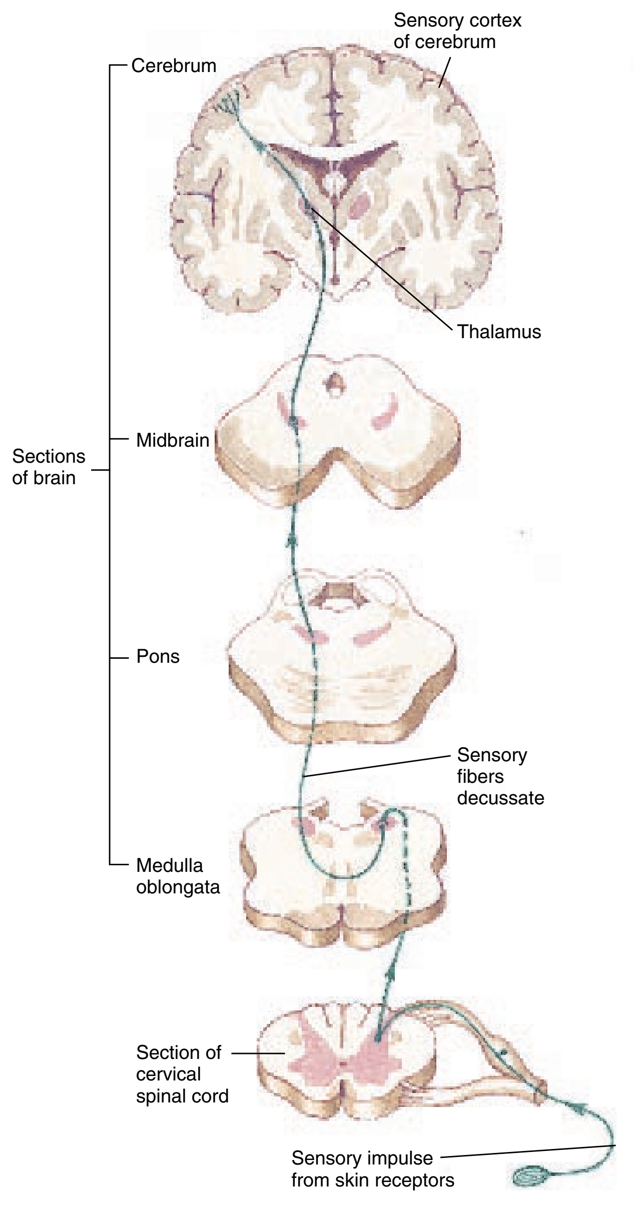


FIGURE 11.42 An ascending tract composed of sensory fibers that decussate (cross over) in the medulla oblongata of the brain stem.

in the precentral gyrus of the frontal lobe. Most (about 85%) of the corticospinal fibers decussate in the pyramids of the medulla oblongata (see fig. 11.23). The remaining 15% do not cross from one side to the other. The fibers that cross compose the **lateral corticospinal tracts,** and the remaining uncrossed fibers compose the **anterior corticospinal tracts.** Because of the crossing of fibers from higher motor neurons in the pyramids, the right hemisphere primarily controls the musculature on the left side of the body, whereas the left hemisphere controls the right musculature.

The corticospinal tracts appear to be particularly important in voluntary movements that require complex interactions between the motor cortex and sensory input. Speech, for example, is impaired when the corticospinal tracts are damaged in the thoracic region of the spinal cord, whereas involuntary breathing continues. Damage to the pyramidal motor system can be detected clinically by the presence of *Babinski's reflex,* in which stimulation of the sole of the foot causes extension (upward movement) of the great toe and fanning out of the other toes. Babinski's reflex is normally present in infants because neural control is not yet fully developed.

TABLE 11.7 Principal Ascending and Descending Tracts of the Spinal Cord

Tract	Funiculus	Origin	Termination	Function
Ascending Tracts				
Anterior spinothalamic	Anterior	Posterior horn on one side of spinal cord; crosses to opposite side	Thalamus, then cerebral cortex	Conduct sensory impulses for crude touch and pressure
Lateral spinothalamic	Lateral	Posterior horn on one side of spinal cord; crosses to opposite side	Thalamus, then cerebral cortex	Conducts pain and temperature impulses that are interpreted within cerebral cortex
Fasciculus gracilis and fasciculus cuneatus	Posterior	Peripheral sensory neurons; does not cross over	Nucleus gracilis and nucleus cuneatus of medulla oblongata; crosses to opposite side; eventually thalamus, then cerebral cortex	Conducts sensory impulses from skin, muscles, tendons, and joints, which are interpreted as sensations of fine touch, precise pressures, and body movements
Posterior spinocerebellar	Lateral	Posterior horn; does not cross over	Cerebellum	Conducts sensory impulses from one side of body to same side of cerebellum for subconscious proprioception required for coordinated muscular contractions
Anterior spinocerebellar	Lateral	Posterior horn; some fibers cross, other do not	Cerebellum	Conducts sensory impulses from both sides of body to cerebellum for subconscious proprioception required for coordinated muscular contractions
Descending Tracts				
Anterior corticospinal	Anterior	Cerebral cortex on one side of brain; crosses to opposite side of spinal cord	Anterior horn	Conducts motor impulses from cerebrum to spinal nerves, and outward to cells of anterior horns for coordinated, precise voluntary movements of skeletal muscle
Lateral corticospinal	Lateral	Cerebral cortex on one side of brain; crosses in base of medulla oblongata to opposite side of spinal cord	Anterior horn	Conducts motor impulses from cerebrum to spinal nerves, and outward to cells of anterior horns for coordinated, precise voluntary movements
Tectospinal	Anterior	Mesencephalon; crosses to opposite side of spinal cord	Anterior horn	Conducts motor impulses to cells of anterior horns, and eventually to muscles that move the head in response to visual, auditory, or curaneous stimuli
Rubrospinal	Lateral	Mesencephalon (red nucleus); crosses to opposite side of spinal cord	Anterior horn	Conduct motor impulses concerned with muscle tone and posture
Vestibulospinal	Anterior	Medulla oblongata; does not cross over	Anterior horn	Conducts motor impulses that regulate body tone and posture (equilibrium) in response to movements of head
Anterior and medial reticulospinal	Anterior	Reticular formation of brain stem; does not cross over	Anterior horn	Conducts motor impulses that control muscle tone and sweat gland activity
Bulboreticulospinal	Lateral	Reticular formation of brain stem; does not cross over	Anterior horn	Conducts motor impulses that control muscle tone and sweat gland activity

