14

The Brain and Cranial Nerves

Learning Outcomes

These Learning Outcomes correspond by number to this chapter's sections and indicate what you should be able to do after completing the chapter.

14-1 Name the **major brain regions, vesicles, and ventricles**, and describe the locations and functions of each.

14-2 Explain how the **brain is protected and supported**, and discuss the **formation, circulation, and function of cerebrospinal fluid**.

14-3 Describe the anatomical differences between the **medulla oblongata** and the **spinal cord**, and identify the **main components and functions of the medulla oblongata**.

14-4 List the main **components of the pons**, and specify the functions of each.

14-5 List the main **components of the cerebellum**, and specify the functions of each.

14-6 List the main **components of the midbrain**, and specify the functions of each.

14-7 List the main **components of the diencephalon**, and specify the functions of each.

14-8 Identify the main **components of the limbic system**, and specify the locations and functions of each.

14-9 Identify the major anatomical **subdivisions and functions of the cerebrum**, and discuss the origin and significance of the major types of brain waves seen in an **electroencephalogram**.

14-10 Describe representative examples of **cranial reflexes** that produce **somatic responses or visceral responses** to specific stimuli.

Clinical Notes

An Introduction to the Brain and Cranial Nerves

This chapter introduces the functional organization of the brain and cranial nerves, and describes simple cranial reflexes. The adult human brain contains almost 97 percent of the body's neural tissue. A "typical" brain weighs 1.4 kg (3 lb) and has a volume of 1200 mL (71 in.^{3}). Brain size varies considerably among individuals. The brains of males are, on average, about 10 percent larger than those of females, due to differences in average body size. No correlation exists between brain size and intelligence. Individuals with the smallest brains (750 mL) and the largest brains (2100 mL) are functionally normal.

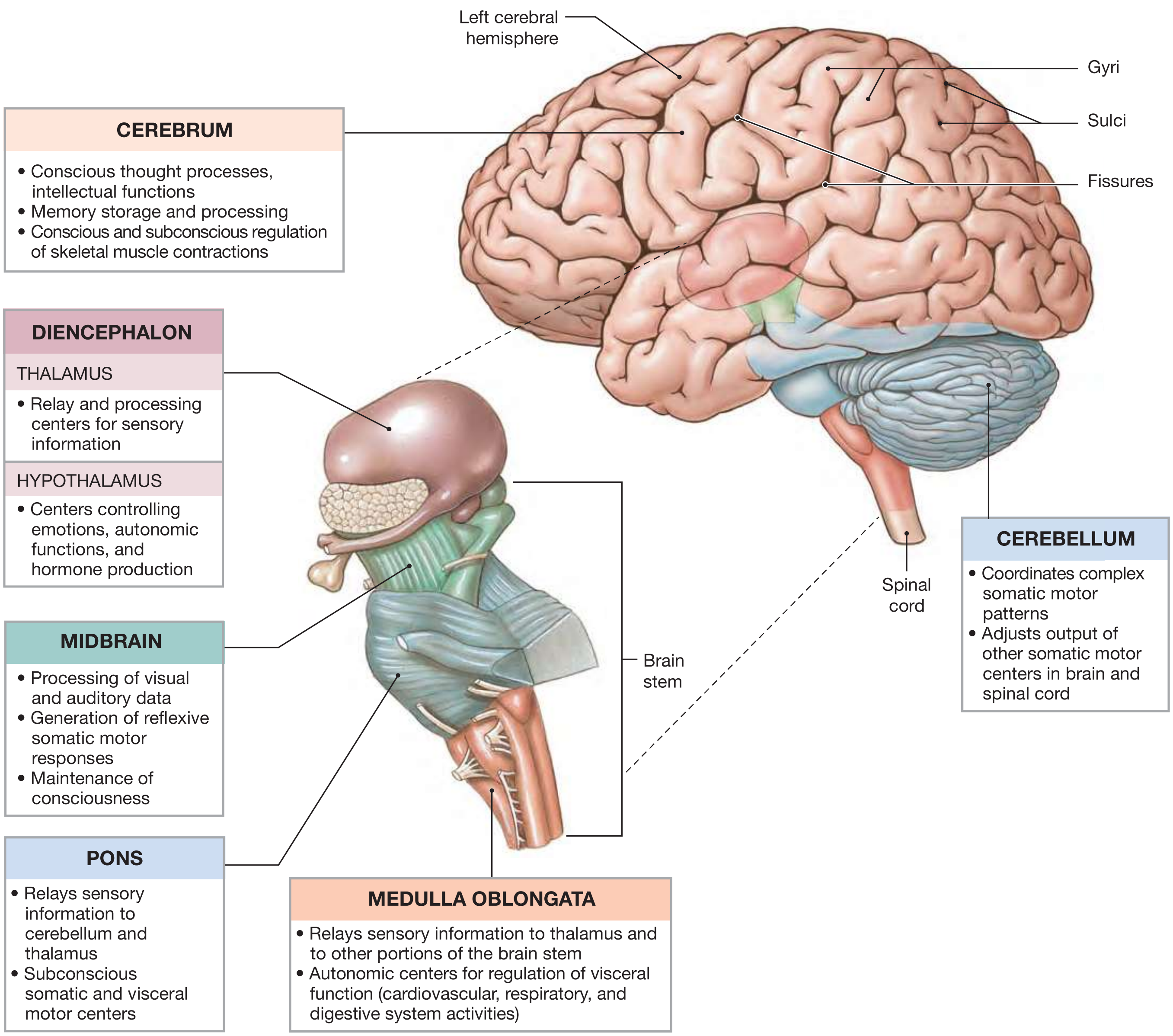
14-1 The brain has several principal structures, each with specific functions

In this section we introduce the anatomical organization of the brain. We begin with an overview of the brain's major regions and landmarks; then we discuss the brain's embryological origins and some prominent internal cavities: the ventricles of the brain.

Major Brain Regions and Landmarks

The adult brain is dominated in size by the cerebrum (**Figure 14–1**). Viewed from the anterior and superior surfaces, the

Figure 14–1 An Introduction to Brain Structures and Functions.



cerebrum (se-RĒ-brum or SER-e-brum) of the adult brain can be divided into large, paired **cerebral hemispheres.** The brain has an extensive area of **neural cortex,** a layer of gray matter covering most of its surface. The surfaces of the cerebral hemispheres are highly folded and covered by **cerebral cortex** (*cortex*, rind or bark), the name given to this superficial layer of neural cortex. This cerebral cortex forms a series of elevated ridges, or **gyri** (JĪ-rī; singular, *gyrus*) that serve to increase its surface area. The gyri are separated by shallow depressions called **sulci** (SUL-sī) or by deeper grooves called **fissures.** The cerebrum is the seat of most higher mental functions. Conscious thoughts, sensations, intellect, memory, and complex movements all originate in the cerebrum.

The **cerebellum** (ser-e-BEL-um) is partially hidden by the cerebral hemispheres, but it is the second-largest part of the brain. Like the cerebrum, the cerebellum has hemispheres that are covered by a layer of gray matter, the *cerebellar cortex*. The cerebellum adjusts ongoing movements by comparing arriving sensations with previously experienced sensations, allowing you to perform the same movements over and over.

14

The other major anatomical regions of the brain can best be examined after the cerebral and cerebellar hemispheres have been removed (**Figure 14–1**). The walls of the **diencephalon** (dī-en-SEF-a-lon; *dia*, through + *encephalos*, brain) are composed of the **left thalamus** and **right thalamus** (THAL-a-mus; plural, *thalami*). Each thalamus contains relay and processing centers for sensory information. The **hypothalamus** (*hypo-*, below), or floor of the diencephalon, contains centers involved with emotions, autonomic function, and hormone production. The *infundibulum*, a narrow stalk, connects the hypothalamus to the **pituitary gland,** a component of the endocrine system. The hypothalamus and the pituitary gland are responsible for the integration of the nervous and endocrine systems.

