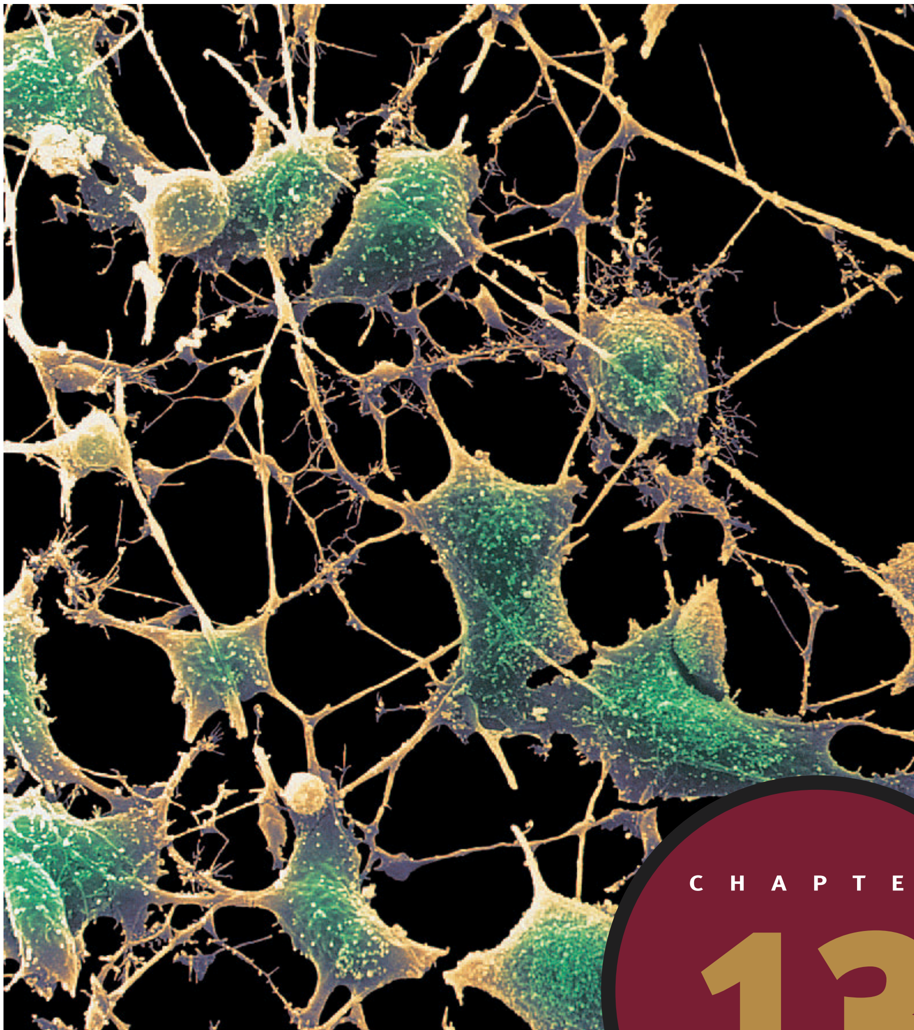


Colorized SEM of a neuron network.

Brain and Cranial Nerves

CHAPTER

13

The brain is that part of the CNS contained within the cranial cavity (figure 13.1). It is the control center for many of the body's functions. The brain is much like a complex central computer but with additional functions that no computer can as yet match. Indeed, one goal in computer technology is to make computers that can function more like the human brain. The brain consists of the brainstem, the cerebellum, the diencephalon, and the crerebrum (table 13.1). The brainstem includes the medulla oblongata, pons, midbrain, and reticular formation. The structure of the brain is described in this chapter. Its functions are primarily discussed in the next chapter.

Twelve pairs of cranial nerves, which are part of the PNS, arise directly from the brain. Two pairs arise from the cerebrum, and the remaining 10 pairs arise form the brainstem.

This chapter describes the *brainstem* (434), *cerebellum* (437), *diencephalon* (439), *cerebrum* (441), *meninges and cerebrospinal fluid* (444), *blood supply to the brain* (448) *development of the CNS* (449), and the *cranial nerves* (449).

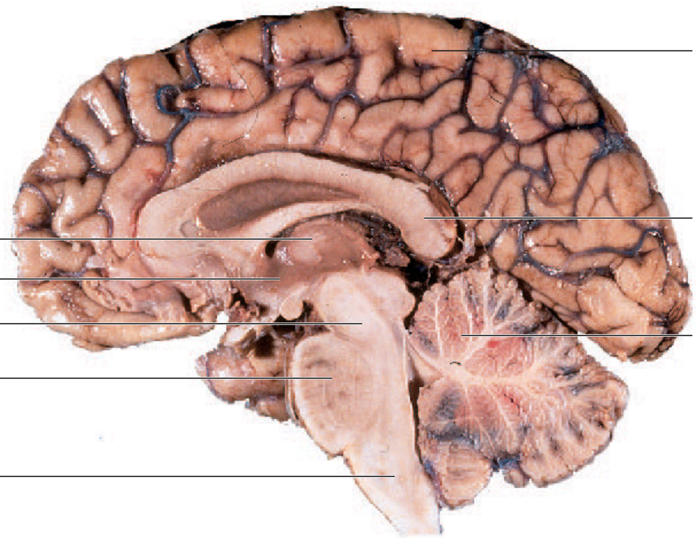


Figure 13.1 Regions of the Right Half of the Brain
(as seen in a midsagittal section)

Brainstem

Objective

- ***Describe the parts of the brainstem and list their functions.***

The medulla oblongata, pons, and midbrain constitute the **brainstem** (figure 13.2). The brainstem connects the spinal cord to the remainder of the brain and is responsible for many essential functions. Damage to small brainstem areas often causes death because many reflexes essential for survival are integrated in the brainstem, whereas relatively large areas of the cerebrum or cerebellum may be damaged without being life-threatening.

Medulla Oblongata

The **medulla oblongata** (ob-long-gah′tă), often called the medulla, is about 3 cm long, is the most inferior part of the brainstem, and is continuous inferiorly with the spinal cord. It contains ascending and descending nerve tracts; cranial nerve nuclei; other, related nuclei; and part of the reticular formation. Superficially, the spinal cord blends into the medulla, but internally several differences exist. Discrete **nuclei,** clusters of gray matter composed mostly of neuron cell bodies and having specific functions, are found in the medulla oblongata, whereas the gray matter of the spinal cord extends as a continuous mass in the center of the cord. In addition, the nerve tracts within the medulla don't have the same organization as those of the spinal cord. Several medullary nuclei function as centers for reflexes, such as those involved in the regulation of heart rate, blood vessel diameter, respiration, swallowing, vomiting, hiccuping, coughing, and sneezing.

Two prominent enlargements on the anterior surface of the medulla oblongata are called **pyramids** because they are broader near the pons and taper toward the spinal cord (figure 13.2*a*). The pyramids are descending nerve tracts involved in the conscious control of skeletal muscles. Near their inferior ends, most of the fibers of the descending nerve tracts cross to the opposite side, or **decussate** (dē′kŭ-sāt, dē-kŭs′āt; the Latin word *decussatus* means to form an X, as in the Roman numeral X). This decussation accounts, in part, for the fact that each half of the brain controls the opposite half of the body. Its role as a conduction pathway is discussed in the description of ascending and descending nerve tracts (see chapter 14).

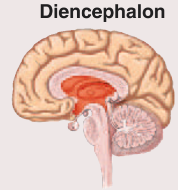
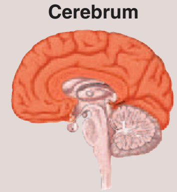
Two rounded, oval structures, called **olives,** protrude from the anterior surface of the medulla oblongata just lateral to the superior margins of the pyramids (figure 13.2*a* and *b*). The olives are nuclei involved in functions such as balance, coordination, and modulation of sound from the inner ear (see chapter 15). The nuclei of cranial nerves V (trigeminal), IX (glossopharyngeal), X (vagus), XI (accessory), and XII (hypoglossal) also are located within the medulla (figure 13.2*c*).

Pons

The part of the brainstem just superior to the medulla oblongata is the **pons** (see figure 13.2*a*), which contains ascending and descending nerve tracts and several nuclei. The pontine nuclei, located in the anterior portion of the pons, relay information from the cerebrum to the cerebellum.

The nuclei for cranial nerves V (trigeminal), VI (abducens), VII (facial), VIII (vestibulocochlear), and IX (glossopharyngeal) are contained within the posterior pons. Other important pontine areas include the pontine sleep center and respiratory center, which

Table 13.1 Divisions and Functions of the Brain

Brainstem 	Connects the spinal cord to the cerebrum; several important functions (see below); location of cranial nerve nuclei.
Medulla oblongata 	Pathway for ascending and descending nerve tracts; center for several important reflexes (e.g., heart rate, breathing, swallowing, vomiting)
Pons 	Contains ascending and descending nerve tracts; relay between cerebrum and cerebellum; reflex centers
Midbrain 	Contains ascending and descending nerve tracts; visual reflex center; part of auditory pathway
Reticular formation 	Scattered throughout brainstem; controls cyclic activities such as the sleep-wake cycle
Cerebellum 	Control of muscle movement and tone; regulates extent of intentional movement; involved in learning motor skills
Diencephalon 	
Thalamus	Major sensory relay center; influences mood and movement
Subthalamus	Contains nerve tracts and nuclei
Epithalamus	Contains nuclei responding to olfactory stimulation and contains pineal body
Hypothalamus	Major control center for maintaining homeostasis and regulating endocrine function
Cerebrum 	Conscious perception, thought, and conscious motor activity; can override most other systems
Basal nuclei	Control of muscle activity and posture
Limbic system	Autonomic response to smell, emotion, mood, and other such functions

work with the respiratory centers in the medulla to help control respiratory movements (see chapter 23).

Midbrain

The **midbrain,** or **mesencephalon,** is the smallest region of the brainstem (see figure 13.2*b*). It's just superior to the pons and contains the nuclei of cranial nerves III (oculomotor), IV (trochlear), and V (trigeminal).

The **tectum** (tek′tŭm; roof) (figure 13.3) of the midbrain consists of four nuclei that form mounds on the dorsal surface, collectively called **corpora** (kōr′pōr-ă; bodies) **quadrigemina** (kwah′dri-jem′i-nă; four twins). Each mound is called a **colliculus** (ko-lik′ū-lŭs; hill); the two superior mounds are called **superior colliculi,** and the two inferior mounds are called **inferior colliculi.** The inferior colliculi are involved in hearing and are an integral part of the auditory pathways in the CNS. Neurons conducting

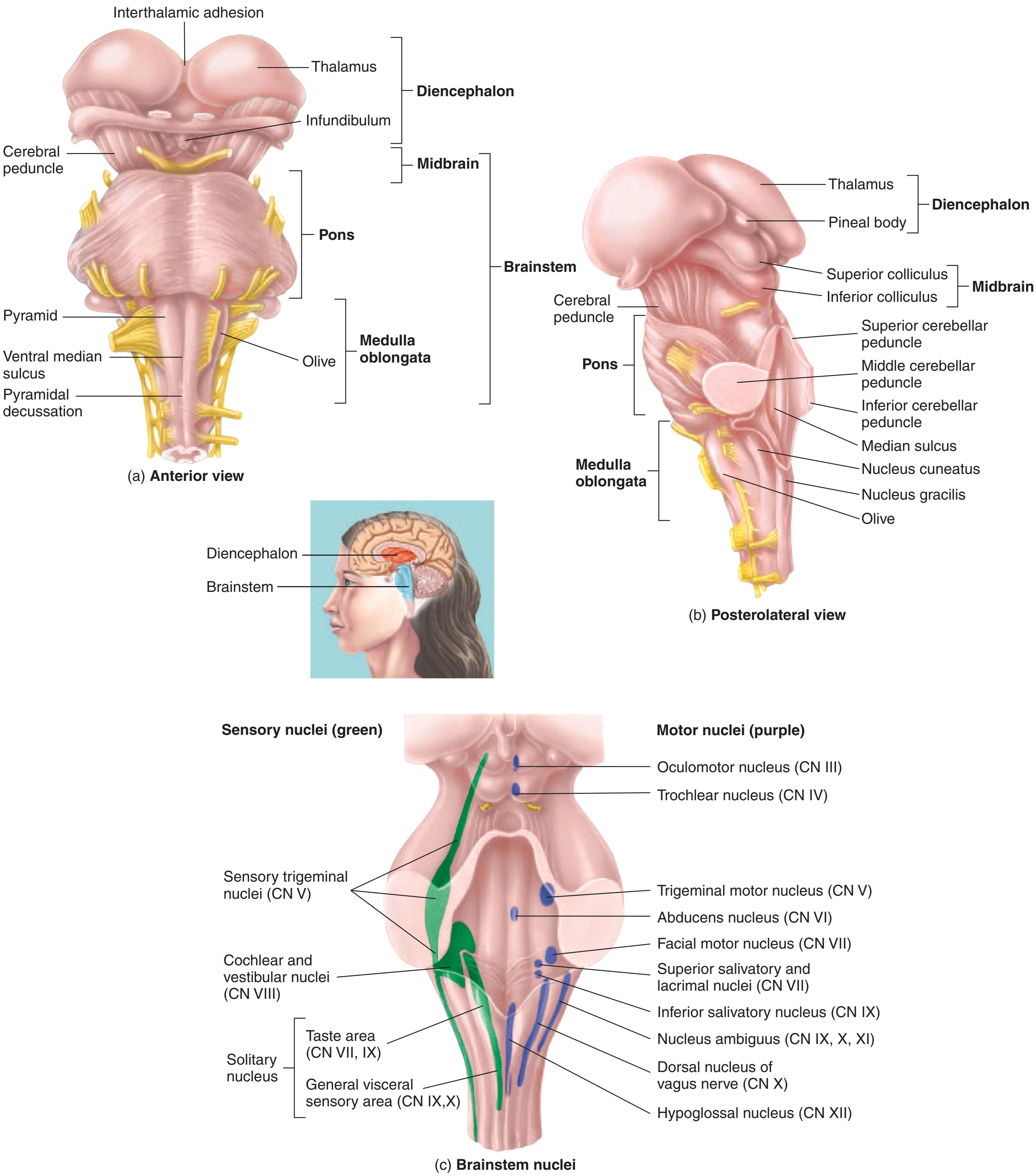


Figure 13.2 Brainstem and Diencephalon

(*a*) Anterior view. (*b*) Posterolateral view. (*c*) Brainstem nuclei. The sensory nuclei are shown on the left (*green*). The motor nuclei are shown on the right (*purple*). Even though the nuclei are shown on only one side, each half of the brainstem has both sensory and motor nuclei. The inset shows the location of the diencephalon (*red*) and brainstem (*blue*). (*CN* = cranial nerve.)

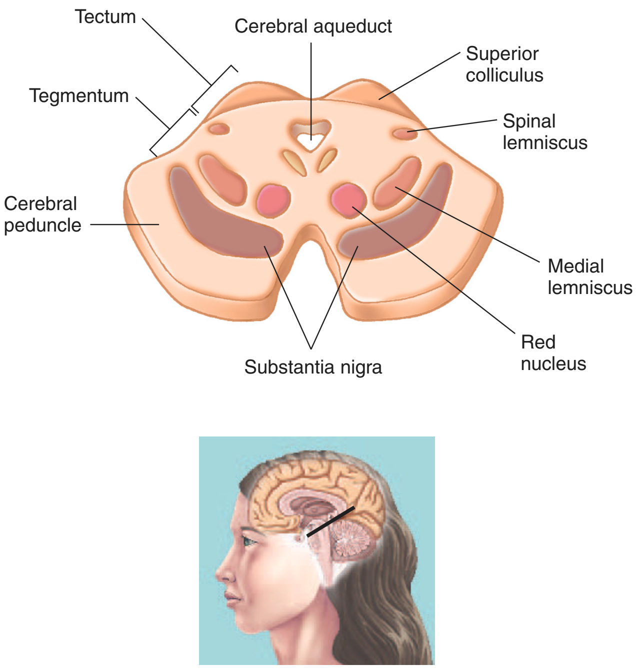


Figure 13.3 **Cross Section Through the Midbrain**
Inset shows the level of section.

action potentials from the structures of the inner ear (see chapter 15) to the brain synapse in the inferior colliculi. The superior colliculi are involved in visual reflexes, and they receive input from the eyes, the inferior colliculi, the skin, and the cerebrum.