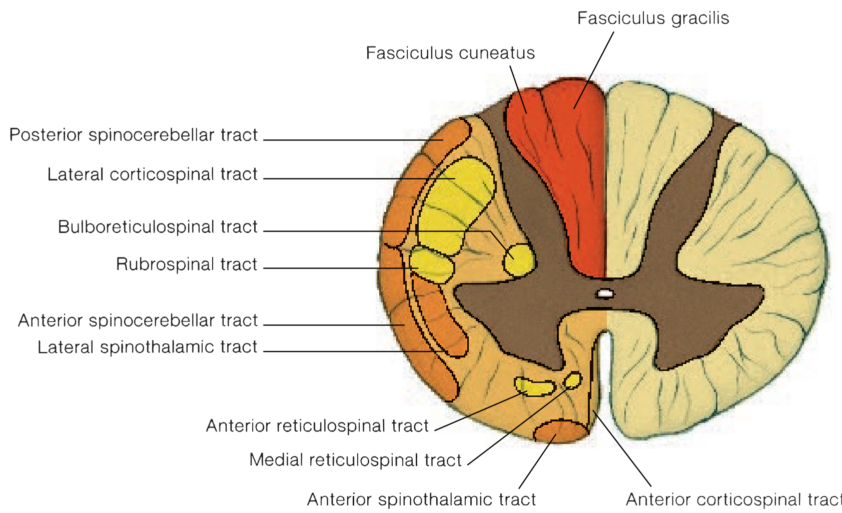


FIGURE 11.43 A cross section showing the principal ascending and descending tracts within the spinal cord.

The remaining descending tracts are **extrapyramidal tracts** that originate in the brain stem region. Electrical stimulation of the cerebral cortex, the cerebellum, and the basal nuclei indirectly evokes movements because of synaptic connections within extrapyramidal tracts.

The **reticulospinal** (*re-tik''yŭ-lo-spi'nal*) **tracts** are the major descending pathways of the extrapyramidal system. These tracts originate in the reticular formation of the brain stem. Neurostimulation of the reticular formation by the cerebrum or cerebellum either facilitates or inhibits the activity of lower motor neurons (depending on the area stimulated) (fig. 11.44).

There are no descending tracts from the cerebellum. The cerebellum can influence motor activity only indirectly, through the vestibular nuclei, red nucleus, and basal nuclei. These structures, in turn, affect lower motor neurons via the **vestibulospinal tracts, rubrospinal tracts,** and **reticulospinal tracts.** Damage to the cerebellum disrupts the coordination of movements with spatial judgment. Underreaching or overreaching for an object may occur, followed by *intention tremor*, in which the limb moves back and forth in a pendulum-like motion.

The basal nuclei, acting through synapses in the reticular formation in particular, appear normally to exert an inhibitory influence on the activity of lower motor neurons. Damage to the basal nuclei thus results in decreased muscle tone. People with such damage display *akinesia* (*a''kĭ-ne'ze-ă*) (complete or partial loss of muscle movement) and *chorea* (*ko-re'ă*) (sudden and uncontrolled random movements).

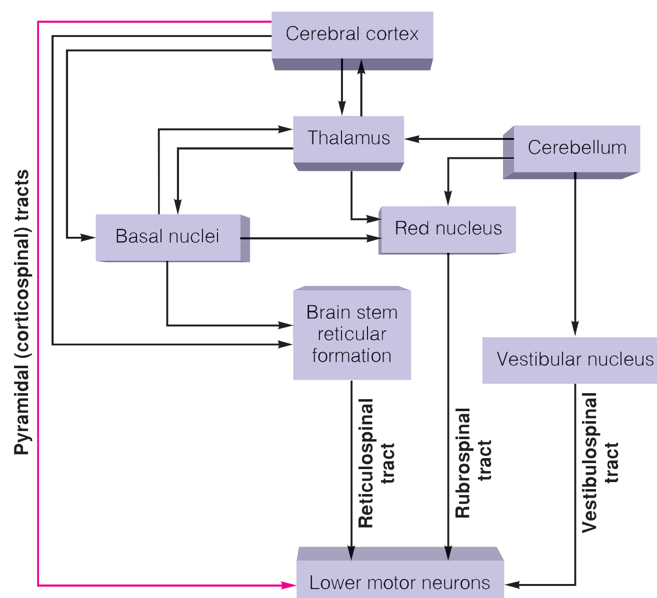


FIGURE 11.44 Pathways involved in the higher motor neuron control of skeletal muscles. (The pyramidal [corticospinal] tracts are shown in red and the extrapyramidal tracts are shown in black.)

CHAPTER 11

akinesia: Gk. *a*, without; *kinesis*, movement
chorea: Fr. *choros*, a dance

Developmental Exposition

The Spinal Cord

EXPLANATION

The spinal cord, like the brain, develops as the neural tube undergoes differentiation and specialization. Throughout the developmental process, the hollow central canal persists while the specialized white and gray matter forms (exhibit III). Changes in the neural tube become apparent during the sixth week as the lateral walls thicken to form a groove called the **sulcus limitans** along each lateral wall of the central canal. A pair of **alar plates** forms dorsal to the sulcus limitans, and a pair of **basal plates** forms ventrally. By the ninth week, the alar plates have specialized to become the **posterior horns,** containing fibers of the sensory cell bodies, and the basal plates have specialized to form the **anterior** and **lateral horns,** containing motor cell bodies. Sensory neurons of spinal nerves conduct impulses toward the spinal cord, whereas motor neurons conduct impulses away from the spinal cord.