The diencephalon is a structural and functional link between the cerebral hemispheres and the components of the brain stem. The **brain stem** contains a variety of important processing centers and nuclei that relay information headed to or from the cerebrum or cerebellum. The brain stem includes the *midbrain*, *pons*, and *medulla oblongata*.[1]

- The **midbrain,** or *mesencephalon*, contains nuclei that process visual and auditory information and control reflexes triggered by these stimuli. For example, your immediate, reflexive responses to a loud, unexpected noise (eye movements and head turning) are directed by nuclei in the midbrain. This region also contains centers that help maintain consciousness.
- The **pons** of the brain connects the cerebellum to the brain stem (*pons* is Latin for "bridge"). In addition to tracts and relay centers, the pons also contains nuclei involved with somatic and visceral motor control.
- The spinal cord connects to the brain at the **medulla oblongata.** Near the pons, the posterior wall of the medulla oblongata is thin and membranous. The inferior portion of the medulla oblongata resembles the spinal cord in that it has a narrow central canal. The medulla oblongata relays sensory information to the thalamus and to centers in other portions of the brain stem. The medulla oblongata also contains major centers that regulate autonomic function, such as heart rate, blood pressure, and digestion.

The boundaries and general functions of the diencephalon and brain stem are indicated in **Figure 14–1**. In considering the individual components of the brain, we will begin at the inferior portion of the medulla oblongata. This region has the simplest organization found anywhere in the brain, and in many respects it resembles the spinal cord. We will then ascend to regions of increasing structural and functional complexity until we reach the cerebral cortex, whose functions and capabilities are as yet poorly understood.

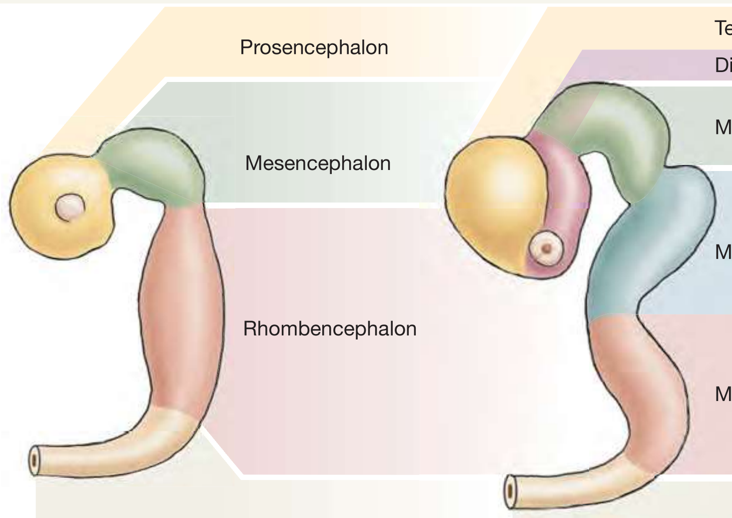
Embryology of the Brain

To understand the internal organization of the adult brain, we must consider its embryological origins. The central nervous system (CNS) begins as a hollow cylinder known as the *neural tube*. This tube has a fluid-filled internal cavity, the *neurocoel*. In the cephalic portion of the neural tube, three areas enlarge rapidly through expansion of the neurocoel. This enlargement creates three prominent divisions called **primary brain vesicles.** The primary brain vesicles are named for their relative positions: the *prosencephalon* (prōz-en-SEF-a-lon; *proso*, forward + *enkephalos*, brain), or "forebrain"; the *mesencephalon*, or "midbrain"; and the *rhombencephalon* (rom-ben-SEF-a-lon), or "hindbrain."

The fates of the three primary divisions of the brain are summarized in **Table 14–1**. The prosencephalon and rhombencephalon are subdivided further, forming **secondary brain vesicles.** The prosencephalon forms the **telencephalon** (tel-en-SEF-a-lon; *telos*, end) and the diencephalon. The telencephalon will ultimately form the cerebrum of the adult brain. The walls of the mesencephalon thicken, and the neurocoel becomes a relatively narrow passageway, comparable to the central canal of the spinal cord. The portion of the rhombencephalon adjacent to the mesencephalon forms the **metencephalon** (met-en-SEF-a-lon; *meta*, after). The dorsal portion of the metencephalon will become the cerebellum, and the ventral portion will develop into the pons. The portion of the rhombencephalon closer to the spinal cord forms the **myelencephalon** (mī-el-en-SEF-a-lon; *myelon*, spinal cord), which will become the medulla oblongata. ATLAS: Embryology Summary 12: The Development of the Brain and Cranial Nerves

[1]Some sources consider the brain stem to include the diencephalon. We will use the more restrictive definition.

Table 14–1 Development of the Brain



Primary Brain Vesicles (3 weeks)	Secondary Brain Vesicles (6 weeks)	Brain Regions at Birth	Ventricles
Prosencephalon	Telencephalon	Cerebrum	Lateral ventricle
	Diencephalon	Diencephalon	Third ventricle
Mesencephalon	Mesencephalon	Midbrain	Cerebral aqueduct
Rhombencephalon	Metencephalon	Cerebellum and Pons	Fourth ventricle
	Myelencephalon	Medulla oblongata	Fourth ventricle

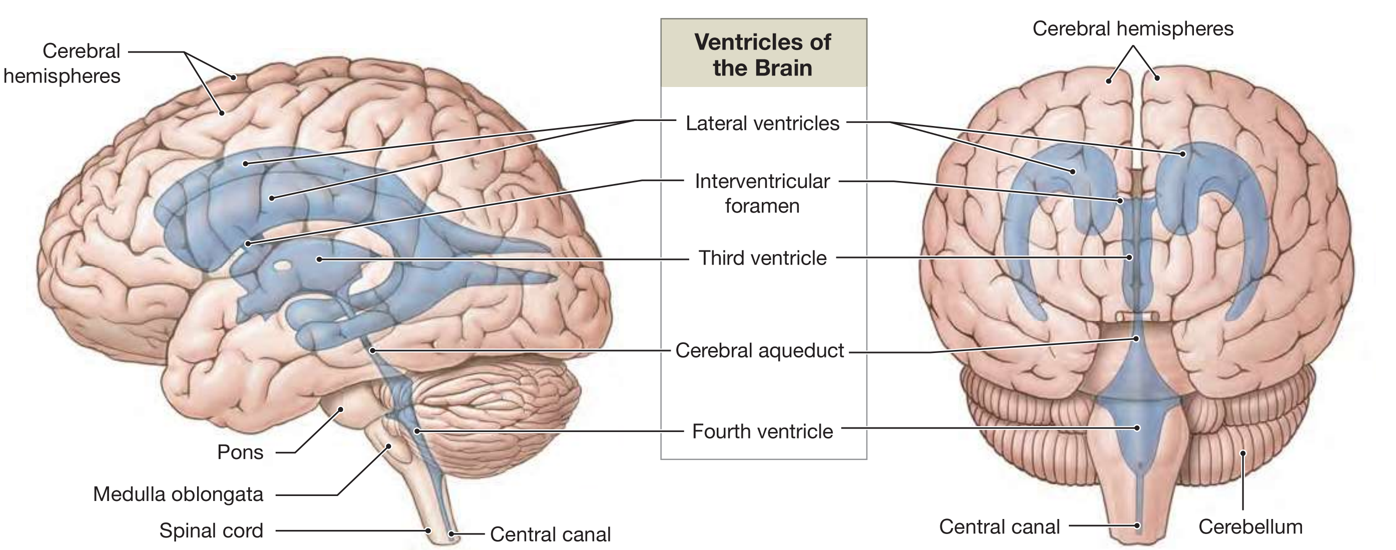
Ventricles of the Brain

During development, the neurocoel within the cerebral hemispheres, diencephalon, metencephalon, and medulla oblongata expands to form chambers called **ventricles** (VEN-tri-kls). Cells of the *ependyma* line the ventricles. ⮌ p. 380

Each cerebral hemisphere contains a large **lateral ventricle** (Figure 14–2). The **septum pellucidum,** a thin medial partition, separates the two lateral ventricles. Because there are *two* lateral ventricles, the ventricle in the diencephalon is called the **third ventricle.** Although the two lateral ventricles are not directly connected, each communicates with the third ventricle of the diencephalon through an **interventricular foramen** (*foramen of Monro*).

The midbrain has a slender canal known as the **cerebral aqueduct.** This passageway connects the third ventricle with the **fourth ventricle.** The superior portion of the fourth ventricle lies between the posterior surface of the pons and the anterior surface of the cerebellum. The fourth ventricle extends into the superior portion of the medulla oblongata. This ventricle then narrows and becomes continuous with the central canal of the spinal cord.

Figure 14–2 Ventricles of the Brain. The orientation and extent of the ventricles as they would appear if the brain were transparent. ATLAS: Plates 10; 12a–c; 13a–e



a Ventricular system, lateral view

b Ventricular system, anterior view

14

The ventricles are filled with cerebrospinal fluid (CSF). The CSF continuously circulates from the ventricles and central canal into the *subarachnoid space* of the surrounding cranial meninges. The CSF passes between the interior and exterior of the CNS through three foramina in the roof of the fourth ventricle; these foramina will be described in a later section.