Reflex Movements of the Eyes and Head

The superior colliculi regulate the reflex movements of the eyes and head in response to various stimuli. When a bright object suddenly appears in a person's field of vision, a reflex turns the eyes to focus on it. When a person hears a sudden, loud noise, a reflex turns the head and eyes toward it. When a part of the body, such as the shoulder, is touched, a reflex turns the person's head and eyes toward that part of the body. In each situation, the pathway involves the superior colliculus.

The **tegmentum** (teg-men′tŭm; floor) of the midbrain largely consists of ascending tracts, like the spinal lemniscus and the medial lemniscus, from the spinal cord to the brain. The tegmentum also contains the paired **red nuclei,** which are so named because in fresh brain specimens, they are pinkish in color as the result of an abundant blood supply. The red nuclei aid in the unconscious regulation and coordination of motor activities. **Cerebral peduncles** (pe-dŭng′klz, pē′dŭng-klz; the foot of a column) constitute that portion of the midbrain ventral to the tegmentum. They consist primarily of descending tracts from the cerebrum to the brainstem and spinal cord and constitute one of the major CNS motor pathways. The **substantia nigra** (nī′gră; black substance) is a nuclear mass between the tegmentum and cerebral peduncles, containing cytoplasmic melanin granules that give it a dark gray or black color (figure 13.3). The substantia nigra is interconnected with other basal nuclei of the cerebrum, described later in this chapter, and it's involved in maintaining muscle tone and in coordinating movements.

Reticular Formation

A group of nuclei collectively called the **reticular formation** (see table 13.1) is scattered like a cloud throughout the length of the brainstem. The reticular formation receives axons from a large number of sources and especially from nerves that innervate the face.

1. What are the major components of the medulla oblongata, pons, midbrain, and reticular formation? What are the general functions of each region?

Cerebellum

Objective

- *Describe the structure and the major functions of the cerebellum.*

The term **cerebellum** (ser-e-bel′ŭm; figure 13.4) means little brain. The cerebellum is attached to the brainstem posterior to the pons. It communicates with other regions of the CNS through three large nerve tracts: the **superior, middle,** and **inferior cerebellar peduncles,** which connect the cerebellum to the midbrain, pons, and medulla oblongata, respectively. The cerebellum has a gray cortex and nuclei, with white medulla in between. The cerebellar cortex has ridges called **folia.** The white matter of the medulla resembles a branching tree and is called the **arbor vitae** (ar′bōr vī′te; tree of life). The nuclei of the cerebellum are located in the deep inferior center of the white matter.

The cerebellum consists of three parts: a small inferior part, the **flocculonodular** (flok′ū-lō-nod′ū-lăr; floccular, meaning a tuft of wool) **lobe;** a narrow central **vermis** (worm-shaped); and two large **lateral hemispheres** (see figure 13.4). The flocculonodular lobe is the simplest part of the cerebellum and helps control balance and eye movements. The vermis and medial portion of the lateral hemispheres are involved in the control of posture, locomotion, and fine motor coordination, thereby producing smooth, flowing movements. The major portion of the lateral hemispheres is involved, with the cerebral cortex of the frontal lobe, in planning, practicing, and learning complex movements.

2. What are the major regions of the cerebellum? Describe the major functions of each.

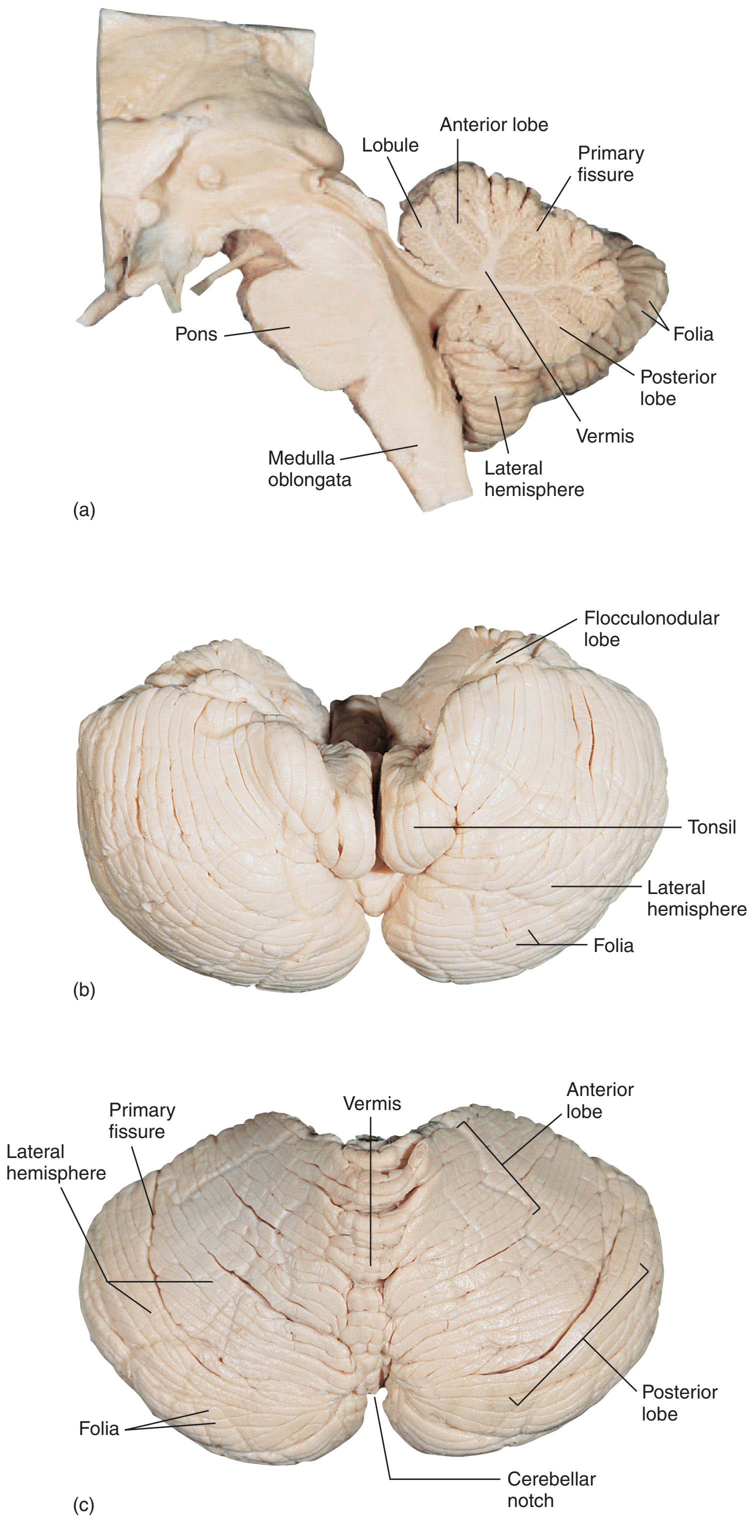


Figure 13.4 Cerebellum

(*a*) Right half of the cerebellum as seen in a midsagittal section. (*b*) Inferior view of the cerebellum. (*c*) Superior view of the cerebellum.

Diencephalon

Objective

- ***List the regions of the diencephalon, and indicate their major functions.***

The **diencephalon** (dī-en-sef′ă-lon) is the part of the brain between the brainstem and the cerebrum (see figures 13.1 and 13.5). Its main components are the thalamus, subthalamus, epithalamus, and hypothalamus.

Thalamus

The **thalamus** (thal′ă-mŭs; figure 13.5*a* and *b*) is by far the largest part of the diencephalon, constituting about four-fifths of its weight. It is a cluster of nuclei shaped somewhat like a yo-yo, with two large, lateral portions connected in the center by a small stalk called the **interthalamic adhesion,** or **intermediate mass.** The space surrounding the interthalamic adhesion and separating the two large portions of the thalamus is the third ventricle of the brain.

Most sensory input projects to the thalamus, where sensory neurons synapse with thalamic neurons, which send projections from the thalamus to the cerebral cortex. Axons carrying auditory information synapse in the **medial geniculate** (je-nik′ū-lāt; Latin, *genu,* meaning bent like a knee) **nucleus** of the thalamus, axons carrying visual information synapse in the **lateral geniculate nucleus,** and most other sensory impulses synapse in the **ventral posterior nucleus.**

The thalamus also influences mood and actions associated with strong emotions like fear or rage. The **ventral anterior** and **ventral lateral nuclei** are involved in motor functions,

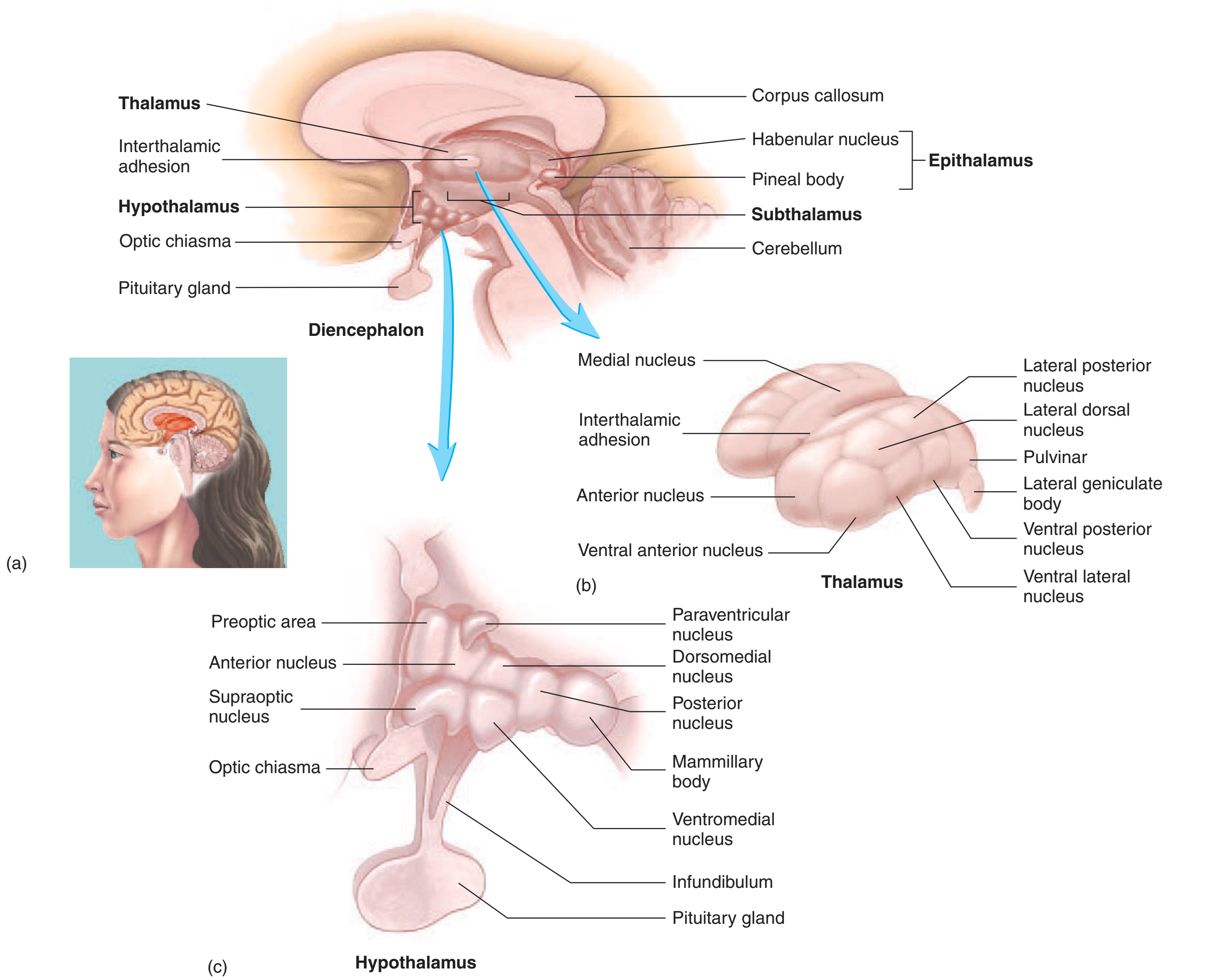


Figure 13.5 Diencephalon

(*a*) General overview of the right half of the diencephalon as seen in a midsagittal section. (*b*) Thalamus showing the nuclei. (*c*) Hypothalamus showing the nuclei and right half of the pituitary.

communicating between the basal nuclei, cerebellum, and the motor cortex (these areas are described later in this chapter). The **anterior** and **medial nuclei** are connected to the limbic system and to the prefrontal cortex (described later in this chapter and in chapter 14). They are involved in mood modification. The **lateral dorsal nucleus** is connected to other thalamic nuclei and to the cerebral cortex and is involved in regulating emotions. The **lateral posterior nucleus** and the **pulvinar** (pŭl-vī′năr; pillow) also have connections to other thalamic nuclei and are involved in sensory integration.

Subthalamus

The **subthalamus** is a small area immediately inferior to the thalamus (see figure 13.5*a*) that contains several ascending and descending nerve tracts and the **subthalamic nuclei.** A small portion of the red nucleus and substantia nigra of the midbrain extend into this area.

The subthalamic nuclei are associated with the basal nuclei and are involved in controlling motor functions.

Epithalamus

The **epithalamus** is a small area superior and posterior to the thalamus (see figure 13.5*a*). It consists of habenular nuclei and the pineal body. The **habenular** (hă-ben′ū-lăr) **nuclei** are influenced by the sense of smell and are involved in emotional and visceral responses to odors. The **pineal** (pin′ē-ăl) **body** is shaped somewhat like a pinecone, from which the name *pineal* is derived. It appears to play a role in controlling the onset of puberty, but data are inconclusive, so active research continues in this field. The pineal body also may influence the sleep–wake cycle.

Brain Sand in the Pineal

In about 75% of adults, the pineal body contains granules of calcium and magnesium salts called "brain sand." These granules can be seen on radiographs and are useful as landmarks in determining whether or not the pineal body has been displaced by a pathologic enlargement of a part of the brain, such as a tumor or a hematoma.

Hypothalamus

The **hypothalamus** is the most inferior portion of the diencephalon (see figure 13.5*a* and *c*) and contains several small nuclei and nerve tracts. The most conspicuous nuclei, called the **mammillary bodies,** appear as bulges on the ventral surface of the diencephalon. They are involved in olfactory reflexes and emotional responses to odors. A funnel-shaped stalk, the **infundibulum** (in-fŭn-dib′ū-lŭm), extends from the floor of the hypothalamus and connects it to the **posterior pituitary gland,** or **neurohypophysis** (noor′ō-hī-pof′i-sis). The hypothalamus plays an important role in controlling the endocrine system because it regulates the pituitary gland's secretion of hormones, which influence functions as diverse as metabolism, reproduction, responses to stressful stimuli, and urine production (see chapter 18).

Sensory neurons that terminate in the hypothalamus provide input from (1) visceral organs; (2) taste receptors of the tongue; (3) the limbic system, which is involved in responses to smell; (4) specific cutaneous areas, such as the nipples and external genitalia; and (5) the prefrontal cortex of the cerebrum carrying information relative to "mood" through the thalamus. Efferent fibers from the hypothalamus extend into the brainstem and the spinal cord, where they synapse with neurons of the autonomic nervous system (see chapter 16). Other fibers extend through the infundibulum to the posterior portion of the pituitary gland (see chapter 18); some extend to trigeminal and facial nerve nuclei to help control the head muscles involved in swallowing; and some extend to motor neurons of the spinal cord to stimulate shivering.

The hypothalamus is very important in a number of functions that are related to mood and emotion (table 13.2). Sensations like sexual pleasure, feeling relaxed and "good" after a meal, rage, and fear are related to hypothalamic functions.