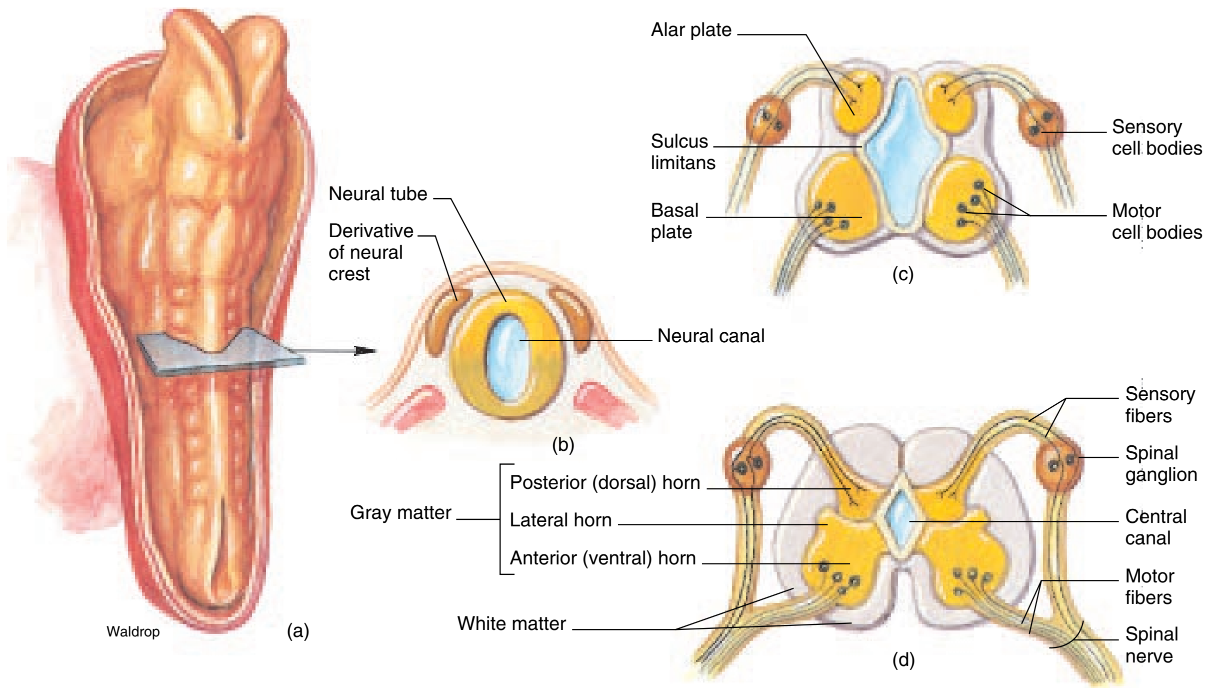


EXHIBIT III The development of the spinal cord. (*a*) A dorsal view of an embryo at 23 days with the position of a transverse cut indicated in (*b*). (*c*) The formation of the alar and basal plates is evident in a transverse section through the spinal cord at 6 weeks. (*d*) The size of the central canal has decreased, and functional posterior and anterior horns have formed at 9 weeks.

Paralysis agitans, better known as *Parkinson's disease,* is a disorder of the basal nuclei involving the degeneration of fibers from the substantia nigra. These fibers, which use dopamine as a neurotransmitter, are required to antagonize the effects of other fibers that use acetylcholine (ACh) as a transmitter. The relative deficiency of dopamine compared to ACh is believed to produce the symptoms of Parkinson's disease, including *resting tremor.* This shaking of the limbs tends to disappear during voluntary movements and then reappear when the limb is again at rest.

Parkinson's disease is treated with drugs that block the effects of ACh and by the administration of L-dopa, which can be converted to dopamine in the brain. (Dopamine cannot be given directly because it does not cross the blood-brain barrier.)

Knowledge Check

39. Diagram a cross section of the spinal cord and label the structures of the gray matter and the white matter. Describe the location of the spinal cord.
40. List the structures and function of the corticospinal tracts. Make a similar list for the extrapyramidal tracts.
41. Explain why damage to the right side of the brain primarily affects motor activities on the left side of the body.

CLINICAL CONSIDERATIONS

The clinical aspects of the central nervous system are extensive and usually complex. Numerous diseases and developmental problems directly involve the nervous system, and the nervous system is indirectly involved with most of the diseases that afflict the body because of the location and activity of sensory pain receptors. Pain receptors are free nerve endings that are present throughout living tissue. The pain sensations elicited by disease or trauma are important in localizing and diagnosing specific diseases or dysfunctions.

Only a few of the many clinical considerations of the central nervous system will be discussed here. These include neurological assessment and drugs, developmental problems, injuries, infections and diseases, and degenerative disorders.

Neurological Assessment and Drugs

Neurological assessment has become exceedingly sophisticated and accurate in the past few years. In a basic physical examination, only the reflexes and sensory functions are assessed. But if the physician suspects abnormalities involving the nervous system, further neurological tests may be done, employing the following techniques.

A **lumbar puncture** is performed by inserting a fine needle between the third and fourth lumbar vertebrae and withdrawing a sample of CSF from the subarachnoid space (fig. 11.45). A **cisternal puncture** is similar to a lumbar puncture except that the CSF is withdrawn from a cisterna at the base of the skull, near the foramen magnum. The pressure of the CSF, which is normally about 10 mmHg, is measured with a *manometer*. Samples of CSF may also be examined for abnormal constituents. In addition, excessive fluid, accumulated as a result of disease or trauma, may be drained.

The condition of the arteries of the brain can be determined through a **cerebral angiogram** (*an'je-ŏ-gram*). In this technique, a radiopaque substance is injected into the common carotid arteries and allowed to disperse through the cerebral vessels. Aneurysms and vascular constrictions or displacements by tumors may then be revealed on radiographs.

The development of the **CT scanner,** or **computerized axial tomographic scanner,** has revolutionized the diagnosis of brain disorders. The CT scanner projects a sharply focused, detailed tomogram, or cross section, of a patient's brain onto a television screen. The versatile CT scanner allows quick and accurate diagnoses of tumors, aneurysms, blood clots, and hemorrhage. The CT scanner may also be used to detect certain types of birth defects, brain damage, scar tissue, and evidence of old or recent strokes.

A machine with even greater potential than the CT scanner is the **DSR,** or **dynamic spatial reconstructor.** Like the CT scanner, the DSR is computerized to transform radiographs into composite video images. However, with the DSR, a three-dimensional view is obtained, and the image is produced much faster than with the CT scanner. The DSR can produce 75,000 cross-sectional images in 5 seconds, whereas the CT scanner can produce only one. With that speed, body functions as well as structures may be studied. Blood flow through vessels of the brain can be observed. These types of data are important in detecting early symptoms of a stroke or other disorders.

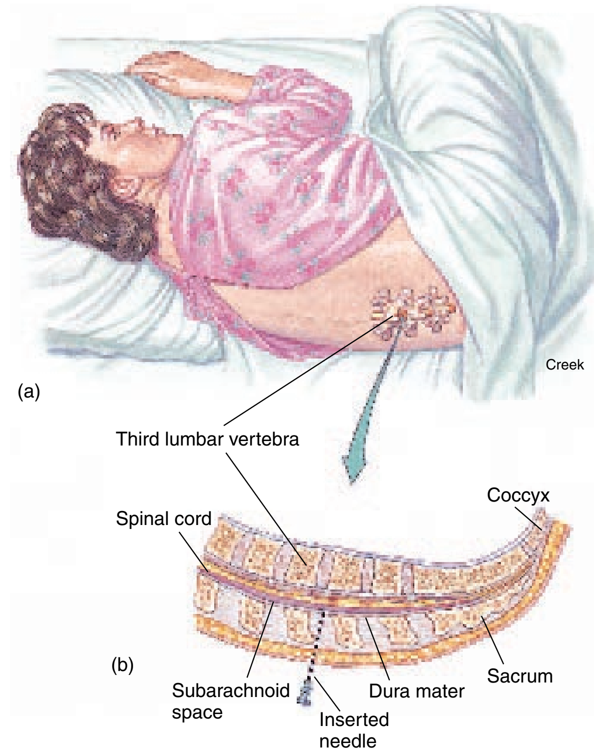


FIGURE 11.45 (*a*) A lumbar puncture is performed by inserting a needle between the third and fourth lumbar vertebrae (L3–L4) and (*b*) withdrawing cerebrospinal fluid from the subarachnoid space.

Certain disorders of the brain may be diagnosed more simply by examining brain-wave patterns using an **electroencephalogram** (see Table 11.5). Sensitive electrodes placed on the scalp record particular EEG patterns being emitted from evoked cerebral activity. EEG recordings are used to monitor epileptic patients to predict seizures and to determine proper drug therapy, and also to monitor comatose patients.