Checkpoint

1. **Name the six major regions of the brain.**
2. **What brain regions make up the brain stem?**
3. **Which primary brain vesicle is destined to form the cerebellum, pons, and medulla oblongata?**

See the blue Answers tab at the back of the book.

14-2 ◗ The brain is protected and supported by the cranial meninges, cerebrospinal fluid, and the blood–brain barrier

The delicate tissues of the brain are protected from mechanical forces by the bones of the cranium, the *cranial meninges*, and cerebrospinal fluid. In addition, the neural tissue of the brain is biochemically isolated from the general circulation by the *blood–brain barrier*. Refer to **Figures 7–3** and **7–4** (pp. 201–203) for a review of the bones of the cranium. We will discuss the other protective factors here.

The Cranial Meninges

The layers that make up the cranial meninges—the cranial dura mater, arachnoid mater, and pia mater—are continuous with those of the spinal meninges. ⮌ p. 420 However, the cranial meninges have distinctive anatomical and functional characteristics (**Figure 14–3a**):

- The cranial *dura mater* consists of outer and inner fibrous layers. The outer layer is fused to the periosteum of the cranial bones. As a result, there is no epidural space superficial to the dura mater, as occurs along the spinal cord. The outer, or *endosteal*, and inner, or *meningeal*, layers of the cranial dura mater are typically separated by a slender gap that contains tissue fluids and blood vessels, including several large venous sinuses. The veins of the brain open into these sinuses, which deliver the venous blood to the *internal jugular veins* of the neck.
- The cranial *arachnoid mater* consists of the arachnoid membrane (an epithelial layer) and the cells and fibers of the arachnoid trabeculae that cross the subarachnoid space to the pia mater. The arachnoid membrane covers the brain, providing a smooth surface that does not follow the brain's underlying folds. This membrane is in contact with the inner epithelial layer of the dura mater. The subarachnoid space extends between the arachnoid membrane and the pia mater.
- The *pia mater* sticks to the surface of the brain, anchored by the processes of astrocytes. It extends into every fold, and accompanies the branches of cerebral blood vessels as they penetrate the surface of the brain to reach internal structures.

Dural Folds

In several locations, the inner layer of the dura mater extends into the cranial cavity, forming a sheet that dips inward and then returns. These **dural folds** provide additional stabilization and support to the brain. **Dural sinuses** are large collecting veins located within the dural folds. The three largest dural folds are called the falx cerebri, the tentorium cerebelli, and the falx cerebelli (**Figure 14–3b**):

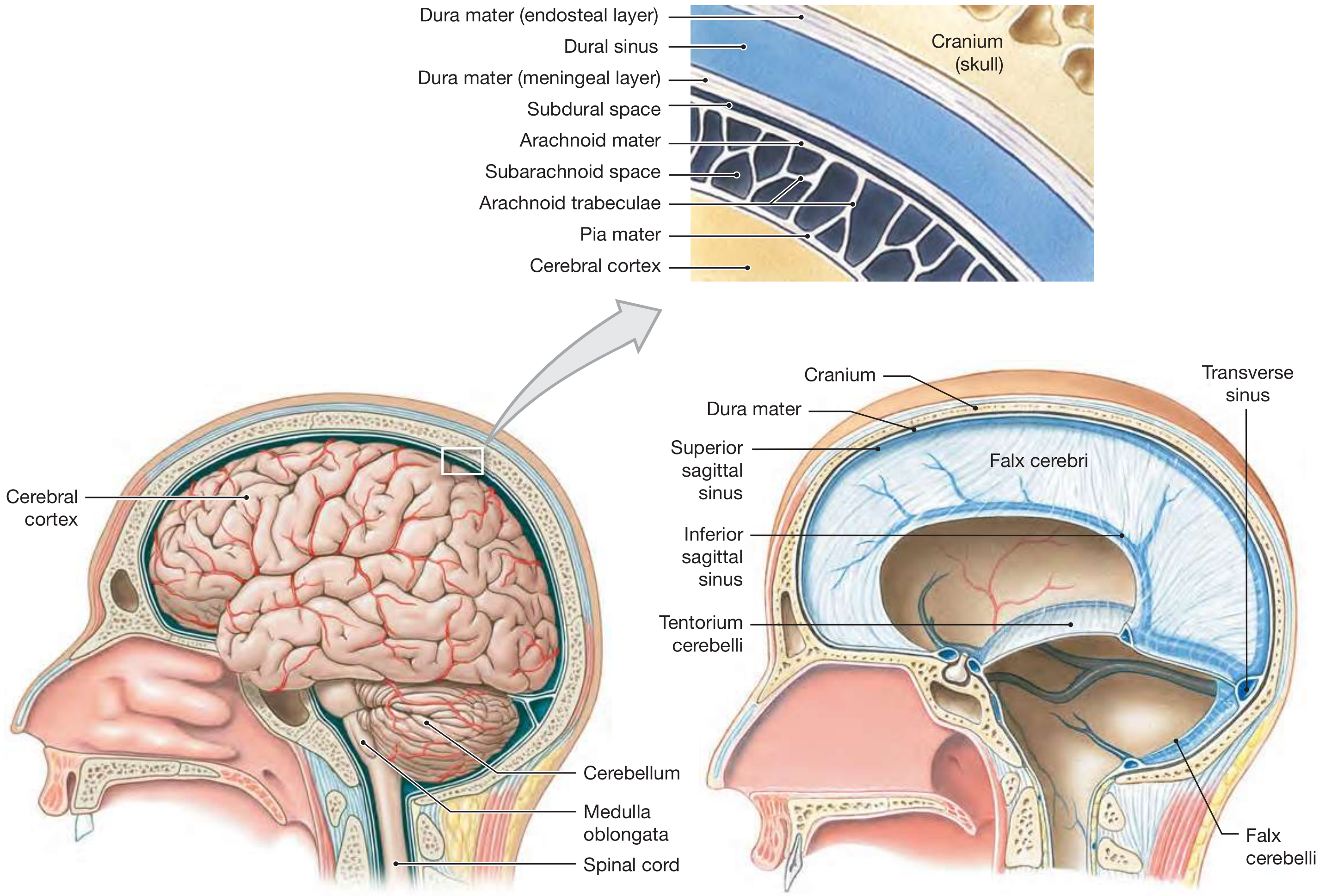
1. The **falx cerebri** (FALKS SER-e-brī; *falx*, curving or sickle-shaped) is a fold of dura mater that projects between the cerebral hemispheres in the longitudinal fissure. Its inferior portions attach anteriorly to the crista galli and posteriorly to the *internal occipital crest*, a ridge along the inner surface of the occipital bone. The **superior sagittal sinus** and the **inferior sagittal sinus,** two large venous sinuses, lie within this dural fold. The posterior margin of the falx cerebri intersects the tentorium cerebelli.
2. The **tentorium cerebelli** (ten-TŌ-rē-um ser-e-BEL-ē; *tentorium*, tent) protects the cerebellar hemispheres and separates them from those of the cerebrum. It extends across the cranium at right angles to the falx cerebri. The **transverse sinus** lies within the tentorium cerebelli.
3. The **falx cerebelli** divides the two cerebellar hemispheres along the midsagittal line inferior to the tentorium cerebelli.

The Protective Function of the Cranial Meninges

The overall shape of the brain corresponds to that of the cranial cavity (**Figure 14–3a**). The cranial bones provide mechanical protection by cradling the brain, but they also pose a threat to safety that is countered by the cranial meninges and the CSF. The brain is like a person driving a car: If the car hits a tree, the car protects the driver from contact with the tree, but serious injury will occur unless a seat belt or airbag protects the driver from contact with the car. The tough, fibrous dural folds act like seat belts that hold the brain in position. The cerebrospinal fluid in the subarachnoid space acts like a bumper by cushioning against sudden jolts and shocks.

Cranial trauma is a head injury resulting from impact with another object. Each year in the United States, about 8 mil-

Figure 14–3 **The Relationship among the Brain, Cranium, and Meninges.** ATLAS: Plates 7a–d



a A lateral view of the brain, showing its position in the cranium and the organization of the meninges

b A diagrammatic view, showing the orientation of the three largest dural folds: the falx cerebri, tentorium cerebelli, and falx cerebelli

lion cases of cranial trauma occur, but only 1 case in 8 results in serious brain damage. The percentage is relatively low because the cranial meninges and CSF are so effective in protecting the brain.