3. ***Name the four main components of the diencephalon.***
4. ***What are the functions of the thalamus and hypothalamus? Explain why the hypothalamus is an important link between the nervous system and the endocrine system.***
5. ***List the general functions of the subthalamus. Name the parts of the epithalamus and give their functions.***

Table 13.2 Hypothalamic Functions

Function	Description
Autonomic	Helps control heart rate, urine release from the bladder, movement of food through the digestive tract, and blood vessel diameter
Endocrine	Helps regulate pituitary gland secretions and influences metabolism, ion balance, sexual development, and sexual functions
Muscle control	Controls muscles involved in swallowing and stimulates shivering in several muscles
Temperature regulation	Promotes heat loss when the hypothalamic temperature increases by increasing sweat production (anterior hypothalamus) and promotes heat production when the hypothalamic temperature decreases by promoting shivering (posterior hypothalamus)
Regulation of food and water intake	Hunger center promotes eating and satiety center inhibits eating; thirst center promotes water intake
Emotions	Large range of emotional influences over body functions; directly involved in stress-related and psychosomatic illnesses and with feelings of fear and rage
Regulation of the sleep–wake cycle	Coordinates responses to the sleep–wake cycle with the other areas of the brain (e.g., the reticular activating system)

Cerebrum

Objectives

- ***Describe the external anatomy and the internal anatomy of the cerebrum.***
- ***Describe the structure of the basal nuclei and limbic system.***

The cerebrum (figure 13.6) is the part of the brain that most people think of when the term *brain* is mentioned. It accounts for the largest portion of the total brain weight, which is about 1200 g in females and 1400 g in males. Brain size is related to body size; larger brains are associated with larger bodies, not with greater intelligence.

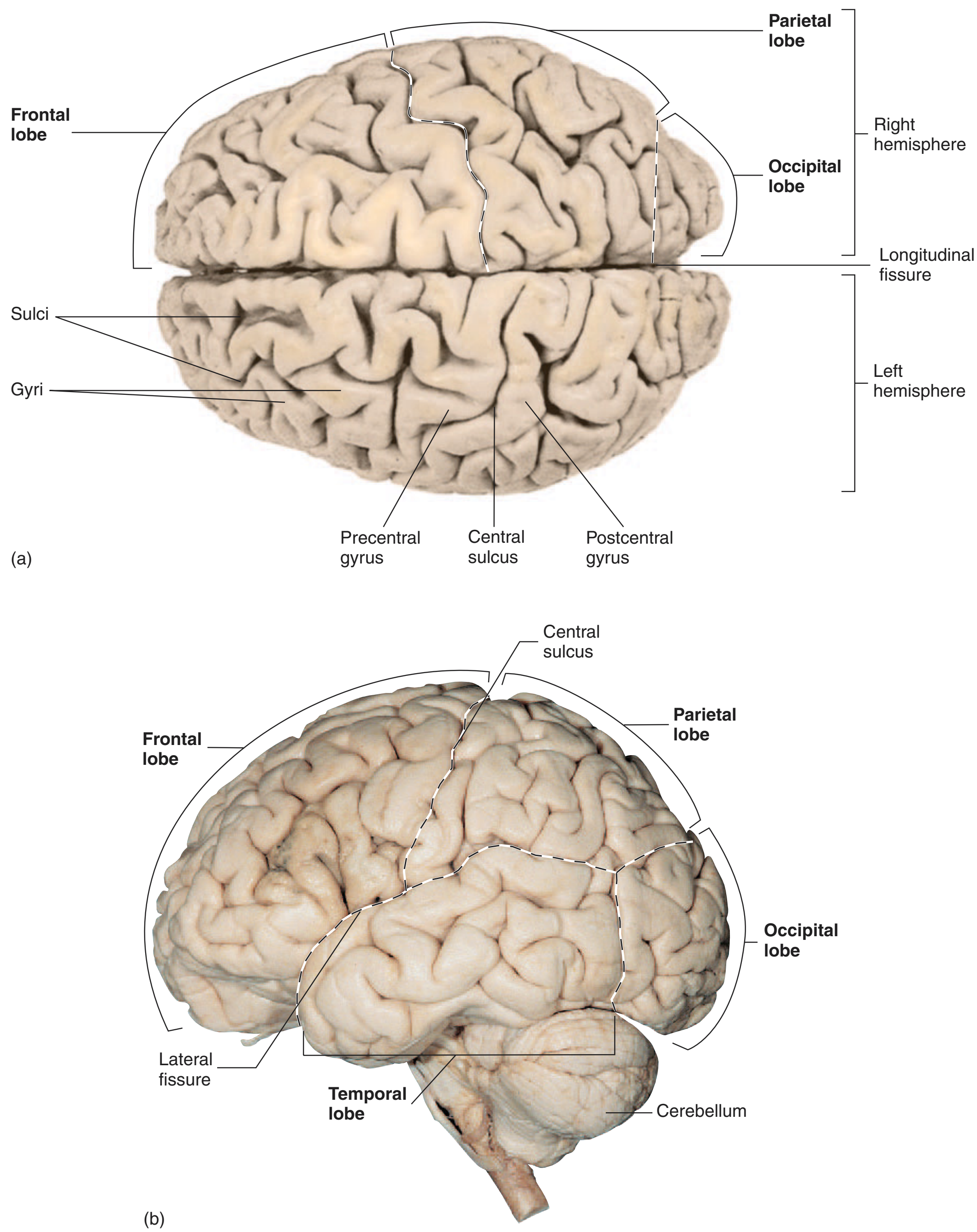
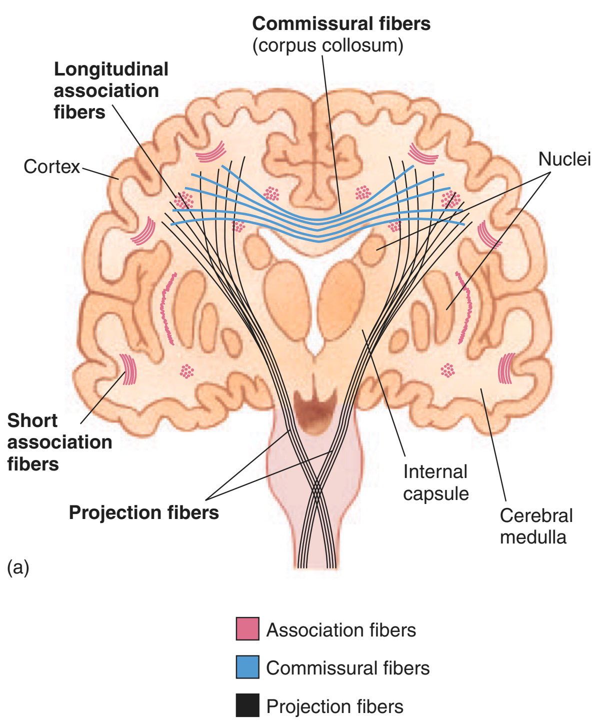


Figure 13.6 The Brain
(*a*) Superior view. (*b*) Lateral view of the left cerebral hemisphere.

The cerebrum is divided into left and right hemispheres by a **longitudinal fissure** (figure 13.6*a*). The most conspicuous features on the surface of each hemisphere are numerous folds called **gyri** (jī′rī; sing., gyrus), which greatly increase the surface area of the cortex. The intervening grooves between the gyri are called **sulci** (sŭl′sī; sing., sulcus). A **central sulcus,** which extends across the lateral surface of the cerebrum from superior to inferior, is located about midway along the length of the brain. The central sulcus is located between the **precentral gyrus** anteriorly, which is the **primary motor cortex,** and a **postcentral gyrus** posteriorly, which is the **primary somatic sensory cortex** (see chapter 14). The general pattern of the gyri is similar in all normal human brains, but some variation exists between individuals and even between the two hemispheres of the same cerebrum.

Each cerebral hemisphere is divided into lobes, which are named for the skull bones overlying each one (figure 13.6*b*). The **frontal lobe** is important in voluntary motor function, motivation, aggression, the sense of smell, and mood. The **parietal lobe** is the major center for the reception and evaluation of sensory information, except for smell, hearing, and vision. The frontal and parietal lobes are separated by the central sulcus. The **occipital lobe** functions in the reception and integration of visual input and is not distinctly separate from the other lobes. The **temporal lobe** receives and evaluates input for smell and hearing and plays an important role in memory. Its anterior and inferior portions are referred to as the "psychic cortex," and they are associated with such brain functions as abstract thought and judgment. The temporal lobe is separated from the rest of the cerebrum by a **lateral fissure,** and deep within the fissure is the **insula** (in′soo-lă; island), often referred to as a fifth lobe.

The gray matter on the outer surface of the cerebrum is the **cortex,** and clusters of gray matter deep inside the brain are nuclei. The white matter of the brain between the cortex and nuclei is the **cerebral medulla.** This term should not be confused with the medulla oblongata; medulla is a general term meaning the center of a structure, or marrow. The cerebral medulla consists of nerve tracts that connect the cerebral cortex to other areas of cortex or other parts of the CNS. These tracts fall into three main categories: (1) **association fibers,** which connect areas of the cerebral cortex within the same hemisphere; (2) **commissural fibers,** which connect one cerebral hemisphere to the other; and (3) **projection fibers,** which are between the cerebrum and other parts of the brain and spinal cord (figure 13.7).



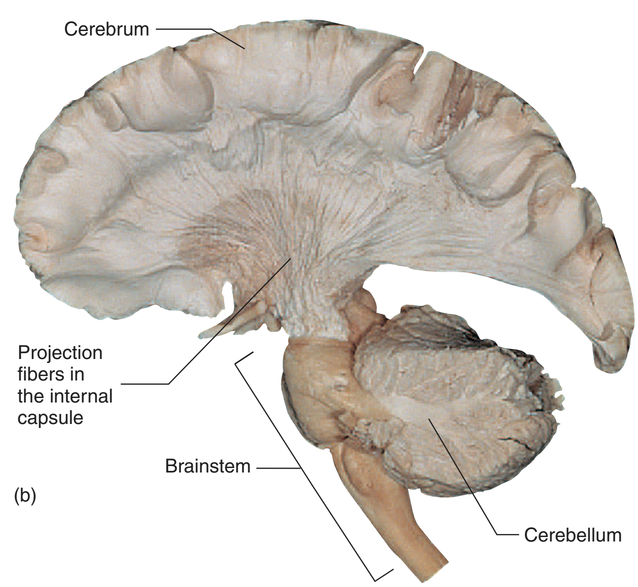


Figure 13.7 Cerebral Medullary Tracts

(*a*) Coronal section of the brain showing commissural, association, and projection fibers. (*b*) Photograph of the left cerebral hemisphere from a lateral view with the cortex and association fibers removed to reveal the projection fibers of the internal capsule deep within the brain.

6. ***Define the terms gyri and sulci. What structures do the longitudinal fissure, central sulcus, and lateral fissure separate?***
7. ***Define the terms cerebral cortex and cerebral medulla.***
8. ***Name the five lobes of the cerebrum, and describe their locations and functions.***
9. ***List three categories of nerve tracts in the cerebral medulla.***

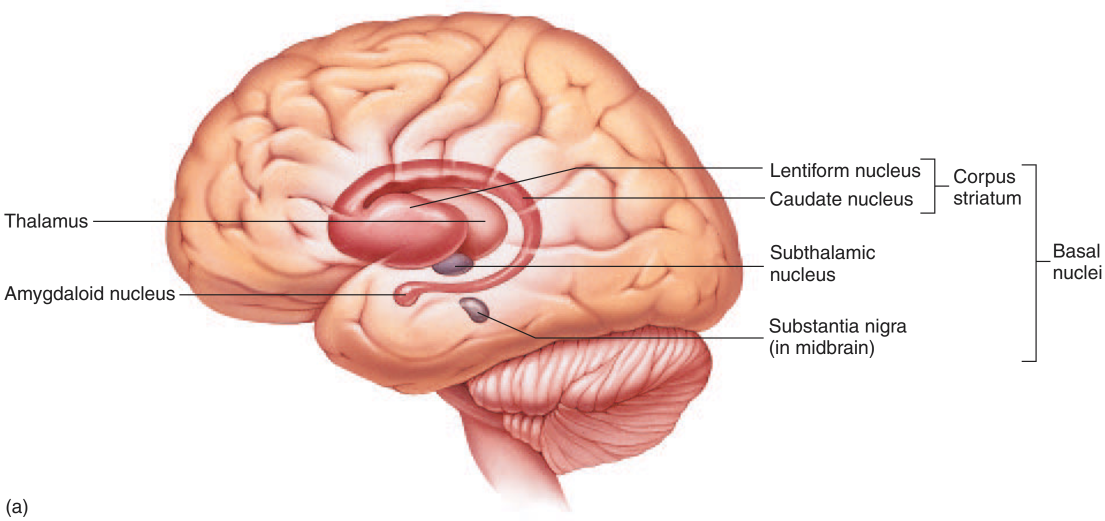
Basal Nuclei

The **basal nuclei,** or basal ganglia, are a group of functionally related nuclei located bilaterally in the inferior cerebrum, diencephalon, and midbrain (figure 13.8). These nuclei are involved in the control of motor functions (see chapter 14). The nuclei in the cerebrum are collectively called the **corpus striatum** (kōr′pŭs strī-ā′tŭm; striped body) and include the **caudate** (kaw′dāt; having a tail) **nucleus** and **lentiform** (len′ti-fōrm; lens-shaped) **nucleus.** They are the largest nuclei of the brain and occupy a large part of the cerebrum. The subthalamic nucleus is located in the diencephalon, and the substantia nigra is located in the midbrain.

10. ***List the basal nuclei and state their general function.***

Limbic System

Parts of the cerebrum and diencephalon are grouped together under the title **limbic** (lim′bik) **system** (figure 13.9). The limbic system plays a central role in basic survival functions such as memory, reproduction, and nutrition. It is also involved in emotions and memory. *Limbus* means border, and the term *limbic* refers to deep



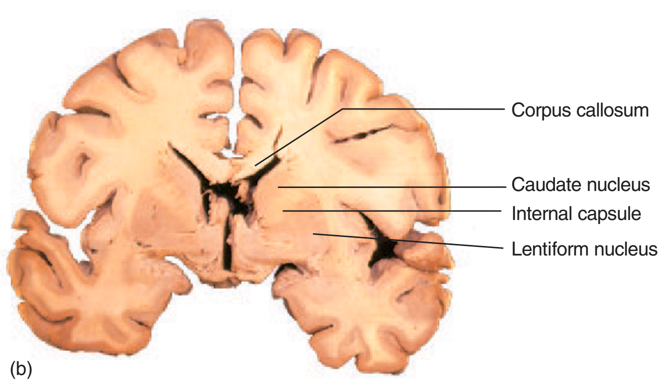


Figure 13.8 Basal Nuclei (Ganglia) of the Left Hemisphere

(*a*) A "transparent 3-D" drawing of the basal nuclei inside the left hemisphere. (*b*) Photograph of a frontal section of the brain showing the basal nuclei and other structures.