The fact that the nervous system is extremely sensitive to various drugs is fortunate; at the same time, this sensitivity has potential for disaster. *Drug abuse* is a major clinical concern because of the addictive and devastating effect that certain drugs have on the nervous system. Much has been written on drug abuse, and it is beyond the scope of this text to elaborate on the effects of drugs. A positive aspect of drugs is their administration in medicine to temporarily interrupt the passage or perception of sensory impulses. Injecting an anesthetic drug near a nerve, as in dentistry, desensitizes a specific area and causes a *nerve block*. Nerve blocks of a limited extent occur if an appendage is cooled or if a nerve is compressed for a period of time. Before the discovery of pharmacological drugs, physicians would frequently cool an affected appendage with ice or snow before performing surgery. **General anesthetics** affect the brain and render a person unconscious. A **local anesthetic** causes a nerve block by desensitizing a specific area.

Developmental Problems

Congenital malformations of the CNS are common and frequently involve overlying bone, muscle, and connective tissue. The more severe abnormalities make life impossible, and the less severe malformations frequently result in functional disability. Neurological malformations usually have a genetic basis, but they also may result from environmental factors such as anoxia, infectious agents, drugs, and ionizing radiation. Some of these malformations were briefly described in the previous chapter.

Spina bifida (*spi'nă bif'ĭ-dă*) is a defective fusion of the vertebral elements and may or may not involve the spinal cord. **Spina bifida occulta** is the most common and least serious type of spina bifida. This defect usually involves few vertebrae, is not externally apparent except for perhaps a pigmented spot with a tuft of hair, and usually does not cause neurological disturbances. **Spina bifida cystica,** a severe type of spina bifida, is a saclike protrusion of skin and underlying meninges that may contain portions of the spinal cord and nerve roots. It is most common in the lower thoracic, lumbar, and sacral regions (see fig. 6.41). The position and extent of the defect determines the degree of neurological impairment.

Anencephaly (*an''en-sef'ă-le*) is a markedly defective development of the brain and surrounding cranial bones. Anencephaly occurs once per thousand births and makes sustained extrauterine life impossible. This congenital defect apparently results from the failure of the neural folds at the cranial portion of the neural plate to fuse and form the prosencephalon.

Microcephaly is an uncommon condition in which brain development is not completed. If enough neurological tissue is present, the infant will survive but will be severely mentally retarded.

Defective skull development frequently causes **cranial encephalocele** (*en-sef'ă-lo-sēl*). This condition occurs approximately once per two thousand births. It is characterized by protrusion of the brain and meninges through a cranial fissure, usually in the occipital region. Occasionally the herniation involves fluid with the meninges, and not brain tissue. In this case, it is referred to as a **cranial meningocele** (*mĕ-ning'go-sēl*).

Hydrocephalus (*hi''dro-sef'ă-lus*) is the abnormal accumulation of cerebrospinal fluid in the ventricles and subarachnoid or subdural space. Hydrocephalus may be caused by the excessive production or blocked flow of cerebrospinal fluid. It may also be associated with other congenital problems, such as spina bifida cystica or encephalocele. Hydrocephalus frequently causes the cranial bones to thin and the cerebral cortex to atrophy.

Many congenital disorders cause an impairment of intellectual function known as **mental retardation.** Chromosomal abnormalities, maternal and fetal infections such as syphilis and German measles, and excessive irradiation of the fetus are all commonly associated with mental retardation.

Injuries

Although the brain and spinal cord seem to be well protected within a bony encasement, they are sensitive organs, highly susceptible to injury.

Certain symptomatic terms are used when determining possible trauma within the CNS. **Headaches** are the most common ailment of the CNS. Most headaches are due to dilated blood vessels within the meninges of the brain. Headaches are generally symptomatic of brain disorders; rather, they tend to be associated with physiological stress, eyestrain, or fatigue. Persistent and intense headaches may indicate a more serious problem, such as a brain tumor. A **migraine** is a specific type of headache that is commonly preceded or accompanied by visual impairments and GI unrest. It is not known why only 5%–10% of the population periodically suffer from migraines or why they are more common in women. Fatigue, allergy, and emotional stress tend to trigger migraines.

Fainting is a brief loss of consciousness that may result from a rapid pooling of blood in the lower extremities. It may occur when a person rapidly arises from a reclined position, receives a blow to the head, or experiences an intense psychologic stimulus, such as viewing a cadaver for the first time. Fainting is of more concern when it is symptomatic of a particular disease.

A **concussion** is an injury resulting from a violent jarring of the brain, usually by a forceful blow to the head. Bones of the skull may or may not be fractured. A concussion usually results in a brief period of unconsciousness, followed by mild **delirium** in which the patient is in a state of confusion. **Amnesia** is a more intense disorientation in which the patient suffers varying degrees of memory loss.

A person who survives a severe head injury may be **comatose** for a short or an extended period of time. A coma is a state of unconsciousness from which the patient cannot be aroused, even by the most intense external stimuli. Severe injury to the reticular activating system is likely to result in irreversible coma. Although a head injury is the most common cause of coma, chemical imbalances associated with certain diseases (e.g., diabetes) or the ingestion of drugs or poisons may also be responsible.

The flexibility of the vertebral column is essential for body movements, but because of this flexibility the spinal cord and spinal nerves are somewhat vulnerable to trauma. Falls or severe blows to the back are a common cause of injury. A skeletal injury, such as a fracture, dislocation, or compression of the vertebrae, usually traumatizes nervous tissue as well. Other frequent causes of trauma to the spinal cord include gunshot wounds, stabbings, herniated discs, and birth injuries. The consequences

amnesia: L. *amnesia,* forgetfulness

comatose: Gk. *koma,* deep sleep

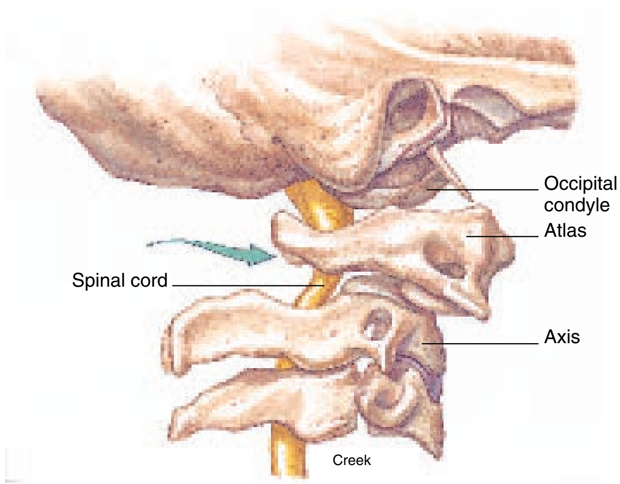


FIGURE 11.46 Whiplash varies in severity from muscle and ligament strains to dislocation of the vertebrae and compression of the spinal cord. Injuries such as this may cause permanent loss of some or all of the spinal cord functions.

of the trauma depend on the location and severity of the injury and the medical treatment the patient receives. If nerve fibers of the spinal cord are severed, motor or sensory functions will be permanently lost.