Cerebrospinal Fluid

Cerebrospinal fluid (CSF) completely surrounds and bathes the exposed surfaces of the CNS. The CSF has several important functions, including the following:

- *Cushioning Delicate Neural Structures.*
- *Supporting the Brain.* In essence, the brain is suspended inside the cranium and floats in the CSF. A human brain weighs about 1400 g (3.09 lb.) in air, but only about 50 g (1.8 oz.) when supported by CSF.
- *Transporting Nutrients, Chemical Messengers, and Waste Products.* Except at the choroid plexus, where CSF is produced, the ependymal lining is freely permeable and the CSF is in constant chemical communication with the interstitial fluid that surrounds the neurons and neuroglia of the CNS.

Because free exchange occurs between the interstitial fluid of the brain and the CSF, changes in CNS function can produce changes in the composition of the CSF. As noted in Chapter 13, a *spinal tap* can provide useful clinical information about CNS injury, infection, or disease. ⮌ p. 421

The Formation of CSF

The **choroid plexus** (*choroid*, vascular coat; *plexus*, network) consists of a combination of specialized ependymal cells and

Clinical Note — Epidural and Subdural Hemorrhages

Dangerous bleeding in the cranial cavity

A severe head injury may damage meningeal blood vessels and cause bleeding into the cranial cavity. The most serious cases involve an arterial break, because arterial blood pressure is relatively high. If blood is forced between the dura mater and the cranium, the condition is known as an **epidural hemorrhage.** The elevated fluid pressure then distorts the underlying tissues of the brain. The individual loses consciousness for a period lasting from minutes to hours after the injury, and death follows in untreated cases. An epidural hemorrhage involving a damaged vein does not produce massive symptoms immediately, and the individual may not have neurological problems for hours, days, or even weeks after the original injury. As a result, the problem may not be noticed until the nervous tissue has been severely damaged. Epidural hemorrhages are rare, occurring in fewer than 1 percent of head injuries. However, the mortality rate is 100 percent in untreated cases and over 50 percent even after the blood pool has been removed and the damaged vessels have been closed.

The term **subdural hemorrhage** may be misleading, because in many cases blood enters the meningeal layer of the dura mater, rather than flowing between the dura mater and the arachnoid mater. Subdural hemorrhages are twice as common as epidural hemorrhages. The most common source of blood is a small vein or one of the dural sinuses, and the pool of blood that forms outside the damaged vessel is called a **subdural hematoma.** Because the venous blood pressure in a subdural hemorrhage is lower than that in an arterial epidural hemorrhage, the distortion produced is gradual and the effects on brain function can be quite variable and difficult to diagnose.

permeable capillaries involved in the production of cerebrospinal fluid. Two extensive folds of the choroid plexus originate in the roof of the third ventricle and extend through the interventricular foramina. These folds cover the floors of the lateral ventricles (**Figure 14–4a**). In the inferior brain stem, a region of the choroid plexus in the roof of the fourth ventricle projects between the cerebellum and the pons.

Specialized ependymal cells, interconnected by tight junctions, surround the capillaries of the choroid plexus. The ependymal cells secrete CSF into the ventricles; they also remove waste products from the CSF and adjust its composition over time. The differences in composition between CSF and blood plasma (blood with the cellular elements removed) are quite noticeable. For example, the blood contains high concentrations of soluble proteins, but the CSF does not. The concentrations of individual ions and the levels of amino acids, lipids, and waste products are also different.

Circulation of CSF

The choroid plexus produces CSF at a rate of about 500 mL/day or 2.1 cups per day. The total volume of CSF at any moment is approximately 150 mL; thus, the entire volume of CSF is replaced roughly every eight hours. Despite this rapid turnover, the composition of CSF is closely regulated, and the rate of removal normally keeps pace with the rate of production.

The CSF circulates from the choroid plexus through the ventricles and fills the central canal of the spinal cord (**Figure 14–4a**). As the CSF circulates, diffusion between it and the interstitial fluid of the CNS is unrestricted between and across the ependymal cells. The CSF reaches the subarachnoid space through two **lateral apertures** and a single **median aperture,** openings in the roof of the fourth ventricle. Cerebrospinal fluid then flows through the subarachnoid space surrounding the brain, spinal cord, and cauda equina.

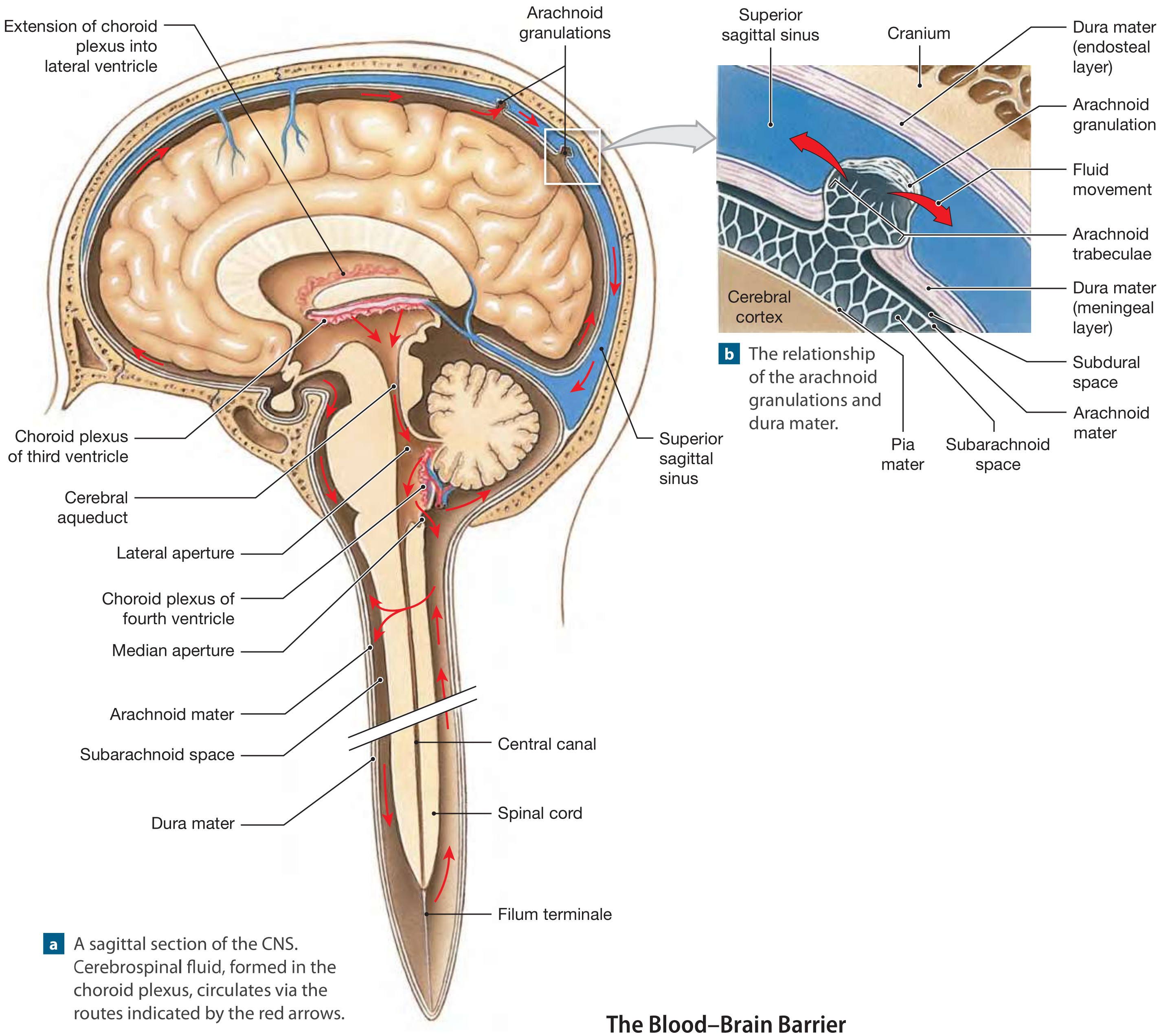
Fingerlike extensions of the arachnoid membrane, called the *arachnoid villi*, penetrate the meningeal layer of the dura mater and extend into the superior sagittal sinus. In adults, clusters of villi form large **arachnoid granulations** (**Figure 14–4b**). Cerebrospinal fluid is absorbed into the venous circulation at the arachnoid granulations.