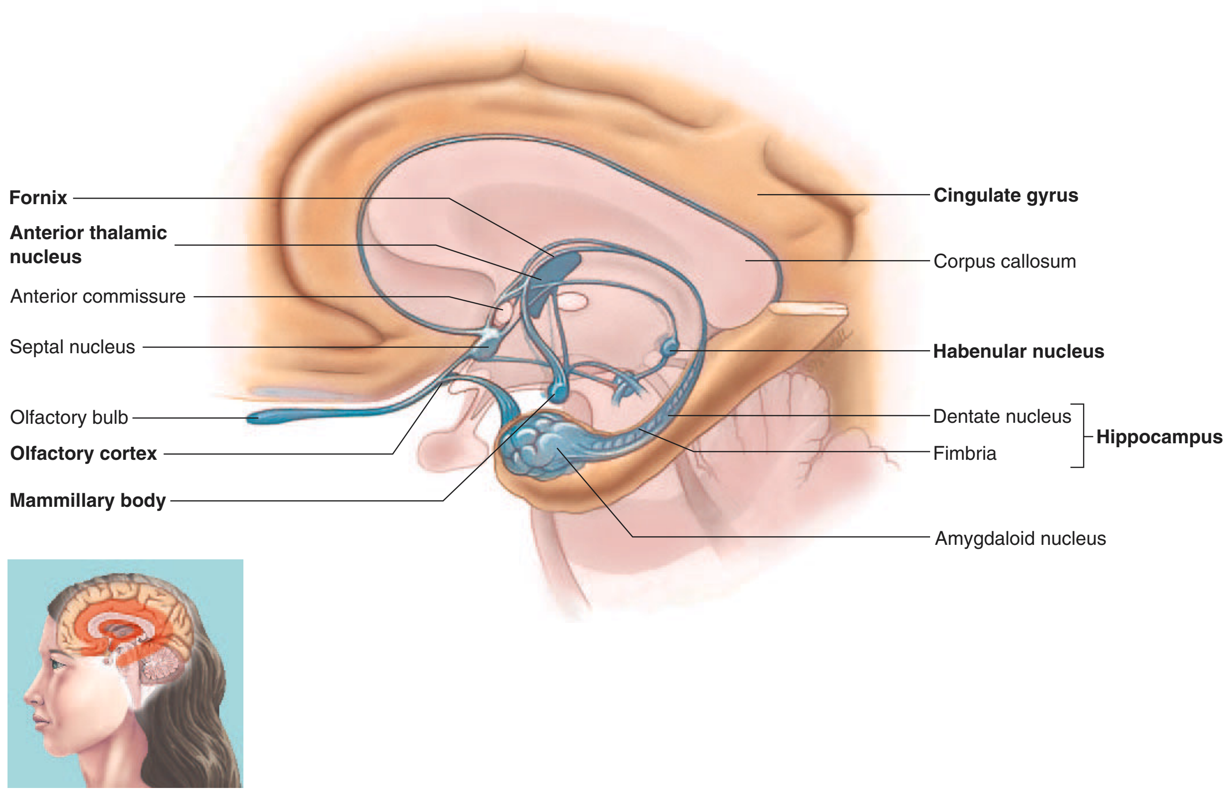


Figure 13.9 Limbic System and Associated Structures of the Right Hemisphere as Seen in a Midsagittal Section

portions of the cerebrum that form a ring around the diencephalon. Structurally the limbic system consists of (1) certain cerebral cortical areas, including the **cingulate** (sin′gū-lāt; to surround) **gyrus,** located along the inner surface of the longitudinal fissure just above the corpus callosum, and the **hippocampus;** (2) various nuclei, such as anterior nuclei of the thalamus and the habenular nuclei in the epithalamus; (3) parts of the basal nuclei; (4) the hypothalamus, especially the mamillary bodies; (5) the **olfactory cortex;** and (6) tracts connecting the various cortical areas and nuclei, such as the **fornix,** which connects the hippocampus to the thalamus and mammillary bodies. The hippocampus is also connected to the **amygdaloid nucleus.**

11. List the parts of the limbic system.

Meninges and Cerebrospinal Fluid

Objectives

- *Describe the membranes and spaces surrounding the central nervous system.*
- *Describe the production and circulation of cerebrospinal fluid.*

Meninges

Three connective tissue membranes, the **meninges** (mĕ-nin′jēz), surround and protect the brain and spinal cord (figure 13.10). The most superficial and thickest membrane is the **dura mater** (doo′ră mā′ter; tough mother). Three dural folds, the falx cerebri, the tentorium cerebelli, and the falx cerebelli, extend into the major brain fissures. The **falx cerebri** (falks se-rē′brī; sĭckle-shaped) is located between the two cerebral hemispheres in the longitudinal fissure, the **tentorium cerebelli** (ten-tō′rē-ŭm ser′ĕ-bel′ī; tent) is between the cerebrum and cerebellum, and the **falx cerebelli** lies between the two cerebellar hemispheres.

The dura mater surrounding the brain is tightly attached to and continuous with the periosteum of the cranial cavity, forming a single functional layer. The dura mater and dural folds help hold the brain in place within the skull and keep it from moving around too freely. The dura mater around the brain separates in several places, primarily at the bases of the three dural folds, to form **dural venous sinuses.** The dural venous sinuses collect most of the blood that returns from the brain, as well as cerebrospinal fluid (CSF) from around the brain (see Cerebrospinal Fluid, p. 446). The sinuses then empty into the veins that exit the skull (see chapter 21).

The next meningeal membrane is a very thin, wispy **arachnoid** (ă-rak′noyd; spiderlike; i.e., cobwebs) **mater.** The space between this membrane and the dura mater is the **subdural space** and contains only a very small amount of serous fluid. The third meningeal layer, the **pia** (pī′ă, pē′ă; affectionate) **mater** is bound very tightly to the surface of the brain. Between the arachnoid mater and the pia mater is the **subarachnoid space,** which contains weblike strands of the arachnoid mater and blood vessels and is filled with CSF.

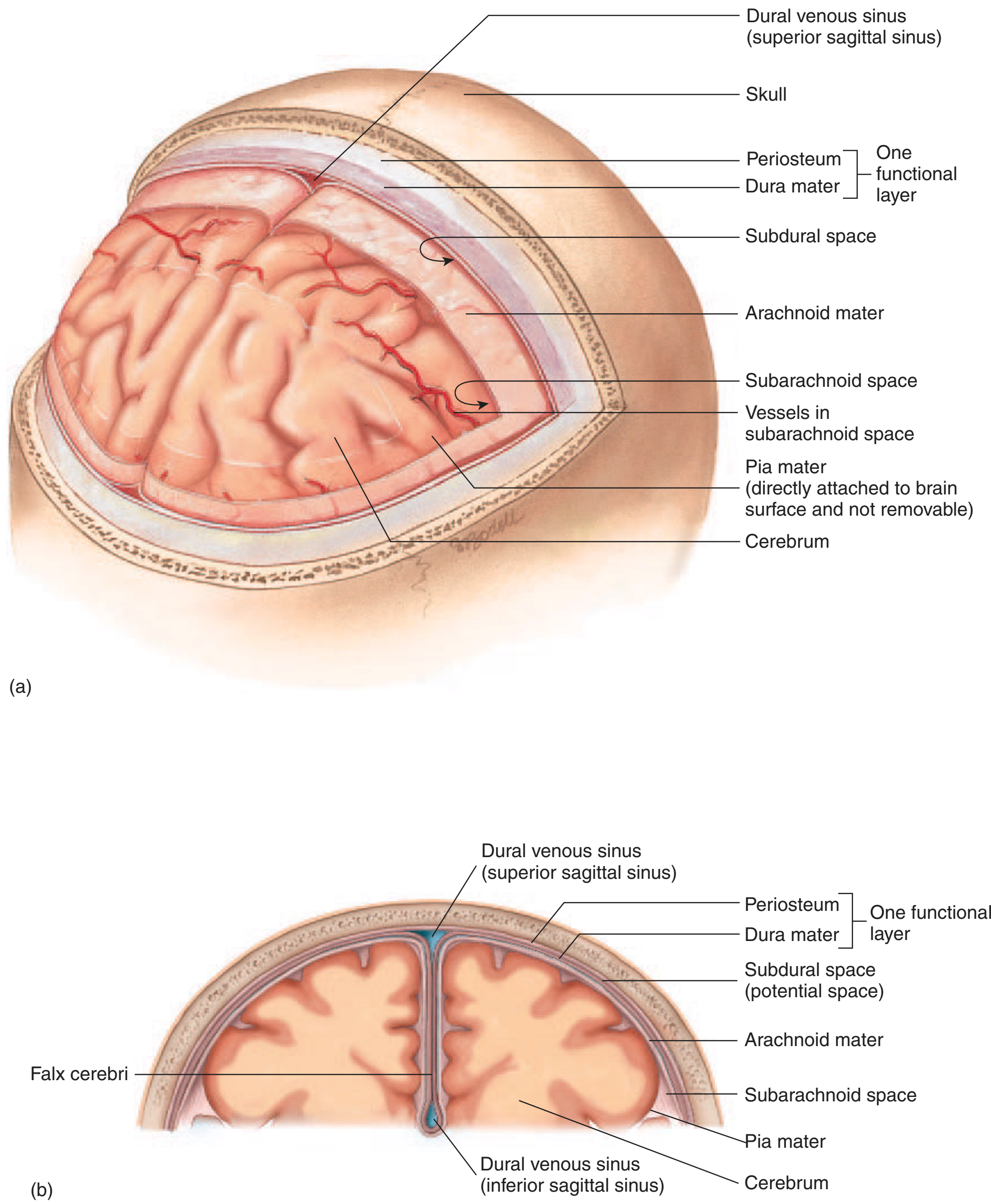


Figure 13.10 **Meninges**

(*a*) Meningeal membranes surrounding the brain. (*b*) Frontal section of head to show the meninges.

Subdural Hematoma

Damage to the venous dural sinuses can cause bleeding into the subdural space, resulting in a **subdural hematoma,** which can cause pressure on the brain.

Ventricles

The CNS is formed as a hollow tube that may be quite reduced in some areas of the adult CNS and expanded in other areas (see discussion of develoment, p. 449). The interior of the tube is lined with a single layer of epithelial cells called **ependymal** (ep-en′di-măl; see chapter 11) **cells**. Each cerebral hemisphere contains a relatively large cavity, the **lateral ventricle** (figure 13.11). The lateral ventricles are separated from each other by thin **septa pellucida** (sep′tă pe-loo′sid-ă,; sing., septum pellucidum; translucent walls), which lie in the midline just inferior to the corpus callosum and usually are fused with each other. A smaller midline cavity, the **third ventricle,** is located in the center of the diencephalon between the two halves of the thalamus. The two lateral ventricles communicate with the third ventricle through two **interventricular foramina** (foramina of Monro). The lateral ventricles can be thought of as the first and

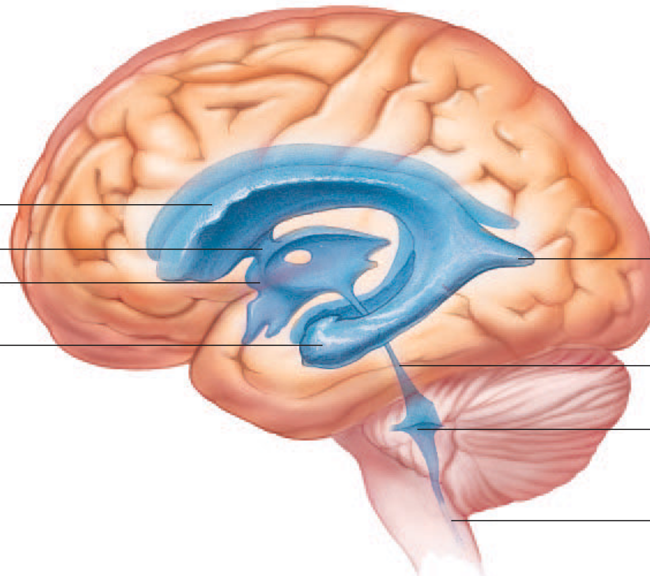


Figure 13.11 Ventricles of the Brain Viewed from the Left

second ventricles in the numbering scheme, but they are not designated as such. The **fourth ventricle** is in the inferior part of the pontine region and the superior region of the medulla oblongata at the base of the cerebellum. The third ventricle communicates with the fourth ventricle through a narrow canal, the **cerebral aqueduct** (aqueduct of Sylvius), which passes through the midbrain. The fourth ventricle is continuous with the central canal of the spinal cord, which extends nearly the full length of the cord. The fourth ventricle is also continuous with the subarachnoid space through two apertures in its walls and one in the roof.

Cerebrospinal Fluid

Cerebrospinal (ser′ĕ-brō-spī-năl; sĕ-rē′brō-spī-năl) **fluid (CSF)** is a fluid similar to serum with most of the proteins removed. It bathes the brain and the spinal cord and provides a protective cushion around the CNS. It also provides some nutrients to CNS tissues. About 80%–90% of the CSF is produced by specialized ependymal cells within the lateral ventricles, with the remainder produced by similar cells in the third and fourth ventricles. These specialized ependymal cells, their support tissue, and the associated blood vessels together are called **choroid** (kō′royd; lacy) **plexuses** (plek′sŭs-ez; figure 13.12). The choroid plexuses are formed by invaginations of the vascular pia mater into the ventricles, thus producing a vascular connective tissue core covered by ependymal cells.

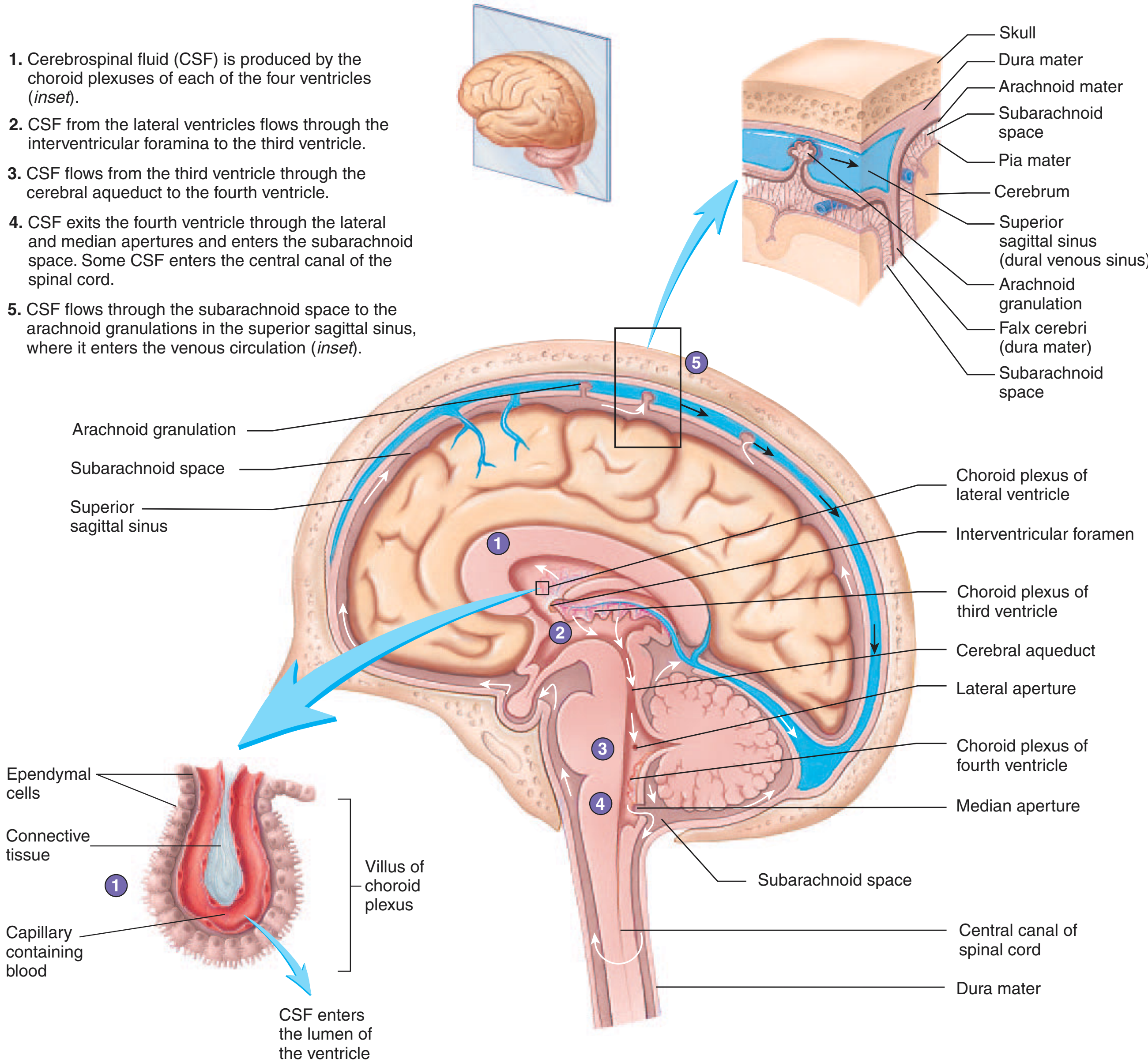
CSF and Skull Fractures

In skull fractures in which the meninges are torn, CSF may leak from the nose if the fracture is in the frontal area or from the ear if the fracture is in the temporal area. Leakage of CSF indicates serious mechanical damage to the head and presents a risk of meningitis, because bacteria may pass from the nose or ear through the tear and into the meninges.

How the choroid plexuses produce CSF is not fully understood. Some portions of the blood plasma simply diffuse across the plexus membranes, whereas other portions require facilitated diffusion or active transport.

Endothelial cells of the blood vessels in the choroid plexuses, which are joined by tight junctions (see chapter 4), form the so-called **blood–brain barrier,** or, more correctly, the **blood–cerebrospinal fluid barrier.** Consequently, substances do not pass between the cells but must pass through the cells.

CSF fills the ventricles, the subarachnoid space of the brain and spinal cord, and the central canal of the spinal cord. Approximately 23 mL of fluid fills the ventricles, and 117 mL fills the subarachnoid space. The route taken by the CSF from its origin in the choroid plexuses to its return to the circulation is depicted in figure 13.12. The flow rate of CSF from its origin to the point at which it enters the bloodstream is about 0.4 mL/min. CSF passes from the lateral ventricles through the interventricular foramina into the third ventricle and then through the cerebral aqueduct into the fourth ventricle. It can exit the interior of the brain only from the fourth ventricle. One **median aperture** (foramen of Magendie), which opens through the roof of the fourth ventricle, and two **lateral apertures** (foramina of Luschka), which open through the walls, allow the CSF to pass from the fourth ventricle to the subarachnoid space. Masses of arachnoid tissue, **arachnoid granulations,** penetrate into the dural venous sinus along the superior edge of the falx cerebri called the superior sagittal sinus. CSF passes into the blood of the dural venous sinuses through these granulations. The sinuses are blood-filled; thus it is within these dural sinuses that the CSF reenters the bloodstream. From the dural venous sinuses, the blood flows through the internal jugular veins to veins of the general circulation.