Paralysis is a permanent loss of motor control, usually resulting from disease or a lesion of the spinal cord or specific nerves. Paralysis of both lower extremities is called **paraplegia.** Paralysis of both the upper and lower extremities on the same side is called **hemiplegia,** and paralysis of all four extremities is **quadriplegia.** Paralysis may be flaccid or spastic. **Flaccid** (*flak'sid*) **paralysis** generally results from a lesion of the anterior horn cells and is characterized by noncontractile muscles that atrophy. **Spastic paralysis** results from lesions of the corticospinal tracts of the spinal cord and is characterized by hypertonicity of the skeletal muscles.

Whiplash is a sudden hyperextension and flexion of the cervical vertebrae (fig. 11.46) such as may occur during a rear-end automobile collision. Recovery of a minor whiplash (muscle and ligament strains) is generally complete, albeit slow. Severe whiplash (spinal cord compression) may cause permanent paralysis to the structures below the level of injury.

Disorders of the Nervous System

Mental Illness

Mental illness is a major clinical consideration of the nervous system and is perhaps the least understood. Traditionally, mental disorders have been grouped into two broad categories: neurosis and psychosis. In **neurosis,** a maladjustment to certain aspects of life interferes with normal functioning, but contact with reality is maintained. An irrational fear (*phobia*) is an example of neurosis. Neurosis frequently causes intense anxiety or abnormal distress that brings about increased sympathetic stimulation. **Psychosis,** a more serious mental condition, is typified by personality disintegration and a loss of contact with reality. The more common forms of psychosis include *schizophrenia,* in which a person withdraws into a world of fantasy; *paranoia,* in which a person has systematized delusions, often of a persecutory nature; and *manic-depressive psychosis*, in which a person's moods swing widely from intense elation to deepest despair.

Epilepsy

Epilepsy is a relatively common brain disorder with a strong hereditary basis, but it also can be caused by head injuries, tumors, or childhood infectious diseases. It is sometimes idiopathic (without demonstrable cause). A person with epilepsy may periodically experience an *epileptic seizure,* which has various symptoms depending on the type of epilepsy.

The most common kinds of epilepsy are petit mal, psychomotor epilepsy, and grand mal. **Petit mal** (*pet'e-mal'*) occurs almost exclusively in children between the ages of 3 and 12. A child experiencing a petit mal seizure loses contact with reality for 5 to 30 seconds but does not lose consciousness or display convulsions. There may, however, be slight uncontrollable facial gestures or eye movements, and the child will stare, as if in a daydream. During a petit mal seizure, the thalamus and hypothalamus produce an extremely slow EEG pattern of 3 waves per second. Children with petit mal usually outgrow the condition by age 9 or 10 and generally require no medication.

Psychomotor epilepsy is often confused with mental illness because of the symptoms characteristic of the seizure. During such a seizure, EEG activity accelerates in the temporal lobes, causing a person to become disoriented and lose contact with reality. Occasionally during a seizure, specific cerebral motor areas will cause involuntary lip smacking or hand clapping. If motor areas in the brain are not stimulated, a person having a psychomotor epileptic seizure may wander aimlessly until the seizure subsides.

Grand mal is a more serious form of epilepsy characterized by periodic convulsive seizures that generally render a person unconscious. Grand mal epileptic seizures are accompanied by rapid EEG patterns of 25 to 30 waves per second. This sudden increase from the norm of about 10 waves per second may cause extensive stimulation of motor units and, therefore, uncontrollable urinary muscle activity. During a grand mal seizure, a person loses

CHAPTER 11

paralysis: Gk. *paralysis,* loosening
paraplegia: Gk. *para,* beside; *plessein,* to strike
epilepsy: Gk. *epi,* upon; *lepsis,* seize
petit mal: L. *pitinnus,* small child; *malus,* bad

consciousness, convulses, and may lose bladder and bowel control. After a few minutes, the muscles relax and the person awakes but he or she remains disoriented for a short time.

Epilepsy almost never affects intelligence and can be effectively treated with drugs in about 85% of the patients.

Cerebral Palsy

Cerebral palsy is a motor nerve disorder characterized by paresis (partial paralysis) and lack of muscular coordination. It is caused by damage to the motor areas of the brain during prenatal development, birth, or infancy. During neural development within an embryo, radiation or bacterial toxins (such as from German measles) transferred through the placenta of the mother may cause cerebral palsy. Oxygen deprivation resulting from complications at birth and hydrocephalus in a newborn may also cause cerebral palsy. The three areas of the brain most severely affected by this disease are the cerebral cortex, the basal nuclei, and the cerebellum. The type of cerebral palsy is determined by the particular region of the brain that is affected.

Some degree of mental retardation occurs in 60% to 70% of cerebral palsy victims. Partial blindness, deafness, and speech problems frequently accompany this disease. Cerebral palsy is nonprogressive; that is, the impairments do not worsen as a person ages. However, neither are there physical improvements.

Neoplasms of the CNS

Neoplasms of the CNS are either **intracranial tumors,** which affect brain cells or cells associated with the brain, or they are **intravertebral** (intraspinal) **tumors,** which affect cells within or near the spinal cord. **Primary neoplasms** develop within the CNS. Approximately half of these are benign, but they may become lethal because of the pressure they exert on vital centers as they grow. Patients with **secondary,** or **metastatic, neoplasms** within the brain have a poor prognosis because the cancer has already established itself in another body organ—frequently the liver, lung, or breast—and has only secondarily spread to the brain. The symptoms of a brain tumor include headache, convulsions, pain, paralysis, or a change in behavior.

Neoplasms of the CNS are classified according to the tissues in which the cancer occurs. Tumors arising in neuroglia are called **gliomas** (*gli-o'maz*) and account for about half of all primary neoplasms within the brain. Gliomas are frequently spread throughout cerebral tissue, develop rapidly, and usually cause death within a year after diagnosis. **Astrocytomas** (*as''tro-si-to'-maz*), **oligodendrogliomas** (*ol''ĭ-go-den''drog-le-o'maz*), and **ependymomas** (*ĕ-pen''dĭ-mo'maz*) are common types of gliomas.

Meningiomas arise from meningeal coverings of the brain and account for about 15% of primary intracranial tumors. Meningiomas are usually harmless if they are treated readily.

Intravertebral tumors are classified as **extramedullary** when they develop on the outside of the spinal cord and as **intramedullary** when they develop within the substance of the spinal cord. Extramedullary neoplasms may cause pain and numbness in body structures distant from the tumor as the growing tumor compresses the spinal cord. An intramedullary neoplasm causes a gradual loss of function below the spinal-segmental level of the affliction.

Methods of detecting and treating cancers within the CNS have greatly improved in the last few years. Early detection and competent treatment have lessened the likelihood of death from these cancers and have reduced the probability of physical impairment.