If the normal circulation or reabsorption of CSF is interrupted, a variety of clinical problems may appear. For example, a problem with the reabsorption of CSF in infancy causes *hydrocephalus*, or "water on the brain." Infants with this condition have enormously expanded skulls due to the presence of an abnormally large volume of CSF. In adults, a failure of reabsorption or a blockage of CSF circulation can distort and damage the brain.

The Blood Supply to the Brain

As noted in Chapter 12, neurons have a high demand for energy, but they have neither energy reserves in the form of carbohydrates or lipids, nor oxygen reserves in the form of myoglobin. Your brain, with billions of neurons, is an extremely active organ with a continuous demand for nutrients and oxygen. These demands are met by an extensive circulatory supply. Arterial blood reaches the brain through the *internal carotid arteries* and the *vertebral arteries*. Most of the venous blood from the brain leaves the cranium in the *internal jugular veins*, which drain the dural sinuses. A head injury that damages cerebral blood vessels may cause bleeding into the dura mater, either near the dural epithelium or between the outer layer of the dura mater and the bones of the skull. These are serious

Figure 14–4 The Formation and Circulation of Cerebrospinal Fluid.



a A sagittal section of the CNS. Cerebrospinal fluid, formed in the choroid plexus, circulates via the routes indicated by the red arrows.

b The relationship of the arachnoid granulations and dura mater.

conditions, because the blood entering these spaces compresses and distorts the soft tissues of the brain.

Cerebrovascular diseases are cardiovascular disorders that interfere with the normal blood supply to the brain. The particular distribution of the vessel involved determines the signs and symptoms, and the degree of oxygen or nutrient starvation determines their severity. A **cerebrovascular accident (CVA),** or *stroke*, occurs when the blood supply to a portion of the brain is shut off. Affected neurons begin to die in a matter of minutes.

The Blood–Brain Barrier

Neural tissue in the CNS is isolated from the general circulation by the **blood–brain barrier (BBB).** This barrier is formed by capillary endothelial cells that are extensively interconnected by tight junctions. These junctions prevent the diffusion of materials between adjacent endothelial cells. In general, only lipid-soluble compounds (including carbon dioxide; oxygen; ammonia; lipids, such as steroids or prostaglandins; and small alcohols) can diffuse across the membranes of endothelial cells into the interstitial fluid of the brain and spinal cord. Water and ions must pass through channels in the apical and basement plasma membranes. Larger, water-soluble compounds can cross the capillary walls only by active or passive transport.

The restricted permeability of the endothelial lining of brain capillaries is in some way dependent on chemicals secreted by astrocytes—cells that are in close contact with CNS capillaries. ⮌ p. 381 The outer surfaces of the endothelial cells are covered by the processes of astrocytes. Because the astrocytes release chemicals that control the permeabilities of the endothelium to various substances, these cells play a key supporting role in the blood–brain barrier. If the astrocytes are damaged or stop stimulating the endothelial cells, the blood–brain barrier disappears.

The choroid plexus is not part of the neural tissue of the brain, so no astrocytes are in contact with the endothelial cells there. Substances do not have free access to the CNS, because specialized ependymal cells create a **blood–CSF barrier.** These cells, also interconnected by tight junctions, surround the capillaries of the choroid plexus.

Transport across the blood–brain and blood–CSF barriers is selective and directional. Even the passage of small ions, such as sodium, hydrogen, potassium, or chloride, is controlled. As a result, the pH and concentrations of sodium, potassium, calcium, and magnesium ions in the blood and CSF are different. Some organic compounds are readily transported, and others cross only in very small amounts. Neurons have a constant need for glucose that must be met regardless of the concentrations in the blood and interstitial fluid. Even when circulating glucose levels are low, endothelial cells continue to transport glucose from the blood to the interstitial fluid of the brain. In contrast, only trace amounts of circulating norepinephrine, epinephrine, dopamine, and serotonin pass into the interstitial fluid or CSF of the brain. This limitation is important, because these compounds are neurotransmitters—their entry from the bloodstream (where concentrations can be relatively high) could result in the uncontrolled stimulation of neurons throughout the brain.

The blood–brain barrier remains intact throughout the CNS, with four noteworthy exceptions:

1. In portions of the hypothalamus, the capillary endothelium is extremely permeable. This permeability exposes hypothalamic nuclei to circulating hormones and permits the diffusion of hypothalamic hormones into the circulation.
2. Capillaries in the posterior lobe of the pituitary gland, which is continuous with the floor of the hypothalamus, are highly permeable. At this site, the hormones antidiuretic hormone and *oxytocin*, produced by hypothalamic neurons, are released into the circulation.
3. Capillaries in the *pineal gland* are also very permeable. The pineal gland, an endocrine structure, is located on the posterior, superior surface of the diencephalon. The capillary permeability allows pineal secretions into the general circulation.
4. Capillaries at the choroid plexus are extremely permeable. Although the capillary characteristics of the blood–brain barrier are lost there, the transport activities of specialized ependymal cells in the choroid plexus maintain the blood–CSF barrier.

Physicians must sometimes get specific compounds into the interstitial fluid of the brain to fight CNS infections or to treat other neural disorders. To do this, they must understand the limitations of the blood–brain barrier and blood–CSF barrier. For example, when considering possible treatments, the antibiotic *tetracycline* isn't used to treat meningitis or other CNS infections because this drug is excluded from the brain, whereas *sulfisoxazole* and *sulfadiazine* enter the CNS very rapidly. Sometimes, chemotherapeutic drugs or imaging dyes may be injected directly into the CSF by lumbar puncture.

Checkpoint

4. **From superficial to deep, name the layers that make up the cranial meninges.**
5. **What would happen if the normal circulation or reabsorption of CSF were blocked?**
6. **How would decreased diffusion across the arachnoid granulations affect the volume of cerebrospinal fluid in the ventricles?**
7. **Many water-soluble molecules that are abundant in the blood occur in small amounts or not at all in the extracellular fluid of the brain. Why?**

See the blue Answers tab at the back of the book.

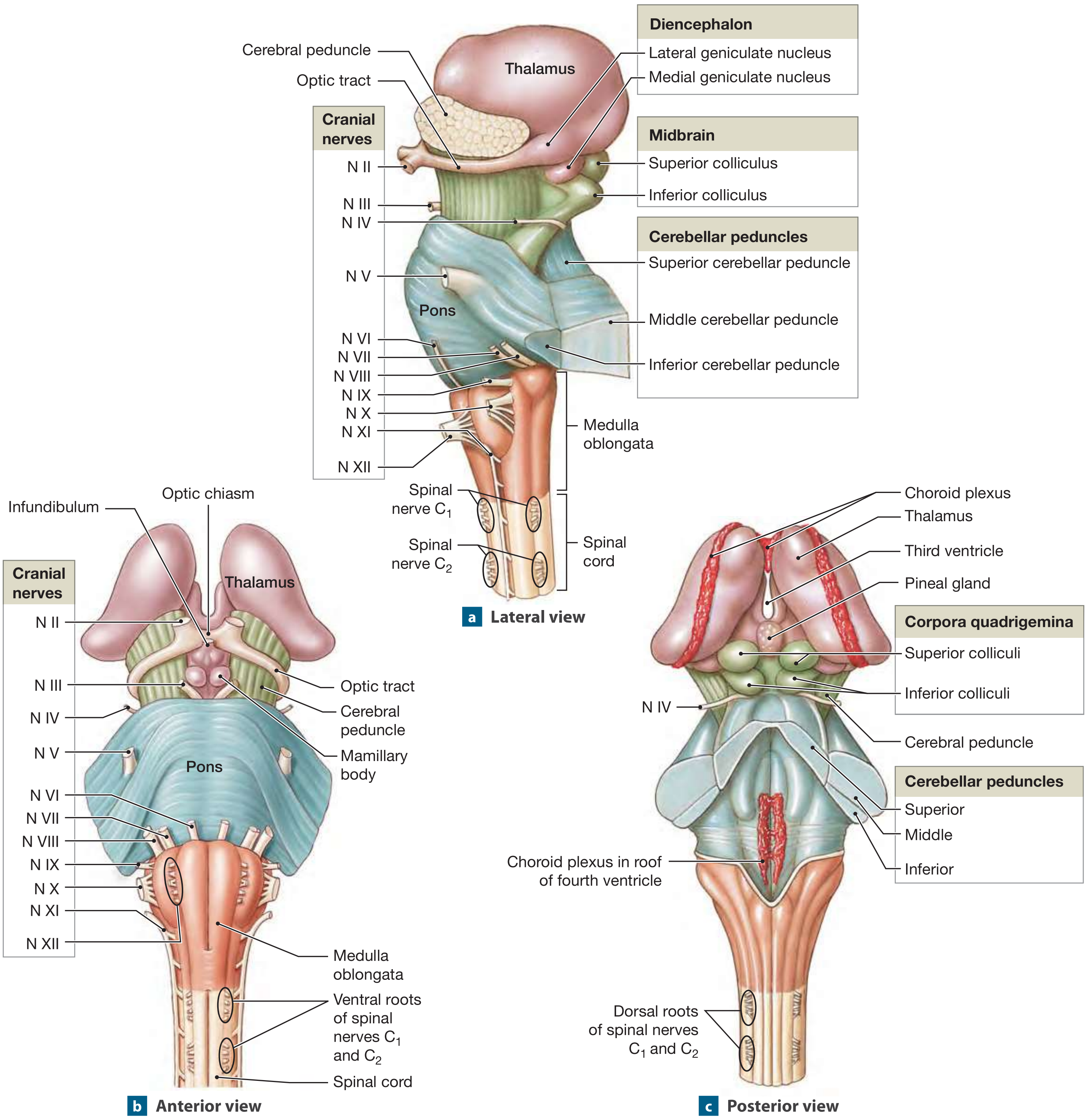
14-3 ◗ The medulla oblongata, which is continuous with the spinal cord, contains vital centers