Process Figure 13.12 Flow of CSF

CSF flow through the ventricles and subarachnoid space is shown by *white arrows*. Those going through the foramina in the wall and roof of the fourth ventricle depict the CSF entering the subarachnoid space. CSF passes back into the blood through the arachnoid granulations (*white and black arrow*), which penetrate the dural sinus. The *black arrows* show the direction of blood flow in the sinuses.

Hydrocephalus

If the foramina of the fourth ventricle or the cerebral aqueduct are blocked, CSF can accumulate within the ventricles. This condition is called **internal hydrocephalus** and it results in increased CSF pressure. The production of CSF continues, even when the passages that normally allow it to exit the brain are blocked. Consequently, fluid builds inside the brain, causing pressure that compresses the nervous tissue and dilates the ventricles. Compression of the nervous tissue usually results in irreversible brain damage. If the skull bones are not completely ossified when the hydrocephalus occurs, the pressure may also severely enlarge the head. The cerebral aqueduct may be blocked at the time of birth or may become blocked later in life because of a tumor growing in the brainstem.

Internal hydrocephalus can be successfully treated by placing a drainage tube (shunt) between the brain ventricles and abdominal cavity to eliminate the high internal pressures. There is some risk of infection being introduced into the brain through these shunts, however, and the shunts must be replaced as the person grows. A subarachnoid hemorrhage may block the return of CSF to the circulation. If CSF accumulates in the subarachnoid space, the condition is called **external hydrocephalus.** In this condition, pressure is applied to the brain externally, compressing neural tissues and causing brain damage.

12. ***Describe the three meninges that surround the CNS. What are the falx cerebri, tentorium cerebelli, and falx cerebelli?***
13. ***Describe and list the contents of the dural sinuses subdural space, and subarachnoid space.***
14. ***Name the four ventricles of the brain, and describe their locations and the connections between them. What are the septa pellucida?***
15. ***Describe the production and circulation of CSF. Where does the CSF return to the blood?***

Blood Supply to the Brain

Objectives

- ***Describe the blood supply to the brain.***
- ***Describe the blood–brain barrier.***

The brain requires a tremendous amount of blood to maintain its normal functions. Even though the brain accounts for only about 2% of the total weight of the body, it receives approximately 15%–20% of blood pumped by the heart. Interruption of the brain's blood supply for only seconds can cause unconsciousness, and interruption of the blood supply for minutes can cause irreversible brain damage. This extreme dependence on blood supply results from the brain's very high metabolic rate and, as a result, its extreme dependence on a constant supply of oxygen and glucose. Brain cells are not capable of storing high-energy molecules for any length of time and depend almost exclusively on glucose as their energy source (see chapter 25).

The brain's blood supply is illustrated in chapter 21 (see figures 21.8 and 21.9). Blood reaches the brain through the **internal carotid arteries,** which ascend to the head along the anterolateral part of the neck, and the **vertebral arteries,** which ascend along the posterior part of the neck, through the transverse foramina of the cervical vertebrae. The internal carotid arteries enter the cranial cavity through the carotid canals, and the vertebral arteries enter by the foramen magnum. The vertebral arteries join together to form the **basilar artery,** which lies on the ventral surface of the brainstem. The basilar artery and internal carotid arteries contribute to the **cerebral arterial circle** (circle of Willis). Branches from this circle and from the basilar artery supply blood to the brain.

The cerebral cortex on each side of the brain is supplied by three branches from the cerebral arterial circle: the **anterior, middle,** and **posterior cerebral arteries.** The middle cerebral artery supplies most of the lateral surface of each cerebral hemisphere. The anterior cerebral artery supplies the medial portion of the parietal and frontal lobes. The posterior cerebral artery supplies the occipital lobe and the medial surface of the temporal lobe.

The arteries to the brain and their larger branches are located in the subarachnoid space. Small cortical arterial branches leave the subarachnoid space and enter the pia mater, where they branch extensively. Precapillary branches leave the pia mater and enter the substance of the brain. Most of these branches are short and remain in the cortex. Fewer, longer branches extend into the medulla.

The arteries within the substance of the brain quickly divide into capillaries. The endothelial cells of these capillaries are completely surrounded by tight junctions, which prevent movement of most substances between epithelial cells. Movement of materials through epithelial cells is regulated by those cells. The capillary endothelial cells, under the influence of the foot processes of astrocytes within the brain tissue and the basement membrane in between, constitute the **blood–brain barrier.** Lipid-soluble substances, such as nicotine, ethanol, and heroin, can diffuse through the blood–brain barrier and enter the brain. Water-soluble molecules such as amino acids and glucose move across the blood–brain barrier by mediated transport (see chapter 3).

Drugs and the Blood–Brain Barrier

The permeability characteristics of the blood–brain barrier must be considered when developing drugs designed to affect the CNS. For example, Parkinson's disease is caused by a lack of the neurotransmitter dopamine, which normally is produced by certain neurons of the brain. This lack results in decreased muscle control and shaking movements. Administering dopamine is not helpful because dopamine cannot cross the blood–brain barrier. Levodopa (L-dopa), a precursor to dopamine, is administered instead because it can cross the blood–brain barrier. CNS neurons then convert levodopa to dopamine, which helps reduce the symptoms of Parkinson's disease.

16. ***Describe the blood supply to the brain. List the arteries supplying each part of the cerebral cortex.***
17. ***Describe the blood–brain barrier.***

Development of the CNS

Objective

■ *Describe the formation of the neural tube, and list the structures that develop from its various parts.*

The CNS develops from a flat plate of tissue, the **neural plate,** on the upper surface of the embryo, as a result of the influence of the underlying rod-shaped **notochord** (figure 13.13*a*). The lateral sides of the neural plate become elevated as waves, called **neural folds.** The crest of each fold is called a **neural crest,** and the center of the neural plate becomes the **neural groove.** The neural folds move toward each other in the midline, and the crests fuse to create a **neural tube** (figure 13.13*b*). The cephalic portion of the neural tube becomes the brain, and the caudal portion becomes the spinal cord. **Neural crest cells** separate from the neural crests and give rise to sensory and autonomic neurons of the peripheral nervous system. They also give rise to all pigment cells of the body, as well as facial bones and dentin of the teeth.

A series of pouches develops in the anterior part of the neural tube (figure 13.14). The pouch walls become the various portions of the adult brain (table 13.3), and the pouch cavities become fluid-filled **ventricles** (ven′tri-klz). The ventricles are continuous with each other and with the **central canal** of the spinal cord. The neural tube develops flexures that cause the brain to be oriented almost 90 degrees to the spinal cord.

Three brain regions can be identified in the early embryo (see table 13.3 and figure 13.14*a*): a forebrain, or **prosencephalon** (pros-en-sef′ă-lon); a midbrain, or **mesencephalon** (mez-en-sef′ă-lon); and a hindbrain, or **rhombencephalon** (rom-ben-sef′ă-lon). During development, the forebrain divides into the **telencephalon** (tel-en-sef′ă-lon), which becomes the cerebrum, and the **diencephalon** (dī-en-sef′ă-lon). The midbrain remains as a single structure, but the hindbrain divides into the **metencephalon** (met′en-sef′ă-lon), which becomes the pons and cerebellum, and the **myelencephalon** (mī′el-en-sef′ă-lon), which becomes the medulla oblongata (figure 13.14*b* and *c*).

18. Explain how the neural tube forms. Name the five divisions of the neural tube and the parts of the brain that each division becomes.

19. What do the cavities of the neural tube become in the adult brain?

Cranial Nerves

Objective

■ *Describe the distribution and functions of the cranial nerves.*

The 12 cranial nerves by convention are indicated by Roman numerals (I–XII) from anterior to posterior (figure 13.15). A given cranial nerve may have one or more of three functions: (1) sensory, (2) somatic motor, and (3) parasympathetic (table 13.4). **Sensory** functions include the special senses like vision and the more general senses like touch and pain. **Somatic** (sō-mat′ik) **motor** functions refer to the control of skeletal muscles through motor neurons. **Proprioception** (prō-prē-ō-sep′shun) informs the brain about the

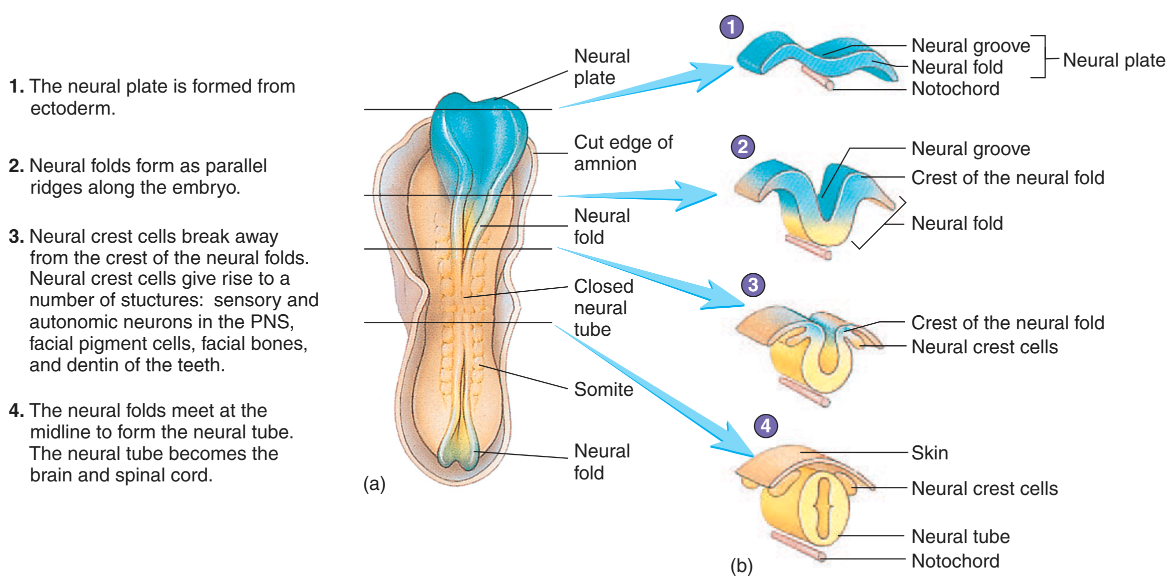
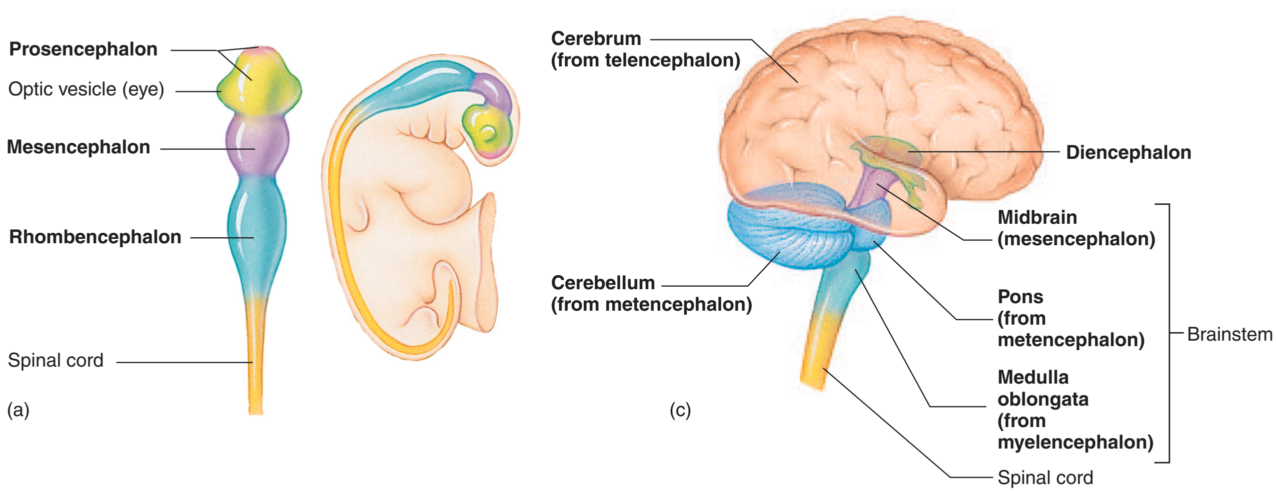


Figure 13.13 Formation of the Neural Tube

(*a*) A 21-day-old human embryo. (*b*) Cross sections through the embryo. The level of each section is indicated by a line in part (*a*).

Table 13.3 Development of the Central Nervous System (see figure 13.14)

Early Embryo	Late Embryo	Adult	Cavity	Function
Prosencephalon (forebrain)	**Telencephalon**	**Cerebrum**	Lateral ventricles	Higher brain functions
	Diencephalon	**Diencephalon** (thalamus, subthalamus, epithalamus, hypothalamus)	Third ventricle	Relay center, autonomic nerve control, endocrine control
Mesencephalon (midbrain)	**Mesencephalon**	**Mesencephalon** (midbrain)	Cerebral aqueduct	Nerve pathways, reflex centers
Rhombencephalon (hindbrain)	**Metencephalon**	**Pons** and **cerebellum**	Fourth ventricle	Nerve pathways, reflex centers, muscle coordination, balance
	Myelencephalon	**Medulla oblongata**	Central canal	Nerve pathways, reflex centers



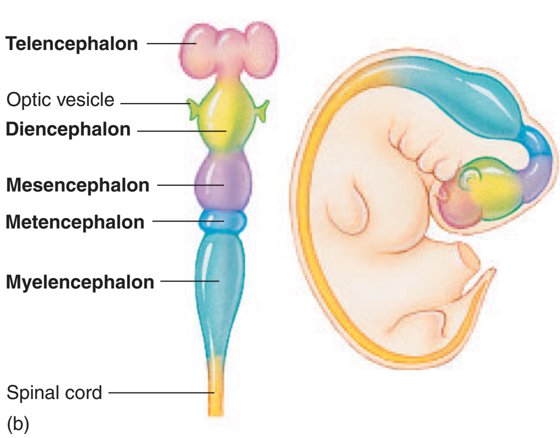


Figure 13.14 Development of the Brain Segments and Ventricles

(*a*) Young embryo. (*b*) Older embryo. (*c*) Adult.

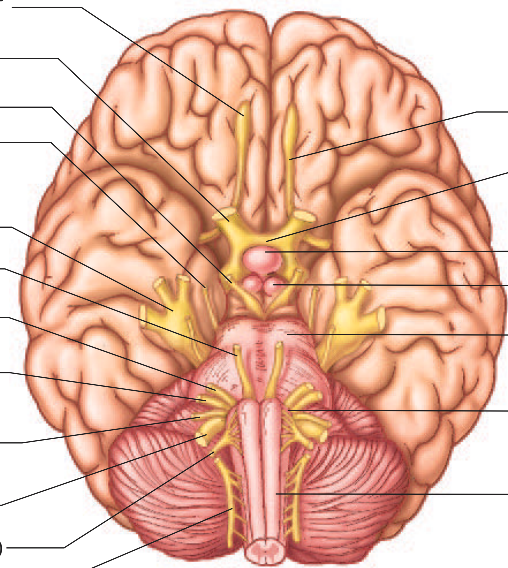


Figure 13.15 Inferior Surface of the Brain Showing the Origin of the Cranial Nerves

Table 13.4 Functional Organization of the Cranial Nerves

Nerve Function	Cranial Nerve	
Sensory	I	Olfactory
	II	Optic
	VIII	Vestibulocochlear
Somatic motor	IV	Trochlear
	VI	Abducens
	XI	Accessory
	XII	Hypoglossal
Somatic motor and sensory	V	Trigeminal
Somatic motor and parasympathetic	III	Oculomotor
Somatic motor, sensory, and parasympathetic	VII	Facial
	IX	Glossopharyngeal
	X	Vagus

position of various body parts, including joints and muscles. The cranial nerves innervating skeletal muscles also contain proprioceptive sensory fibers, which convey action potentials to the CNS from those muscles. Because proprioception is the only sensory function of several otherwise somatic motor cranial nerves, however, that function is usually ignored, and the nerves are designated by convention as motor only. **Parasympathetic** function involves the regulation of glands, smooth muscles, and cardiac muscle. These functions are part of the autonomic nervous system and are discussed in chapter 16. Several of the cranial nerves have associated ganglia, and these ganglia are of two types: parasympathetic and sensory. Table 13.5 lists specific information about each cranial nerve.