Dyslexia

Dyslexia is a defect in the language center within the brain. In dyslexia, otherwise intelligent people reverse the order of letters in syllables, of syllables in words, and of words in sentences. The sentence: "The man saw a red dog," for example might be read by the dyslexic as "A red god was the man." Dyslexia is believed to result from the failure of one cerebral hemisphere to respond to written language, perhaps because of structural defects. Dyslexia can usually be overcome by intense remedial instruction in reading and writing.

Meningitis

The nervous system is vulnerable to a variety of organisms and viruses that may cause abscesses or infections. Meningitis is an infection of the meninges. It may be confined to the spinal cord, in which case it is referred to as **spinal meningitis,** or it may involve the brain and associated meninges, in which case it is known as **encephalitis.** When both the brain and spinal cord are involved, the correct term is encephalomyelitis (*en-sef''ă-lo-mi''ĕ-li'tis*). The microorganisms that most commonly cause meningitis are meningococci, streptococci, pneumococci, and tubercle bacilli. Viral meningitis is more serious than bacterial meningitis; nearly 20% of viral encephalitides are fatal. The organisms that cause meningitis probably enter the body through respiratory passageways.

Poliomyelitis

Poliomyelitis, or infantile paralysis, is primarily a childhood disease caused by a virus that destroys nerve cell bodies within the anterior horn of the spinal cord, especially those within the cervical and lumbar enlargements. This degenerative disease is characterized by fever, severe headache, stiffness and pain in the head and back, and the loss of certain somatic reflexes. Muscle paralysis follows within several weeks, and eventually the muscles atrophy. Death results if the virus invades the vasomotor and respiratory nuclei within the medulla oblongata or anterior horn cells controlling respiratory muscles. Poliomyelitis has been effectively controlled with immunization.

Syphilis

Syphilis is a sexually transmitted disease that, if untreated, progressively destroys body organs. When syphilis causes organ degeneration, it is said to be in the *tertiary stage* (10 to 20 years after the primary infection). The organs of the nervous system are frequently infected, causing a condition called **neurosyphilis.** Neurosyphilis is classified according to the tissue involved, and the symptoms vary correspondingly. If the meninges are infected, the condition is termed **chronic meningitis. Tabes** (*ta'bēz*) **dorsalis** is a form of neurosyphilis in which there is a progressive degeneration of the posterior funiculi of the spinal cord and posterior roots of spinal nerves. Motor control is gradually lost and patients eventually become bedridden, unable even to feed themselves.

Senescence of the Nervous System

With respect to the nervous system, little is known about the extent of changes related to normal aging. It has been estimated that perhaps 100,000 neurons die each day of our adult life. Empirical studies, however, show that such claims are unfounded. It is believed that relatively few neural cells are lost during the normal aging process. Neurons are extremely sensitive, however. They are susceptible to various drugs or interruptions of vascular supply such as caused by strokes or other cardiovascular diseases.

There is evidence that senescence alters neurotransmitters. Depression and other age-related conditions, or specific diseases such as Parkinson's disease, may be caused by an imbalance of neurotransmitter chemicals. Changes in sleeping patterns in elderly people also probably result from neurotransmitter problems.

The slowing of the nervous system with age is most apparent in tests of reaction time. It is not certain whether this is a result of a slowing in the transmission of impulses along neurons or in neurotransmitter relays at the synapses.

Although the nervous system does deteriorate with age (in ways that are not well understood), in most people it functions effectively throughout life. Brain dysfunction is not a common characteristic of senescence.

Degenerative Diseases of the Nervous System

Degenerative diseases of the CNS are characterized by a progressive, symmetrical deterioration of vital structures of the brain or spinal cord. The etiologies of these diseases are poorly understood, but it is thought that most of them are genetic.

Cerebrovascular Accident (CVA)

Cerebrovascular accident is the most common disease of the nervous system. It is the third most frequent cause of death in the United States, and perhaps the number one cause of disability. The term **stroke** is frequently used as a synonym for CVA, but actually a stroke refers to the sudden and dramatic appearance of a neurological defect. *Cerebral thrombosis,* in which a thrombus, or clot, forms in an artery of the brain, is the most common cause of CVA. Other causes of CVA include intracerebral hemorrhages, aneurysms, atherosclerosis, and arteriosclerosis of the cerebral arteries.

Patients who recover from CVA frequently suffer partial paralysis and mental disorders, such as loss of language skills. The dysfunction depends on the severity of the CVA and the regions of the brain that were injured. Patients surviving a CVA can often be rehabilitated, but approximately two-thirds die within 3 years of the initial damage.

Multiple Sclerosis

Multiple sclerosis (MS) is a relatively common neurological disease in people between the ages of 20 and 40. MS is a chronic, degenerating, remitting, and relapsing disease that progressively destroys the myelin layers of neurons in multiple areas of the CNS. Initially, lesions form on the myelin layers and soon develop into hardened *scleroses* or scars (hence the name). The destruction of myelin layers prohibits the normal conduction of impulses, resulting in a progressive loss of functions. Because myelin degeneration is widely distributed, MS has a wider variety of symptoms than any other neurologic disease. This characteristic, coupled with remission, frequently causes the disease to be misdiagnosed.

During the early stages of MS, many patients are believed to be neurotic because of the variability and temporary nature of their symptoms. As the disease progresses, the symptoms may include double vision (diplopia), spots in the visual field, blindness, tremor, numbness of appendages, and locomotor difficulty. Eventually the patient is bedridden, and death may occur anytime from 7 to 30 years after the first symptoms appear.

Syringomyelia

Syringomyelia (*sĭ-ring''go-mi-e'le-ă*) is a relatively uncommon condition characterized by the appearance of cystlike cavities, called *syringes,* within the gray matter of the spinal cord. These syringes progressively destroy the cord from the inside out. As the spinal cord deteriorates, the patient experiences muscular weakness and atrophy and sensory loss, particularly of the senses of pain and temperature. The cause of syringomyelia is unknown.

Tay–Sachs Disease

In Tay–Sachs disease, the myelin sheaths are destroyed by the excessive accumulation of one of the lipid components of the myelin. This results from an enzyme defect caused by the inheritance of genes carried by the parents in a recessive state. The disease is inherited primarily by individuals of Eastern European Jewish descent and appears before the infant is a year old. It causes blindness, loss of mental and motor ability, and ultimately death by the age of 3. Potential parents can tell if they are carriers for this condition by the use of a special blood test for the defective enzyme.

multiple sclerosis: L. *multiplus,* many parts; Gk. *skleros,* hardened

Tay–Sachs disease: from Warren Tay, English physician, 1843–1927, and Bernard Sachs, American neurologist, 1858–1944

Diseases Involving Neurotransmitters

Parkinson's disease, or **paralysis agitans,** is a major cause of neurological disability in people over 60 years of age. It is a progressive degenerative disease of unknown cause. Nerve cells within the substantia nigra, an area within the basal nuclei of the brain, are destroyed. This causes muscle tremors, muscular rigidity, speech defects, and other severe problems. The symptoms of this disease can be partially treated by altering the neurotransmitter status of the brain. Patients are given L-dopa to increase the production of dopamine in the brain, and may also be given anticholinergic drugs to decrease the production of acetylcholine.