The medulla oblongata is the most inferior of the brain regions. **Figure 14–5** shows the position of the medulla oblongata in relation to the other components of the brain stem and the diencephalon. It also illustrates the attachment sites for 11 of the 12 pairs of cranial nerves. The individual cranial nerves are identified by a capital N followed by a Roman numeral. (The full names and functions of these nerves are introduced in a later section.)

In sectional view, the inferior portion of the medulla oblongata resembles the spinal cord, with a small central canal. However, the gray matter and white matter organization is more complex. As one ascends the medulla oblongata, the central canal opens into the fourth ventricle, and the similarity to the spinal cord all but disappears.

The medulla oblongata is a very busy place—all communication between the brain and spinal cord involves tracts that ascend or descend through the medulla oblongata. In addition, the medulla oblongata is a center for the coordination of complex autonomic reflexes and the control of visceral functions.

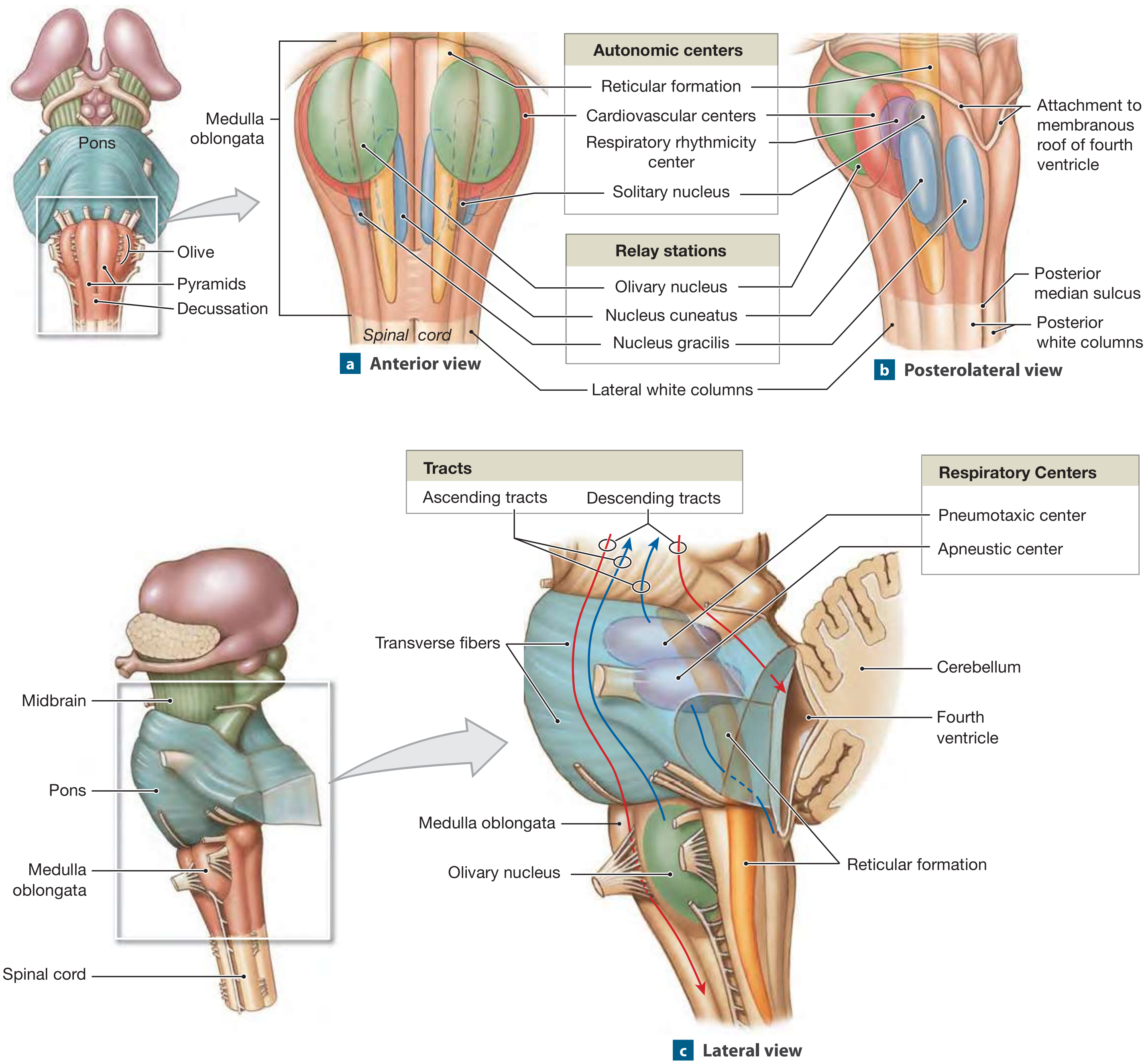
Figure 14–5 The Diencephalon and Brain Stem.



The medulla oblongata (**Figure 14–6a,b**) includes three groups of nuclei that we will encounter in later chapters:

1. *Autonomic Nuclei Controlling Visceral Activities.* The **reticular formation** is a loosely organized mass of gray matter that contains embedded nuclei. It extends from the medulla oblongata to the midbrain. The portion of the reticular formation in the medulla oblongata contains nuclei and centers that regulate vital autonomic functions. These **reflex centers** receive inputs from cranial nerves, the cerebral cortex, and the brain stem. Their output controls or adjusts the

Figure 14–6 **The Medulla Oblongata and Pons.** ATLAS: Plates 9a–c; 11c



activities of one or more peripheral systems. There are two major groups of reflex centers. The **cardiovascular centers** adjust the heart rate, the strength of cardiac contractions, and the flow of blood through peripheral tissues. (In terms of function, the cardiovascular centers are subdivided into **cardiac** and **vasomotor centers,** but their anatomical boundaries are difficult to determine.) The **respiratory rhythmicity centers** set the basic pace for respiratory movements. Their activity is regulated by inputs from the apneustic and pneumotaxic centers of the pons.

2. *Sensory and Motor Nuclei of Cranial Nerves.* The medulla oblongata contains sensory and motor nuclei associated with five of the cranial nerves (VIII, IX, X, XI, and XII). These cranial nerves provide motor commands to muscles of the pharynx, neck, and back as well as to the visceral organs of the thoracic and peritoneal cavities. Cranial nerve VIII carries sensory information from receptors in the internal ear to the vestibular and cochlear nuclei, which extend from the pons into the medulla oblongata.

3. *Relay Stations along Sensory and Motor Pathways.* The **nucleus gracilis** and the **nucleus cuneatus** pass somatic sensory information to the thalamus. Tracts leaving these nuclei cross to the opposite side of the brain before reaching their destinations. This crossing over is called *decussation* (dē-kuh-SĀ-shun; *decussatio*, crossing over). The **solitary nucleus** on either side receives visceral sensory information that reaches the CNS from the spinal nerves and cranial nerves. This information is integrated and forwarded to other autonomic centers in the medulla oblongata and elsewhere. The **olivary nuclei** relay information to the cerebellar cortex about somatic motor commands as they are issued by motor centers at higher levels. The bulk of the olivary nuclei create the **olives,** prominent olive-shaped bulges along the ventrolateral surface of the medulla oblongata.