The **olfactory (I)** and **optic (II) nerves** are exclusively sensory and are involved in the special senses of smell and vision, respectively. These nerves are discussed in chapter 15.

The **oculomotor nerve (III)** innervates four of the six muscles that move the eyeball and the levator palpebrae superioris muscle, which raises the superior eyelid. In addition, parasympathetic nerve fibers in the oculomotor nerve innervate smooth muscles in the eye and regulate the size of the pupil and the shape of the lens of the eye.

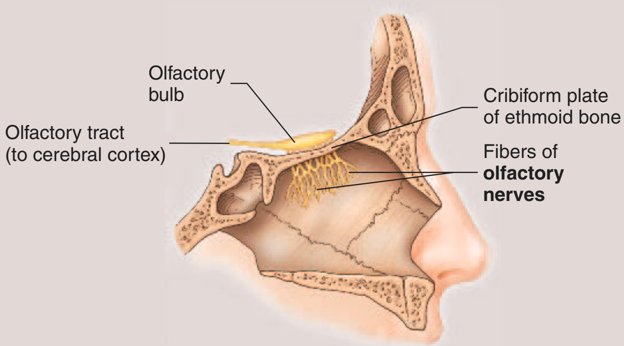
The **trochlear** (trōk′lē-ar) **nerve (IV)** is a somatic motor nerve that innervates one of the six eye muscles responsible for moving the eyeball.

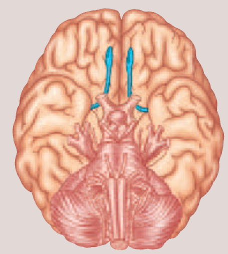
The **trigeminal** (trī-jem′i-năl) **nerve (V)** has somatic motor, proprioceptive, and cutaneous sensory functions. It supplies motor innervation to the muscles of mastication, one middle ear muscle, one palatine muscle, and two throat muscles. In addition to proprioception associated with its somatic motor functions, the trigeminal nerve also carries proprioception from the temporomandibular joint. Damage to the trigeminal nerve may impede chewing.

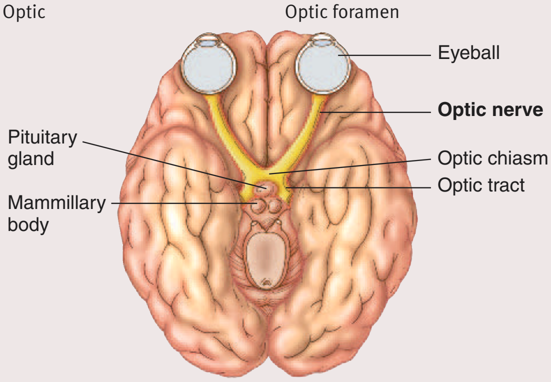
The trigeminal nerve has the greatest general sensory function of all the cranial nerves and is the only cranial nerve involved in **sensory cutaneous innervation.** All other cutaneous innervation comes from spinal nerves (see figure 12.15). Trigeminal means three twins, and the sensory distribution of the trigeminal nerve in the face is divided into three regions, each supplied by a branch of the nerve. The three branches—ophthalmic, maxillary, and mandibular—arise directly from the trigeminal ganglion, which serves the same function as the dorsal root ganglia of the spinal nerves. Only the mandibular branch has motor axons, which bypass the trigeminal ganglion, much like the ventral root of a spinal nerve bypasses a dorsal root ganglion.

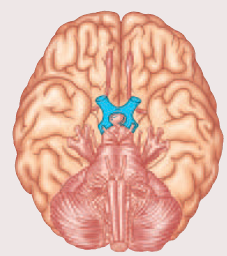
Table 13.5 Cranial Nerves and Their Functions

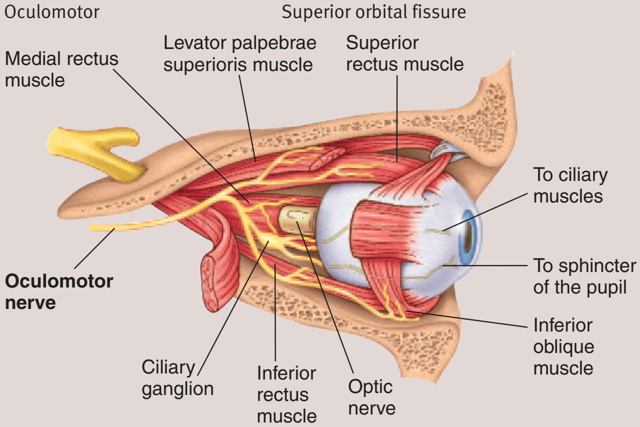
Cranial Nerve	Foramen or Fissure*	Function
I: Olfactory	Cribriform plate	Sensory Special sense of smell
II: Optic	Optic foramen	Sensory Special sense of vision
III: Oculomotor	Superior orbital fissure	Motor† and parasympathetic Motor to eye muscles (superior, medial, and inferior rectus; inferior oblique) and upper eyelid (levator palpebrae superioris) Proprioceptive from those muscles Parasympathetic to the sphincter of the pupil (causing constriction) and the ciliary muscle of the lens (causing accomodation)

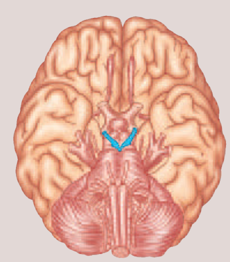












*Route of entry or exit from the skull.

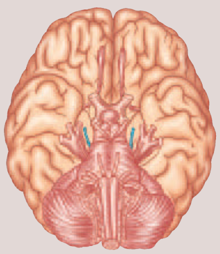
†Proprioception is a sensory function, not a motor function; however, motor nerves to muscles also contain some proprioceptive afferent fibers from those muscles. Because proprioception is the only sensory information carried by some cranial nerves, these nerves still are considered "motor."

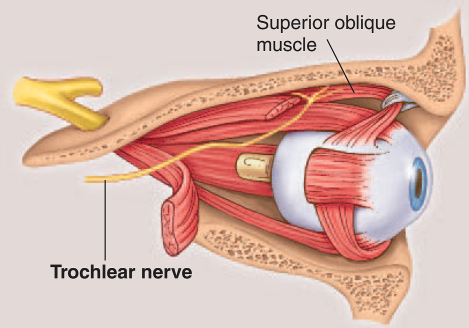
continued

In addition to these cutaneous functions, the maxillary and mandibular branches are important in dentistry. The maxillary nerve supplies sensory innervation to the maxillary teeth, palate, and gingiva (jin′jī-vă; gum). The mandibular branch supplies sensory innervation to the mandibular teeth, tongue, and gingiva. The various nerves innervating the teeth are referred to as **alveolar** (al-vē′ō-lăr; refers to the sockets in which the teeth are located). The **superior alveolar nerves** to the maxillary teeth are derived from the maxillary branch of the trigeminal nerve, and the **inferior alveolar nerves** to the mandibular teeth are derived from the mandibular branch of the trigeminal nerve.

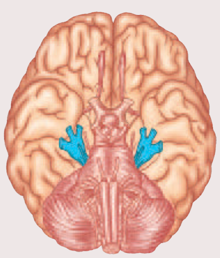
Table 13.5 *continued*

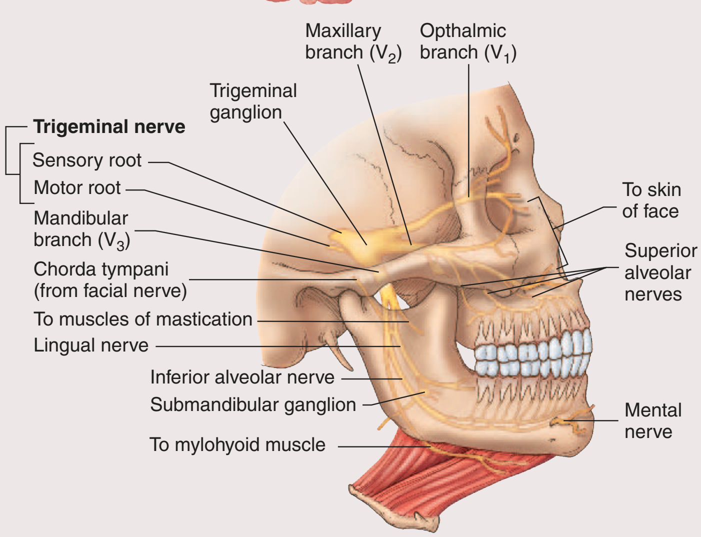
Cranial Nerve	Foramen or Fissure*	Function
IV: Trochlear	Superior orbital fissure	Motor† Motor to one eye muscle (superior oblique) Proprioceptive from that muscle





Cranial Nerve	Foramen or Fissure*	Function
V: Trigeminal The trigeminal nerve is divided into three branches: the ophthalmic (V_1), the maxillary (V_2), and the mandibular (V_3)		
Opththalmic branch (V_1)	Superior orbital fissure	Sensory Sensory from scalp, forehead, nose, upper eyelid, and cornea
Maxillary branch (V_2)	Foramen rotundum	Sensory Sensory from palate, upper jaw, upper teeth and gums, nasopharynx, nasal cavity, skin and mucous membrane of cheek, lower eyelid, and upper lip
Mandibular branch (V_3)	Foramen ovale	Sensory and motor† Sensory from lower jaw, lower teeth and gums, anterior two-thirds of tongue, mucous membrane of cheek, lower lip, skin of cheek and chin, auricle, and temporal region Motor to muscles of mastication (masseter, temporalis, medial and lateral pterygoids), soft palate (tensor veli palatini), throat (anterior belly of digastric, mylohyoid), and middle ear (tensor tympani) Proprioceptive from those muscles





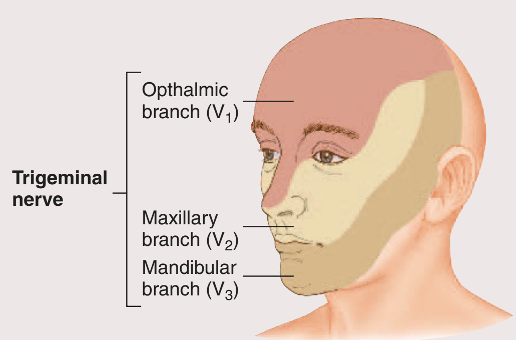


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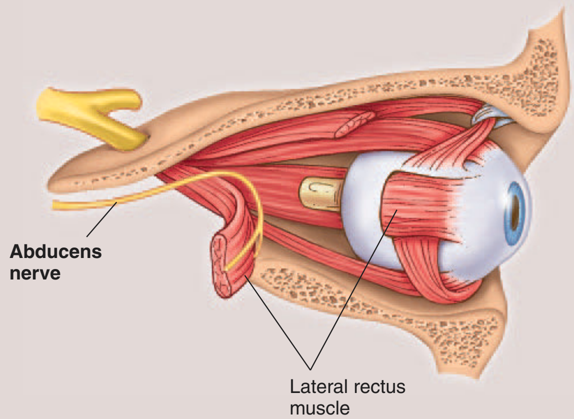
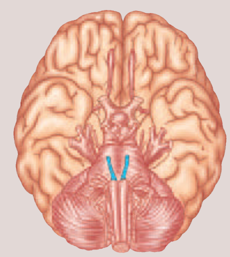
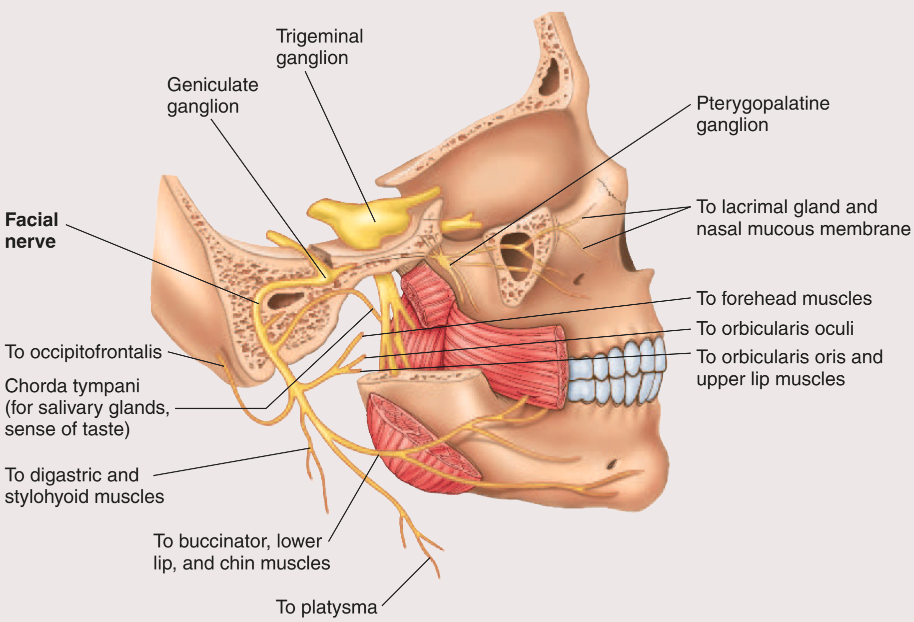
Table 13.5 *continued*

Cranial Nerve	Foramen or Fissure*	Function
VI: Abducens	Superior orbital fissure	Motor† Motor to one eye muscle (lateral rectus) Proprioceptive from that muscle





Cranial Nerve	Foramen or Fissure*	Function
VII: Facial	Internal auditory meatus Stylomastoid foramen	Sensory, motor,† and parasymathetic Sense of taste from anterior two-thirds of tongue, sensory from some of external ear and palate Motor to muscles of facial expression, throat (posterior belly of digastric, stylohyoid), and middle ear (stapedius) Proprioceptive from those muscles Parasympathetic to submandibular and sublingual salivary glands, lacrimal gland, and glands of the nasal cavity and palate



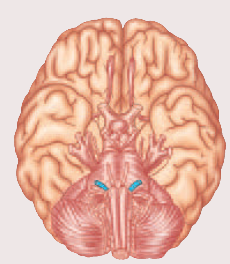


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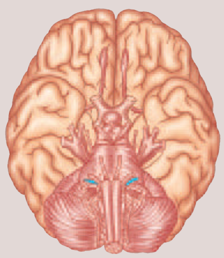
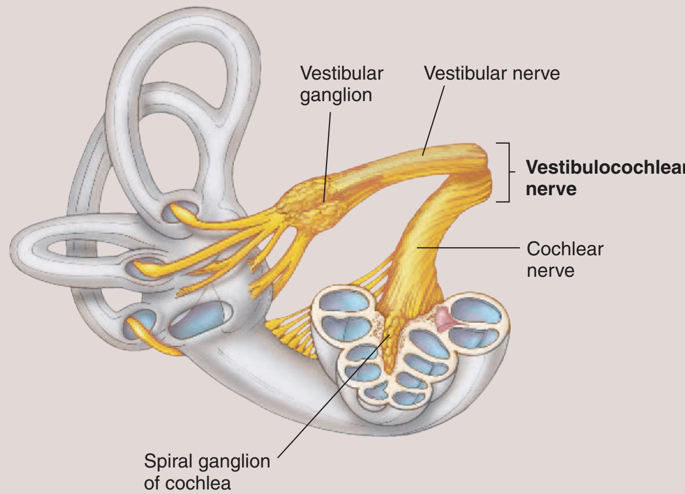
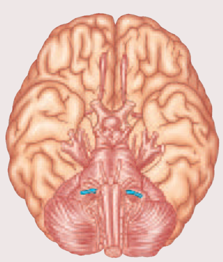
Table 13.5 *continued*

Cranial Nerve	Foramen or Fissure*	Function
VIII: Vestibulocochlear	Internal auditory meatus	Sensory Special senses of hearing and balance
IX: Glossopharyngeal	Jugular foramen	Sensory, motor,† and parasympathetic Sense of taste from posterior third of tongue, sensory from pharynx, palatine tonsils, posterior third of tongue, middle ear, carotid sinus and carotid body Motor to pharyngeal muscle (stylopharyngeus) Proprioceptive from that muscle Parasympathetic to parotid salivary gland and the glands of the posterior third of tongue