Alzheimer's disease is the most common cause of dementia, often beginning in middle age and producing progressive mental deterioration. The cause of Alzheimer's disease is unknown, but evidence suggests that it is associated with the decreased ability of the brain to produce acetylcholine. Attempts to increase ACh production by increased ingestion of precursor molecules (choline or lecithin) have thus far not been successful. Drugs that block acetylcholinesterase, an enzyme that inactivates ACh, offer promise but are so far still in the experimental stage.

At least some psychiatric disorders may be produced by dysfunction of neurotransmitters. There is evidence that **schizophrenia** is associated with hyperactivity of the neurons that use dopamine as a neurotransmitter. Drugs that are effective in the treatment of schizophrenia (e.g., chlorpromazine) act by blocking dopamine receptor proteins. **Depression** is associated with decreased activity of the neurons that use monoamines—norepinephrine and serotonin—as neurotransmitters. Antidepressant drugs enhance the action of these neurotransmitters. In a similar way, barbiturates and benzodiazepine (e.g., Valium), which decrease **anxiety,** act by enhancing the action of the neurotransmitter GABA in the CNS.

Clinical Case Study Answer

The affected upper motor neurons have cell bodies that reside in the right cerebral hemisphere. They give rise to fibers that, as they course downward, cross in the medulla oblongata to the left side of the brain stem and spinal cord. They continue on the left side, eventually synapsing at the appropriate level with lower motor neurons in the anterior horn of the spinal cord. The lower motor neurons then give rise to fibers that travel to the periphery, where they innervate end organs; namely, muscle cells in the left side of the body. Because the patient's neurological deficits are all motor as opposed to sensory, the tumor is most likely located in the right frontal lobe. The parietal lobe contains sensory neurons. The persistent headache is due to the pressure of the tumorous mass on the meninges, which are heavily sensory innervated.

Parkinson's disease: from James Parkinson, British physician, 1755–1824
Alzheimer's disease: from Alois Alzheimer, German neurologist, 1864–1915

CLINICAL PRACTICUM 11.1

A teenage girl is brought to the emergency room unconscious. Her father says the girl was hit in the side of the head by a baseball. She was knocked unconscious for about 30 seconds, but then she awakened and seemed fine except for a big bruise with swelling over her right temporal area and a slight headache. However, about an hour later she became very drowsy and was soon comatose. That's when he rushed her to the hospital.

You see the bruised and swollen temporal area, confirm the comatose state, and notice that the right pupil is fixed and dilated. You call for the neurosurgeon and arrange an emergent CT scan of the head.

QUESTIONS:

1. Why does the collection of blood seen in the adjacent CT scan have such smooth borders and pointed tips?
2. Why did the patient become comatose after she appeared to be fine?
3. Why did her pupil dilate?

Chapter Summary

Organization and Functions of the Nervous System (pp. 344–345)

1. The central nervous system (CNS) consists of the brain and spinal cord and contains gray and white matter. It is covered with meninges and bathed in cerebrospinal fluid.
2. The functions of the nervous system include orientation, coordination, assimilation, and programming of instinctual behavior.

Neurons and Neuroglia (pp. 348–356)

1. Neurons are the basic structural and functional units of the nervous system. Specialized cells called neuroglia provide structural and functional support for the activities of neurons.
2. A neuron contains dendrites, a cell body, and an axon.
   (a) The cell body contains the nucleus, chromatophilic substances, neurofibrils, and other organelles.
   (b) Dendrites respond to stimuli and the axon conducts action potentials away from the cell body.
3. Neuroglia are of six types: neurolemmocytes form myelin layers around axons in the PNS; oligodendrocytes form myelin layers around axons in the CNS; microglia perform a phagocytic function in the CNS; astrocytes regulate passage of substances from the blood to the CNS; ependymal cells assist the movement of cerebrospinal fluid in the CNS; and ganglionic gliocytes support neuron cell bodies in the PNS.
   (a) The neuroglia that surround an axon form a covering called a myelin layer.
   (b) Myelinated neurons have limited capabilities for regeneration following trauma.
4. A nerve is a collection of dendrites and axons in the PNS.
   (a) Sensory (afferent) neurons are pseudounipolar.
   (b) Motor (efferent) neurons are multipolar.
   (c) Association (interneurons) are located entirely within the CNS.
   (d) Somatic motor nerves innervate skeletal muscle; visceral motor (autonomic) nerves innervate smooth muscle, cardiac muscle, and glands.

Transmission of Impulses (pp. 357–358)

1. Irritability and conductivity are properties of neurons that permit transmission of action potentials.
2. Neurotransmitters facilitate synaptic impulse transmission.

General Features of the Brain (pp. 358–362)

1. The brain, composed of gray matter and white matter, is protected by meninges and is bathed in cerebrospinal fluid.
2. About 750 ml of blood flows to the brain each minute.

Cerebrum (pp. 363–371)

1. The cerebrum, consisting of two convoluted hemispheres, is concerned with higher brain functions, such as the perception of sensory impulses, the instigation of voluntary movement, the storage of memory, thought processes, and reasoning ability.
2. The cerebral cortex is convoluted with gyri and sulci.
3. Each cerebral hemisphere contains frontal, parietal, temporal, and occipital lobes. The insula lies deep within the cerebrum and cannot be seen in an external view.
4. Brain waves generated by the cerebral cortex are recorded as an electroencephalogram and may provide valuable diagnostic information.
5. The white matter of the cerebrum consists of association, commissural, and projection fibers.
6. Basal nuclei are specialized masses of gray matter located within the white matter of the cerebrum.

Diencephalon (pp. 372–373)

1. The diencephalon is a major autonomic region of the brain.
2. The thalamus is an ovoid mass of gray matter that functions as a relay center for sensory impulses and responds to pain.
3. The hypothalamus is an aggregation of specialized nuclei that regulate many visceral activities. It also performs emotional and instinctual functions, and has a limited regulatory role on the pituitary gland.
4. The epithalamus contains the pineal gland and the vascular choroid plexus over the roof of the third ventricle.

Mesencephalon (pp. 373–374)

1. The mesencephalon contains the corpora quadrigemina, the cerebral peduncles, and specialized nuclei that help to control posture and movement.
2. The superior colliculi of the corpora quadrigemina are concerned with visual reflexes and the inferior colliculi are concerned with auditory reflexes.
3. The red nucleus and the substantia nigra are concerned with motor activities.

Metencephalon (pp. 374–376)

1. The pons consists of fiber tracts connecting the cerebellum and medulla oblongata to other structures of the brain. The pons also contains nuclei for certain cranial nerves and the regulation of respiration.
2. The cerebellum consists of two hemispheres connected by the vermis and supported by three paired cerebellar peduncles.
   (a) The cerebellum is composed of a white matter tract called the arbor vitae, surrounded by a thin convoluted cortex of gray matter.
   (b) The cerebellum is concerned with coordinated contractions of skeletal muscle.