Table 14–2 summarizes the major components of the medulla oblongata and pons.

Checkpoint

8. **Identify the components of the medulla oblongata that are responsible for relaying somatic sensory information to the thalamus.**
9. **The medulla oblongata is one of the smallest sections of the brain, yet damage there can cause death, whereas similar damage in the cerebrum might go unnoticed. Why?**

See the blue Answers tab at the back of the book.

14-4 The pons contains nuclei and tracts that carry or relay sensory and motor information

The pons links the cerebellum with the midbrain, diencephalon, cerebrum, and spinal cord. Important features and regions of the pons are indicated in **Figures 14–5** and **14–6c** and **Table 14–2**. The pons contains four groups of components:

1. *Sensory and Motor Nuclei of Cranial Nerves.* These cranial nerves (V, VI, VII, and VIII) innervate the jaw muscles, the anterior surface of the face, one of the extrinsic eye muscles (the lateral rectus), and the sense organs of the internal ear (the *vestibular* and *cochlear nuclei*).
2. *Nuclei Involved with the Control of Respiration.* On each side of the pons, the reticular formation in this region contains two respiratory centers: the *apneustic center* and the *pneumotaxic center*. These centers modify the activity of the *respiratory rhythmicity center* in the medulla oblongata.
3. *Nuclei and Tracts That Process and Relay Information Sent to or from the Cerebellum.* The pons links the cerebellum with the brain stem, cerebrum, and spinal cord.
4. *Ascending, Descending, and Transverse Tracts.* Longitudinal tracts interconnect other portions of the CNS. The middle cerebellar peduncles are connected to the **transverse fibers,** which cross the anterior surface of the pons. These

Table 14–2 Components and Functions of the Medulla Oblongata and Pons

Region/Subdivision	Component	Function
MEDULLA OBLONGATA		
Gray matter	**Nucleus gracilis** **Nucleus cuneatus**	Relay somatic sensory information to the thalamus
	Olivary nuclei	Located within the olives; relay information from the red nucleus, other nuclei of the midbrain, and the cerebral cortex to the cerebellum
	Solitary nucleus	Integrates and relays visceral sensory information to autonomic processing centers
	Reflex centers	
	Cardiac centers	Regulate heart rate and force of contraction
	Vasomotor centers	Regulate distribution of blood flow
	Respiratory rhythmicity centers	Set the pace of respiratory movements
	Other nuclei/centers	Contain sensory and motor nuclei of cranial nerves VIII (in part), IX, X, XI (in part), and XII; relay ascending sensory information from the spinal cord to higher centers
White matter	**Ascending and descending tracts**	Link the brain with the spinal cord
PONS		
Gray matter	**Nuclei associated with cranial nerves V, VI, VII, and VIII (in part)**	Relay sensory information and issue somatic motor commands
	Apneustic and pneumotaxic centers	Adjust activities of the respiratory rhythmicity centers in the medulla oblongata
	Relay centers	Relay sensory and motor information to the cerebellum
White matter	**Ascending tracts**	Carry sensory information from the nucleus cuneatus and nucleus gracilis to the thalamus
	Descending tracts	Carry motor commands from higher centers to motor nuclei of cranial or spinal nerves

fibers are axons that link nuclei of the pons (*pontine nuclei*) with the cerebellar hemisphere of the opposite side.

Checkpoint

10. **Name the four groups of components found in the pons.**
11. **If the respiratory centers of the pons were damaged, what respiratory controls might be lost?**

See the blue Answers tab at the back of the book.

14-5 The cerebellum coordinates learned and reflexive patterns of muscular activity at the subconscious level

14

The cerebellum (**Figure 14–7** and **Table 14–3**) is an automatic processing center. It has two primary functions:

1. *Adjusting the Postural Muscles of the Body.* The cerebellum coordinates rapid, automatic adjustments that maintain balance and equilibrium. These alterations in muscle tone and position are made by modifying the activities of motor centers in the brain stem.
2. *Programming and Fine-Tuning Movements Controlled at the Conscious and Subconscious Levels.* The cerebellum refines learned movement patterns. This function is performed indirectly by regulating activity along motor pathways at the cerebral cortex, basal nuclei, and motor centers in the brain stem. The cerebellum compares the motor commands with proprioceptive information (position sense) and stimulates any adjustments needed to make the movement smooth.

The cerebellum has a complex, highly convoluted surface composed of neural cortex. The **folia** (FŌ-lē-uh; leaves), or folds of the cerebellum surface, are less prominent than the folds in the surfaces of the cerebral hemispheres (**Figure 14–7a**). The **primary fissure** separates the **anterior** and **posterior lobes.** Along the midline, a narrow band of cortex known as the **vermis** (VER-mis) separates the **cerebellar hemispheres.** The slender **flocculonodular** (flok-ū-lō-NOD-ū-lar) **lobe** lies between the roof of the fourth ventricle and the cerebellar hemispheres and vermis (**Figure 14–7b**).

Like the cerebrum, the cerebellum has a superficial layer of neural cortex. The cerebellar cortex contains huge, highly branched **Purkinje** (pur-KIN-jē) **cells.** The extensive dendrites of each Purkinje cell receive input from up to 200,000 synapses. The internal white matter of the cerebellum forms a branching array that in sectional view resembles a tree. Anatomists call it the **arbor vitae,** or "tree of life" (**Figure 14–7b**).

The cerebellum receives proprioceptive information from the spinal cord and monitors all proprioceptive, visual, tactile, balance, and auditory sensations received by the brain. Most axons that carry sensory information do not synapse in the cerebellar nuclei but pass through the deeper layers of the cerebellum on their way to the Purkinje cells of the cerebellar cortex. Information about the motor commands issued at the conscious and subconscious levels reaches the Purkinje cells indirectly, after being relayed by nuclei in the pons or by the **cerebellar nuclei** embedded within the arbor vitae.

Tracts that link the cerebellum with the brain stem, cerebrum, and spinal cord leave the cerebellar hemispheres as the superior, middle, and inferior cerebellar peduncles. The **superior cerebellar peduncles** link the cerebellum with nuclei in the midbrain, diencephalon, and cerebrum. The **middle cerebellar peduncles** are connected to a broad band of fibers that cross the ventral surface of the pons at right angles to the axis of the brain stem. The middle cerebellar peduncles also connect the cerebellar hemispheres with sensory and motor nuclei in the pons. The **inferior cerebellar peduncles** communicate between the cerebellum and nuclei in the medulla oblongata and carry ascending and descending cerebellar tracts from the spinal cord.

The cerebellum can be permanently damaged by trauma or stroke, or temporarily affected by drugs such as alcohol. The result is **ataxia** (a-TAK-sē-uh; *ataxia*, lack of order), a disturbance in muscular coordination. In severe ataxia, the individual cannot sit or stand without assistance.