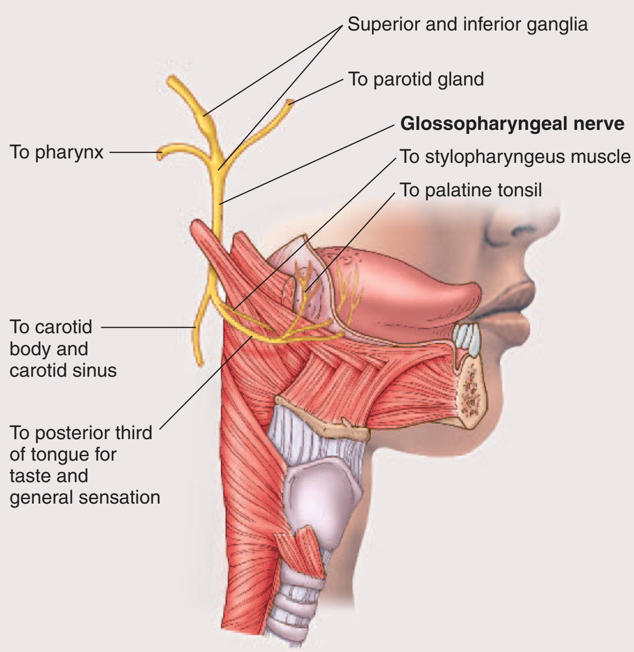


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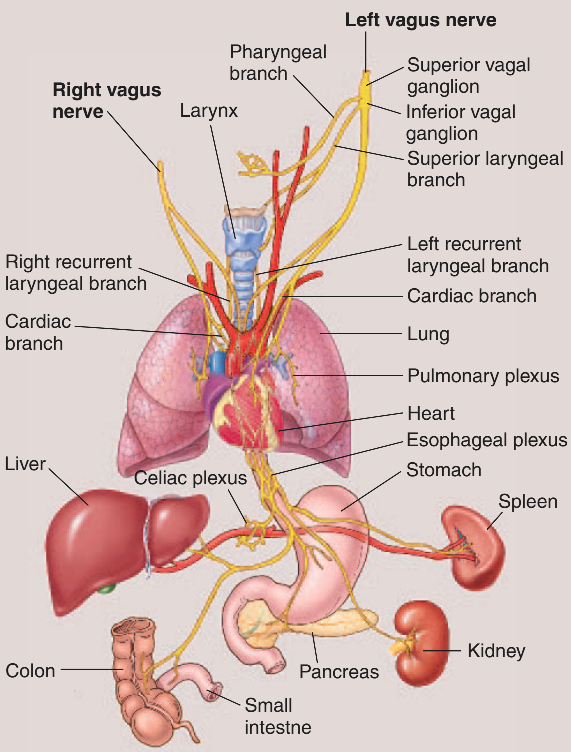
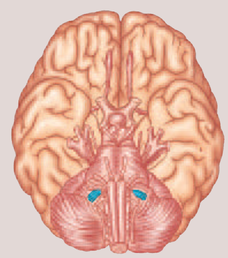
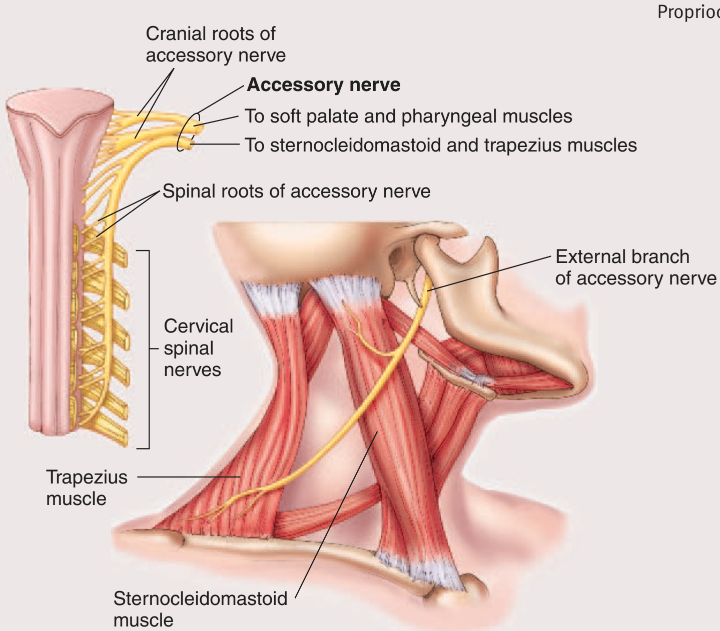
Table 13.5 *continued*

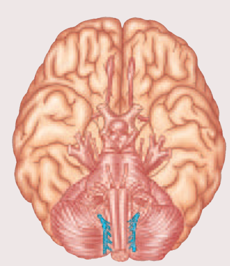
Cranial Nerve	Foramen or Fissure*	Function
X: Vagus	Jugular foramen	Sensory, motor,† and parasympathetic Sensory from inferior pharynx, larynx, thoracic and abdominal organs, sense of taste from posterior tongue Motor to soft palate, pharynx, intrinsic laryngeal muscles (voice production), and an extrinsic tongue muscle (palatoglossus) Proprioceptive from those muscles Parasympathetic to thoracic and abdominal viscera





Cranial Nerve	Foramen or Fissure*	Function
XI: Accessory	Foramen magnum Jugular foramen	Motor† Motor to soft palate, pharynx, sternocleidomastoid, and trapezius Proprioceptive from those muscles

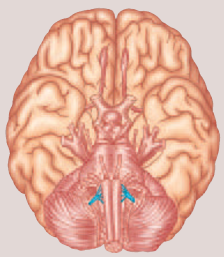


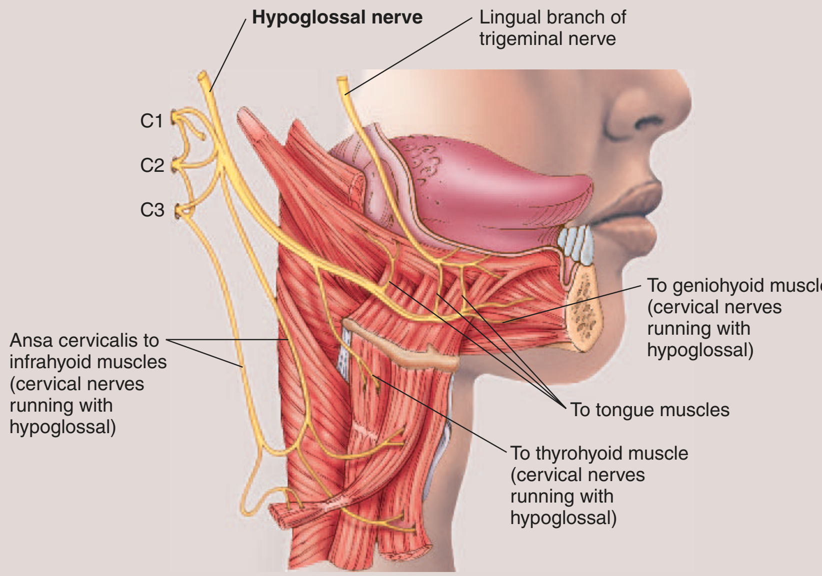


continued

Table 13.5 *continued*

Cranial Nerve	Foramen or Fissure*	Function
XII: Hypoglossal	Hypoglossal canal	Motor† Motor to intrinsic and extrinsic tongue muscles (styloglossus, hypoglossus, genioglossus) and throat muscles (thyrohyoid and geniohyoid) Proprioceptive from those muscles





Dental Anesthesia

Dentists inject anesthetic to block sensory transmission by the alveolar nerves. The superior alveolar nerves are not usually anesthetized directly because they are difficult to approach with a needle. For this reason, the maxillary teeth are usually anesthetized locally by inserting the needle beneath the oral mucosa surrounding the teeth. The inferior alveolar nerve probably is anesthetized more often than any other nerve in the body. To anesthetize this nerve, the dentist inserts the needle somewhat posterior to the patient's last molar.

Several nondental nerves are usually anesthetized during an inferior alveolar block. The mental nerve, which supplies cutaneous innervation to the anterior lip and chin, is a distal branch of the inferior alveolar nerve. When the inferior alveolar nerve is blocked, the mental nerve is blocked also, resulting in a numb lip and chin. Nerves lying near the point where the inferior alveolar nerve enters the mandible often are also anesthetized during inferior alveolar anesthesia. For example, the lingual nerve can be anesthetized to produce a numb tongue. The facial nerve lies some distance from the inferior alveolar nerve, but in rare cases anesthetic can diffuse far enough posteriorly to anesthetize that nerve. The result is a temporary facial palsy (paralysis or paresis), with the injected side of the face drooping because of flaccid muscles, which disappears when the anesthesia wears off. If the facial nerve is cut by an improperly inserted needle, permanent facial palsy may occur.

The **abducens** (ab-doo′senz) **nerve (VI),** like the trochlear nerve, is a somatic motor nerve that innervates one of the six eye muscles responsible for moving the eyeball.

PREDICT 1

A drooping upper eyelid on one side of the face is a sign of possible oculomotor nerve damage. Describe how this could possibly be evaluated by examining other oculomotor nerve functions. Describe the movements of the eye that would distinguish among oculomotor, trochlear, and abducens nerve damage.

The **facial nerve (VII)** is somatic motor, sensory, and parasympathetic. It controls all the muscles of facial expression, a small muscle in the middle ear, and two throat muscles. It is sensory for the sense of taste in the anterior two-thirds of the tongue (see chapter 15). The facial nerve supplies parasympathetic innervation to the submandibular and sublingual salivary glands and to the lacrimal glands.

The **vestibulocochlear** (ves-tib′ū-lō-kok′lē-ăr) **nerve (VIII),** like the olfactory and optic nerves, is exclusively sensory and transmits action potentials from the inner ear responsible for the special senses of hearing and balance (see chapter 15).

The **glossopharyngeal** (glos′ō-fă-rin′jē-ăl) **nerve (IX),** like the facial nerve, is somatic motor, sensory, and parasympathetic and has both sensory and parasympathetic ganglia. The glossopharyngeal nerve is somatic motor to one muscle of the pharynx and supplies parasympathetic innervation to the parotid salivary glands. The glossopharyngeal nerve is sensory for the sense of taste in the posterior third of the tongue. It also supplies tactile sensory innervation from the posterior tongue, middle ear, and pharynx and transmits sensory stimulation from receptors in the carotid arteries and the aortic arch, which monitor blood pressure and blood carbon dioxide, blood oxygen, and blood pH levels (see chapter 21).

The **vagus** (vā′gŭs) **nerve (X),** like the facial and glossopharyngeal nerves, is somatic motor, sensory, and parasympathetic and has both sensory and parasympathetic ganglia. Most muscles of the soft palate, pharynx, and larynx are innervated by the vagus nerve. Damage to the laryngeal branches of the vagus nerve can interfere with normal speech. The vagus nerve is sensory for taste from the root of the tongue (see chapter 15). It's sensory for the inferior pharynx and the larynx and assists the glossopharyngeal nerve in transmitting sensory stimulation from receptors in the carotid arteries and the aortic arch, which monitor blood pressure and carbon dioxide, oxygen, and pH levels in the blood (see chapter 21). In addition, the vagus nerve conveys sensory information from the thoracic and abdominal organs. The parasympathetic part of the vagus nerve is very important in regulating the functions of the thoracic and abdominal organs. It carries parasympathetic fibers to the heart and lungs in the thorax and to the digestive organs and kidneys in the abdomen.

The **accessory (XI)** and **hypoglossal (XII) nerves** are somatic motor nerves. The accessory nerve has both a cranial and a spinal component. The cranial component joins the vagus nerve (hence the name *accessory*) and participates in its function. The spinal component of the accessory nerve provides the major innervation to the sternocleidomastoid and trapezius muscles of the neck and shoulder. The hypoglossal nerve supplies the intrinsic tongue muscles, three of the four extrinsic tongue muscles, and the thyrohyoid and the geniohyoid muscles.

20. What are the three major functions of the cranial nerves?
21. Which cranial nerves are sensory only? With what sense is each of these nerves associated?
22. Name the cranial nerves that are somatic motor and proprioceptive only. What muscles or muscle groups does each nerve supply?
23. The sensory cutaneous innervation of the face is provided by what cranial nerve? How is this nerve important in dentistry? Name the muscles that would not function if this nerve was damaged.
24. Which four cranial nerves have a parasympathetic function? Describe the function of each of these nerves.
25. Name the cranial nerves that control the movement of the eyeball.
26. Which cranial nerves are involved in the sense of taste? What part of the tongue does each supply?
27. Speech production involves which cranial nerves? Describe the branches of these nerves.

P R E D I C T 2

Injury to the spinal portion of the accessory nerve may result in sternocleidomastoid muscle dysfunction, a condition called "wry neck." If the head of a person with wry neck is turned to the left, would this position indicate injury to the left or right spinal component of the accessory nerve?

P R E D I C T 3

Unilateral damage to the hypoglossal nerve results in loss of tongue movement on one side, which is most obvious when the tongue is protruded. If the tongue is deviated to the right, is the left or right hypoglossal nerve damaged?

Reflexes in the Brainstem Involving Cranial Nerves

Reflexes integrated within the spinal cord were discussed in chapter 12. Many of the body's functions, especially those involved in maintaining homeostasis, involve reflexes that are integrated within the brain. Some of these reflexes, such as those involved in the control of heart rate (see chapter 20), blood pressure (see chapter 21), and respiration (see chapter 23), are integrated in the brainstem and many involve cranial nerve X (vagus nerve).

Many of the brainstem reflexes are associated with cranial nerve function. The circuitry of most of these reflexes is too complex for our discussions, but some general outlines can be presented. These reflexes involve sensory input from the cranial nerves or spinal cord, and the motor output of the motor cranial nerves.

Turning of the eyes toward a flash of light, sudden noise, or a touch on the skin are examples of brainstem reflexes. Moving the eyes to track a moving object is another, complex brainstem reflex. Some of the sensory neurons from cranial nerve VIII form a reflex arc with neurons of cranial nerves V and VII, which send axons to muscles of the middle ear and dampen the effects of very loud, sustained noises on delicate inner ear structures (see chapter 15). Reflexes that occur during the process of chewing allow the jaws to react to foods of various hardness and protect the teeth from breakage from very hard food items. Both the sensory and motor components of the reflex arc are carried by cranial nerve V. Reflexes involving input through cranial nerve V and output through cranial nerve XII move the tongue about to position food between the teeth for chewing and then move the tongue out of the way so it isn't bitten!

Clinical Focus Peripheral Nervous System Disorders—Cranial Nerves

General issues of PNS disorders are described in chapter 12. This chapter addresses only those specific to the cranial nerves.

Trigeminal neuralgia, also called tic douloureux, involves one or more of the trigeminal nerve branches and consists of sharp bursts of pain in the face. This disorder often has a trigger point in or around the mouth, which, when touched, elicits the pain response in some other part of the face. The cause of trigeminal neuralgia is unknown.

Facial palsy (called Bell's palsy) is a unilateral paralysis of the facial muscles. The affected side of the face droops because of the absence of muscle tone. Facial palsy involves the facial nerve and may result from facial nerve neuritis.

Infections

Herpes simplex I is usually characterized by one or more lesions (sores) on the lips or nose. The virus apparently remain dormant in the trigeminal ganglion. Eruptions are usually recurrent and often occur in times of reduced resistance, such as during a case of the common cold. For this reason they are called cold sores or fever blisters.

Genetic and Autoimmune Disorders

Neurofibromatosis (noor′ō-fī-brō-mă-tō′sis) is a genetic disorder in which small skin lesions appear in early childhood followed by the development of multiple subcutaneous neurofibromas, which are benign tumors resulting from Schwann cell proliferation. The neurofibromas may slowly increase in size and number over several years and cause extreme disfiguration.

S U M M A R Y

Brainstem (p. 434)

Medulla Oblongata

1. The medulla oblongata is continuous with the spinal cord and contains ascending and descending nerve tracts.
2. The pyramids are nerve tracts controlling voluntary muscle movement.
3. The olives are nuclei that function in equilibrium, coordination, and modulation of sound from the inner ear.
4. Medullary nuclei regulate the heart, blood vessels, respiration, swallowing, vomiting, coughing, sneezing, and hiccuping. The nuclei of cranial nerves V and IX–XII are in the medulla.