Myelencephalon (pp. 376–378)

1. The medulla oblongata is composed of the ascending and descending tracts of the spinal cord and contains nuclei for several autonomic functions.
2. The reticular formation functions as the reticular activating system in arousing the cerebrum.

Meninges (pp. 378–381)

1. The cranial dura mater consists of an outer periosteal layer and an inner meningeal layer. The spinal dura mater is a single layer surrounded by the vascular epidural space.
2. The arachnoid is a netlike meninx surrounding the subarachnoid space, which contains cerebrospinal fluid.
3. The thin pia mater adheres to the contours of the CNS.

Ventricles and Cerebrospinal Fluid (pp. 381–384)

1. The lateral (first and second), third, and fourth ventricles are interconnected chambers within the brain that are continuous with the central canal of the spinal cord.
2. These chambers are filled with cerebrospinal fluid, which also flows throughout the subarachnoid space.
3. Cerebrospinal fluid is continuously formed by the choroid plexuses from blood plasma and is returned to the blood at the arachnoid villi.
4. The blood-brain barrier determines which substances within blood plasma can enter the extracellular fluid of the brain.

Spinal Cord (pp. 384–390)

1. The spinal cord is composed of 31 segments, each of which gives rise to a pair of spinal nerves.
   (a) It is characterized by a cervical enlargement, a lumbar enlargement, and two longitudinal grooves that partially divide it into right and left halves.
   (b) The conus medullaris is the terminal portion of the spinal cord, and the cauda equina are nerve roots that radiate interiorly from that point.
2. Ascending and descending spinal cord tracts are referred to as funiculi.
   (a) Descending tracts are grouped as either corticospinal (pyramidal) or extrapyramidal.
   (b) Many of the fibers in the funiculi decussate (cross over) in the spinal cord or in the medulla oblongata of the brain stem.

Review Activities

Objective Questions

Match the following structures of the brain to the region in which they are located:

1. cerebellum
2. cerebral cortex
3. medulla oblongata
   (a) telencephalon
   (b) diencephalon
   (c) mesencephalon
   (d) metencephalon
   (e) myelencephalon
4. The neuroglial cells that form myelin sheaths in the peripheral nervous system are
   (a) oligodendrocytes.
   (b) ganglionic gliocytes.
   (c) neurolemmocytes.
   (d) astrocytes.
   (e) microglia.
5. A collection of neuron cell bodies located outside the CNS is called
   (a) a tract. (c) a nucleus.
   (b) a nerve. (d) a ganglion.
6. Which of the following types of neurons are pseudounipolar?
   (a) sensory neurons
   (b) somatic motor neurons
   (c) neurons in the retina
   (d) autonomic motor neurons
7. Depolarization of an axon is produced by the movement of
   (a) Na^+ into the axon and K^+ out of the axon.
   (b) Na^+ into the axon to bond with K^-.
   (c) K^+ into the axon and Na^+ out of the axon.
   (d) Na^+ and K^+ within the axon toward the axon terminal.
8. The principal connection between the cerebral hemispheres is
   (a) the corpus callosum.
   (b) the pons.
   (c) the intermediate mass.
   (d) the vermis.
   (e) the precentral gyrus.
9. The structure of the brain that is most directly involved in the autonomic response to pain is
   (a) the pons.
   (b) the hypothalamus.
   (c) the medulla oblongata.
   (d) the thalamus.
10. Which statement is *false* concerning the basal nuclei?
    (a) They are located within the cerebrum.
    (b) They regulate the basal metabolic rate.
    (c) They consist of the caudate nucleus, lentiform nucleus, putamen, and globus pallidus.
    (d) They indirectly exert an inhibitory influence on lower motor neurons.
11. The corpora quadrigemina, red nucleus, and substantia nigra are structures of
    (a) the diencephalon.
    (b) the metencephalon.
    (c) the mesencephalon.
    (d) the myelencephalon.
12. The fourth ventricle is contained within
    (a) the cerebrum.
    (b) the cerebellum.
    (c) the midbrain.
    (d) the metencephalon.

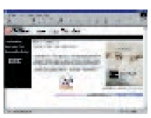
Essay Questions

1. Describe the formation of the neural crest and explain how derivatives of neural crest tissue can be located in different parts of the body.
2. Diagram and label a neuron. Beside each label, list the function of the identified structure. Why are neurons considered the basic functional units of the nervous system?
3. What is meant by a myelinated neuron? Describe how an injured nerve fiber may regenerate.
4. List the six principal types of neuroglia and discuss the location, structure, and function of each.
5. What is an action potential and how is it generated? Why is it called an all-or-none response?
6. What is a synapse and what is the role of a neurotransmitter in relaying an action potential?
7. List the types of brain waves recorded on an electroencephalogram and explain the diagnostic value of each.
8. List the functions of the hypothalamus. Why is the hypothalamus considered a major part of the autonomic nervous system?
9. What structures are located within the midbrain? List the nuclei located in the midbrain and state the function of each.
10. Describe the location and structure of the medulla oblongata. List the nuclei contained within it. What are the functions of the medulla oblongata?
11. What is cerebrospinal fluid? Explain how it is produced and describe its path of circulation?
12. What do EEG, ANS, CSF, PNS, RAS, CT scan, MS, DSR, and CVA stand for?
13. What are some of the psychological terms used to describe mental illness? Define these terms.

14. What is epilepsy? What causes it and how is it controlled?
15. What do meningitis, poliomyelitis and neurosyphilis have in common? How do these conditions differ?

Critical-Thinking Questions

1. In a patient's case study, any observed or suspected structural/functional abnormalities of body structures are reported. Prepare a brief case study of a patient who has suffered severe trauma to the medulla oblongata from a blow to the back of the skull.
2. A young man develops weakness in his legs over the course of several days, which worsens until he can no longer walk. He also loses urinary bladder control and complains of loss of sensation from the umbilicus down. Locate the probable site of neurological impairment.
3. Electrical stimulation of the cerebellum or the basal nuclei can produce skeletal movements. How would damage to these two regions of the brain affect skeletal muscle function differently?
4. If an entire cerebral hemisphere is destroyed, a person can still survive. Yet, damage to the medulla oblongata, a much smaller mass of tissue, can be fatal. Explain this difference.
5. A seizure occurs when abnormal electrical activity overwhelms the brain's normal function. A *focal seizure* originates from a specific irritable tissue, such as a tumorous mass, and causes isolated muscle jerking or sensory abnormalities. Immediately before a focal seizure, the sufferer frequently perceives a fleeting sensation, called an aura, that suggests the origin of the electrical burst. Using your knowledge of cerebral lobe function, predict the origin of a seizure that was preceded by the perception of a foul odor. A flash of light. A painful hand. A familiar song.
6. Explain how meningitis contracted through the meninges over the roof of the nose may be detected from a spinal tap performed in the lumbar region.



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CHAPTER 11