Pons

1. The pons is superior to the medulla.
2. Ascending and descending nerve tracts pass through the pons.
3. Pontine nuclei regulate sleep and respiration. The nuclei of cranial nerves V–IX are in the pons.

Midbrain

1. The midbrain is superior to the pons.
2. The midbrain contains the nuclei for cranial nerves III, IV, and V.
3. The tectum consists of four colliculi. The two inferior colliculi are involved in hearing and the two superior colliculi in visual reflexes.
4. The tegmentum contains ascending tracts and the red nuclei, which are involved in motor activity.
5. The cerebral peduncles are the major descending motor pathway.
6. The substantia nigra connects to other basal nuclei and is involved with muscle tone and movement.

Reticular Formation

The reticular formation consists of nuclei scattered throughout the brainstem. The reticular-activating system extends to the thalamus and cerebrum and maintains consciousness.

Cerebellum (p. 437)

1. The cerebellum has three parts that control balance, gross motor coordination, and fine motor coordination.
2. The cerebellum functions to correct discrepancies between intended movements and actual movements.
3. The cerebellum can "learn" highly specific complex motor activities.

Diencephalon (p. 439)

The diencephalon is located between the brainstem and the cerebrum.

Thalamus

1. The thalamus consists of two lobes connected by the intermediate mass. The thalamus functions as an integration center.
2. Most sensory input synapses in the thalamus.
3. The thalamus also has some motor functions.

Subthalamus

The subthalamus is inferior to the thalamus and is involved in motor function.

Epithalamus

The epithalamus is superior and posterior to the thalamus and contains the habenular nuclei, which influence emotions through the sense of smell. The pineal body may play a role in the onset of puberty.

Hypothalamus

1. The hypothalamus, the most inferior portion of the diencephalon, contains several nuclei and tracts.
2. The mamillary bodies are reflex centers for olfaction.
3. The hypothalamus regulates many endocrine functions (e.g., metabolism, reproduction, response to stress, and urine production). The pituitary gland attaches to the hypothalamus.
4. The hypothalamus regulates body temperature, hunger, thirst, satiety, swallowing, and emotions.

Cerebrum (p. 441)

1. The cortex of the cerebrum is folded into ridges called gyri and grooves called sulci, or fissures.
2. The longitudinal fissure divides the cerebrum into left and right hemispheres. Each hemisphere has five lobes.
   - The frontal lobes are involved in smell, voluntary motor function, motivation, aggression, and mood.

- The parietal lobes contain the major sensory areas receiving general sensory input, taste, and balance.
- The occipital lobes contain the visual centers.
- The temporal lobes receive olfactory and auditory input and are involved in memory, abstract thought, and judgment.

3. Nerve tracts connect areas of the cortex within the same hemisphere (association fibers), between different hemispheres (commissural fibers), and with other parts of the brain and the spinal cord (projection fibers).

Basal Nuclei

1. Basal nuclei include the subthalamic nuclei, substantia nigra, and corpus striatum.
2. The basal nuclei are important in controlling motor functions.

Limbic System

1. The limbic system includes parts of the cerebral cortex, basal nuclei, thalamus, hypothalamus, and the olfactory cortex.
2. The limbic system controls visceral functions through the autonomic nervous system and the endocrine system and is also involved in emotions and memory.

Meninges and Cerebrospinal Fluid (p. 444)

Meninges

1. The brain and spinal cord are covered by the dura, arachnoid, and pia mater.
2. The dura mater attaches to the skull and has two layers that can separate to form dural sinuses.
3. Beneath the arachnoid mater the subarachnoid space contains CSF that helps cushion the brain.
4. The pia mater attaches directly to the brain.

Ventricles

1. The lateral ventricles in the cerebrum are connected to the third ventricle in the diencephalon by the interventricular foramen.
2. The third ventricle is connected to the fourth ventricle in the pons by the cerebral aqueduct. The central canal of the spinal cord is connected to the fourth ventricle.

Cerebrospinal Fluid

1. CSF is produced from the blood in the choroid plexus of each ventricle. CSF moves from the lateral to the third and then to the fourth ventricle.
2. From the fourth ventricle CSF enters the subarachnoid space through three foramina.
3. CSF leaves the subarachnoid space through arachnoid granulations and returns to the blood in the dural sinuses.

Blood Supply to the Brain (p. 448)

1. The brain receives blood from the internal carotid and vertebral arteries. The latter form the basilar artery. The basilar and internal carotid arteries contribute to the cerebral arterial circle. Branches from the circle and basilar artery supply the brain.
2. The blood–brain barrier is formed from the endothelial cells of the capillaries in the brain, the astrocytes in the brain tissue, and the basement membrane in between.

Development of the CNS (p. 449)

The brain and spinal cord develop from the neural tube. The ventricles and central canal develop from the lumen of the neural tube.

Cranial Nerves (p. 449)

1. Cranial nerves perform sensory, somatic motor, proprioceptive, and parasympathetic functions.
2. The olfactory (I) and optic (II) nerves are involved in the sense of smell and vision.
3. The oculomotor nerve (III) innervates four of six extrinsic eye muscles and the upper eyelid. The oculomotor nerve also provides parasympathetic supply to the iris and lens of the eye.
4. The trochlear nerve (IV) controls an extrinsic eye muscle.
5. The trigeminal nerve (V) supplies the muscles of mastication, as well as a middle ear muscle, a palatine muscle, and two throat muscles. The trigeminal nerve has the greatest cutaneous sensory distribution of any cranial nerve. The trigeminal nerve has three branches. Two of the three trigeminal nerve branches innervate the teeth.
6. The abducens nerve (VI) controls an extrinsic eye muscle.
7. The facial nerve (VII) supplies the muscles of facial expression, an inner ear muscle, and two throat muscles. It is involved in the sense of taste. It's parasympathetic to two sets of salivary glands and to the lacrimal glands.
8. The vestibulocochlear nerve (VIII) is involved in the sense of hearing and balance.
9. The glossopharyngeal nerve (IX) is involved in taste and supplies tactile sensory innervation from the posterior tongue, middle ear, and pharynx. It's also sensory for receptors that monitor blood pressure and gas levels in the blood. The glossopharyngeal nerve is parasympathetic to the parotid salivary glands.
10. The vagus nerve (X) innervates the muscles of the pharynx, palate, and larynx. It's also involved in the sense of taste. The vagus nerve is sensory for the pharynx and larynx and for receptors that monitor blood pressure and gas levels in the blood. The vagus nerve is sensory for thoracic and abdominal organs. The vagus nerve provides parasympathetic innervation to the thoracic and abdominal organs.
11. The accessory nerve (XI) has a cranial and a spinal component. The cranial component joins the vagus nerve. The spinal component supplies the sternocleidomastoid and trapezius muscles.
12. The hypoglossal nerve (XII) supplies the intrinsic tongue muscles, three of four extrinsic tongue muscles, and two throat muscles.

Reflexes in the Brainstem Involving Cranial Nerves

Many reflexes involved in homeostasis involve the cranial nerves and occur in the brainstem.

R E V I E W   A N D   C O M P R E H E N S I O N

1. If a section is made that separates the brainstem from the rest of the brain, the cut is between the
   a. medulla oblongata and pons.
   b. pons and midbrain.
   c. midbrain and diencephalon.
   d. thalamus and cerebrum.
   e. medulla oblongata and spinal cord.
2. Important centers for heart rate, blood pressure, respiration, swallowing, coughing, and vomiting are located in the
   a. cerebrum.
   b. medulla oblongata.
   c. midbrain.
   d. pons.
   e. cerebellum.

3. In which of these parts of the brain does decussation of descending nerve tracts involved in the conscious control of skeletal muscles occur?
   a. cerebrum
   b. diencephalon
   c. midbrain
   d. pons
   e. medulla oblongata
4. Important respiratory centers are located in the
   a. cerebrum.
   b. cerebellum.
   c. pons and medulla oblongata.
   d. midbrain
   e. limbic system.
5. The cerebral peduncles are a major descending motor pathway found in the
   a. cerebrum.
   b. cerebellum.
   c. pons.
   d. midbrain.
   e. medulla oblongata.
6. The superior colliculi are involved in ______________, whereas the inferior colliculi are involved in ______________.
   a. hearing, visual reflexes
   b. visual reflexes, hearing
   c. balance, motor pathways
   d. motor pathways, balance
   e. respiration, sleep
7. The cerebellum communicates with other regions of the CNS through the
   a. flocculonodular lobe.
   b. cerebellar peduncles.
   c. vermis.
   d. lateral hemispheres.
   e. folia.
8. The major relay station for sensory input that projects to the cerebral cortex is the
   a. hypothalamus.
   b. thalamus.
   c. pons.
   d. cerebellum.
   e. midbrain.
9. Which part of the brain is involved with olfactory reflexes and emotional responses to odors?
   a. inferior colliculi
   b. superior colliculi
   c. mamillary bodies
   d. pineal body
   e. pituitary gland
10. The part of the diencephalon directly connected to the pituitary gland is the
   a. hypothalamus.
   b. epithalamus.
   c. subthalamus.
   d. thalamus.
11. Which of the following is a function of the hypothalamus?
   a. regulates autonomic nervous system functions
   b. regulates the release of hormones from the posterior pituitary
   c. regulates body temperature
   d. regulates food intake (hunger) and water intake (thirst)
   e. all of the above
12. The grooves on the surface of the cerebrum are called the
   a. nuclei.
   b. commissures.
   c. tracts.
   d. sulci.
   e. gyri.
13. Which of these areas is located in the postcentral gyrus of the cerebral cortex?
   a. olfactory cortex
   b. visual cortex
   c. primary motor cortex
   d. primary somatic sensory cortex
   e. primary auditory cortex
14. Which of these cerebral lobes is important in voluntary motor function, motivation, aggression, sense of smell, and mood?
   a. frontal
   b. insula
   c. occipital
   d. parietal
   e. temporal
15. Fibers that connect areas of the cerebral cortex within the same hemisphere are
   a. projection fibers.
   b. commissural fibers.
   c. association fibers.
   d. all of the above.
16. The basal nuclei are located in the
   a. inferior cerebrum
   b. diencephalon
   c. midbrain
   d. all of the above
17. The most superficial of the meninges is a thick, tough membrane called the
   a. pia mater.
   b. dura mater.
   c. arachnoid mater.
   d. epidural mater.
18. The ventricles of the brain are interconnected. Which of these ventricles are *not* correctly matched with the structures that connect them?
   a. lateral ventricle to the third ventricle—interventricular foramina
   b. left lateral ventricle to right lateral ventricle—central canal
   c. third ventricle to fourth ventricle—cerebral aqueduct
   d. fourth ventricle to subarachnoid space—median and lateral apertures
19. Cerebrospinal fluid is produced by the ______________, circulates through the ventricles, and enters the subarachnoid space. The cerebrospinal fluid leaves the subarachnoid space through the ______________.
   a. choroid plexuses, arachnoid granulations
   b. arachnoid granulations, choroid plexuses
   c. dural sinuses, dura mater
   d. dura mater, dural sinuses
20. Given these spaces:
   1. third ventricle
   2. epidural space
   3. subarachnoid space
   4. subdural space
   5. superior sagittal sinus

   Which of these spaces contains cerebrospinal fluid (CSF)?
   a. 1, 3
   b. 1,2,3
   c. 1,3,5
   d. 1,2,3,5
   e. 2,3,4,5

21. Water-soluble molecules such as glucose and amino acids move across the blood–brain barrier by
    a. diffusion.
    b. endocytosis.
    c. exocytosis.
    d. mediated transport.
    e. filtration.
22. Which of these parts of the embryonic brain is correctly matched with the structure it becomes in the adult brain?
    a. mesencephalon—midbrain
    b. metencephalon—medulla oblongata
    c. myelencephalon—cerebrum
    d. telencephalon—pons and cerebellum
23. The cranial nerve involved in chewing food is the
    a. trochlear (IV).
    b. trigeminal (V).
    c. abducens (VI).
    d. facial (VII).
    e vestibulocochlear (VIII).
24. The cranial nerve responsible for focusing the eye (innervates the ciliary muscle of the eye) is the
    a. optic (II).
    b. oculomotor (III).
    c. trochlear (IV).
    d. abducens (VI).
    e. facial (VII).
25. The cranial nerve involved in moving the tongue is the
    a. trigeminal (V).
    b. facial (VII).
    c. glossopharyngeal (IX).
    d. accessory (XI).
    e. hypoglossal (XII).
26. The cranial nerve involved in feeling a toothache is the
    a. trochlear (IV).
    b. trigeminal (V).
    c. abducens (VI).
    d. facial (VII).
    e. vestibulocochlear (VIII).
27. From this list of cranial nerves:
    1. olfactory (I)
    2. optic (II)
    3. oculomotor (III)
    4. abducens (VI)
    5. vestibulocochlear (VIII)

    Select the nerves that are sensory only.
    a. 1,2,3
    b. 2,3,4
    c. 1,2,5
    4. 2,3,5
    5. 3,4,5
28. From this list of cranial nerves:
    1. optic (II)
    2. oculomotor (III)
    3. trochlear (IV)
    4. trigeminal (V)
    5. abducens (VI)

    Select the nerves that are involved in moving the eyes.
    a. 1,2,3
    b. 1,2,4,
    c. 2,3,4
    d. 2,4,5
    e. 2,3,5
29. From this list of cranial nerves:
    1. trigeminal (V)
    2. facial (VII)
    3. glossopharyngeal (IX)
    4. vagus (X)
    5. hypoglossal (XII)

    Select the nerves that are involved in the sense of taste.
    a. 1,2,3
    b. 1,4,5
    c. 2,3,4
    d. 2,3,5
    e. 3,4,5
30. From this list of cranial nerves:
    1. trigeminal (V)
    2. facial (VII)
    3. glossopharyngeal (IX)
    4. vagus (X)
    5. hypoglossal (XII)

    Select the nerves that innervate the salivary glands.
    a. 1,2
    b. 2,3
    c. 3,4
    d. 4,5
    e. 3,5
31. From this list of cranial nerves:
    1. oculomotor (III)
    2. trigeminal (V)
    3. facial (VII)
    4. vestibulocochlear (VIII)
    5. glossopharyngeal (IX)
    6. vagus (X)

    Select the nerves that are part of the parasympathetic division of the ANS.
    a. 1,2,4,5
    b. 1,3,5,6
    c. 1,4,5,6
    d. 2,3,4,5
    e. 2,3,5,6

Answers in Appendix F

C R I T I C A L T H I N K I N G

1. A patient looses all sense of feeling in the left side of the back, below the upper limb, and extending in a band around to the chest, also below the upper limb. All sensation on the right is normal. The line between normal and absent sensation is the anterior and posterior midline. Explain this condition.
2. The cerebral cortex of humans is highly convoluted. What advantage does this provide?
3. What happens to the developing brain if the CSF is not properly drained, resulting in early hydrocephalus?
4. A patient exhibits enlargement of the lateral and third ventricles, but no enlargement of the fourth ventricle. What would you conclude?
5. During a spinal tap of a patient, blood is discovered in the CSF. What does this finding suggest?

Answers in Appendix G

ANSWERS TO PREDICT QUESTIONS

1. The oculomotor nerve innervates four eye muscles and the levator palpebrae superioris muscle. One cause of ptosis, a drooping upper eyelid, can be oculomotor nerve damage and subsequent paralysis of the levator palpebrae superioris muscle. The four eye muscles innervated by the oculomotor nerve move the eyeball so that the gaze is directed superiorly, inferiorly, medially, or superolaterally. Damage to this nerve can be tested by having the patient look in these directions. The abducens nerve directs the gaze laterally, and the trochlear nerve directs the gaze inferolaterally. If the patient can move the eyes in these directions, the associated nerves are intact.
2. The sternocleidomastoid muscle pulls the mastoid process (located behind the ear) toward the sternum, thus turning the face to the opposite side. If the innervation to one sternocleidomastoid muscle is eliminated (accessory nerve injury), the opposite muscle is unopposed and turns the face toward the side of injury. A person with wry neck whose head is turned to the left most likely has an injured left accessory nerve.
3. The tongue is protruded by contraction of the geniohyoid muscle, which pulls the back of the tongue forward, thereby pushing the muscle mass of the tongue forward. With one side pushed forward and unopposed by muscles of the opposite side, the tongue deviates toward the nonfunctional side. In the example, therefore, the right hypoglossal nerve is damaged.

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