Checkpoint

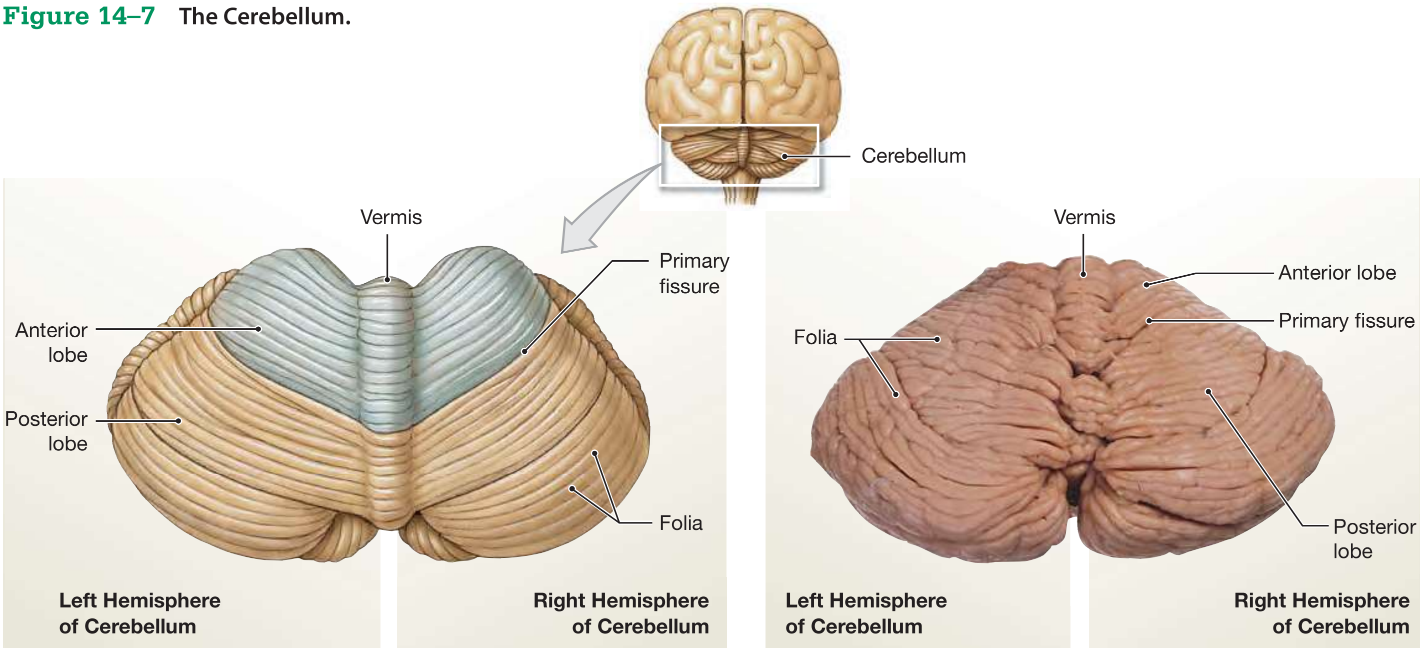
12. **Identify the components of the cerebellar gray matter.**
13. **What part of the brain has the arbor vitae? What is its function?**

See the blue Answers tab at the back of the book.

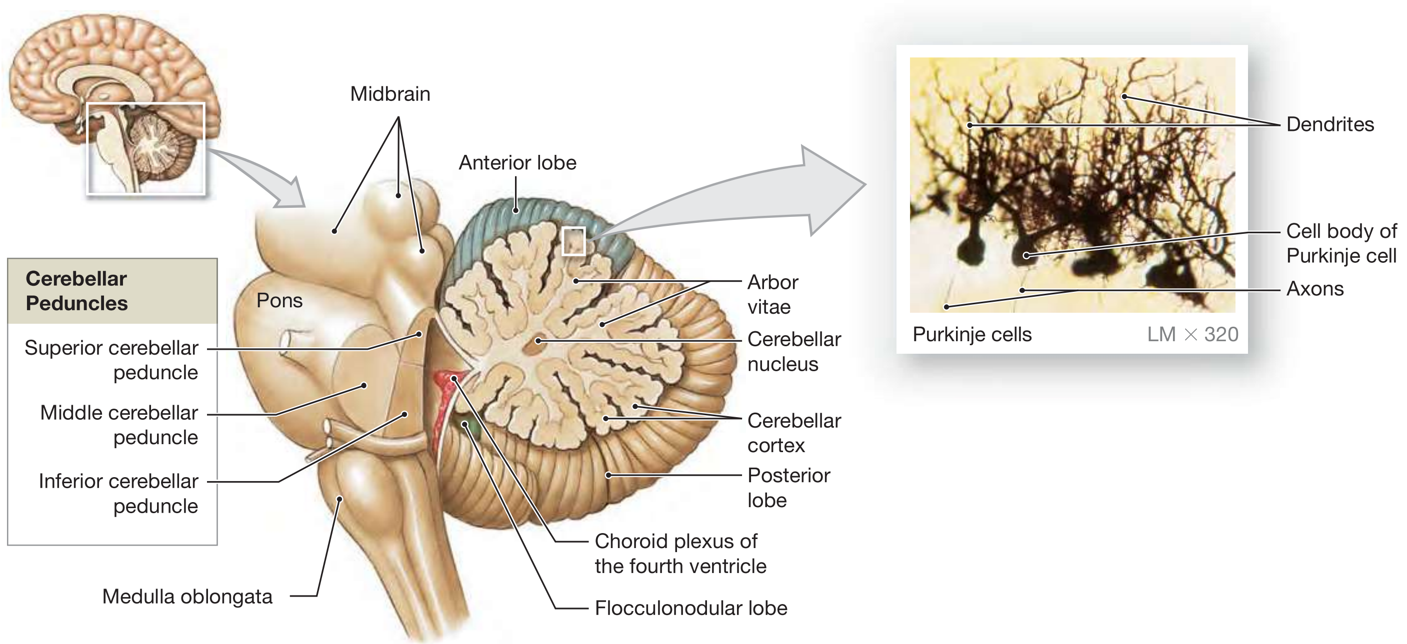
14-6 The midbrain regulates auditory and visual reflexes and controls alertness

The external anatomy of the midbrain is shown in **Figure 14–5**, and the major nuclei are listed in **Table 14–4** and shown in **Figure 14–8**. The **tectum,** or roof of the midbrain, is the region posterior to the cerebral aqueduct. It contains two pairs of sensory nuclei known collectively as the **corpora quadrigemina** (KOR-pōr-uh qua-dri-JEM-i-nuh). These nuclei, the superior and inferior colliculi, process visual and auditory sensations. Each **superior colliculus** (ko-LIK-ū-lus; *colliculus*, hill) receives visual inputs from the lateral geniculate nucleus of the

Figure 14–7 **The Cerebellum.**



a The posterior, superior surface of the cerebellum, showing major anatomical landmarks and regions



b A sectional view of the cerebellum, showing the arrangement of gray matter and white matter

14

Table 14–3 **Components of the Cerebellum**

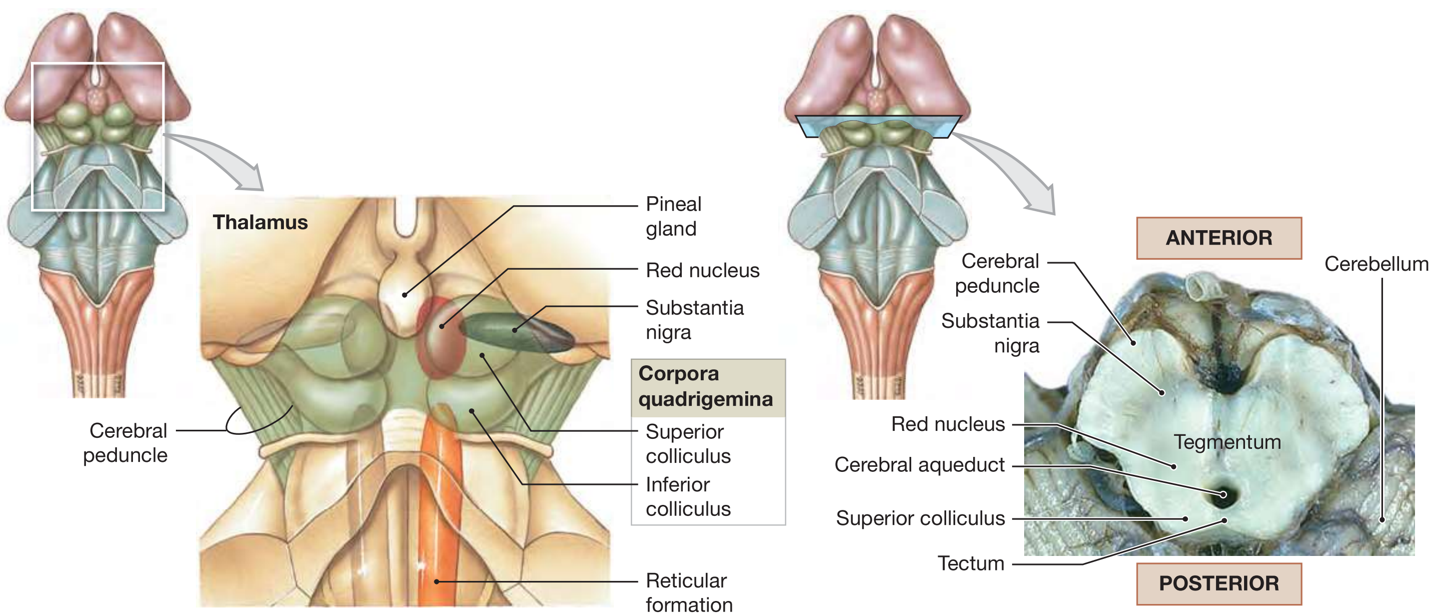
Subdivision	Region/Nuclei	Function
Gray matter	**Cerebellar cortex**	Involuntary coordination and control of ongoing body movements
	Cerebellar nuclei	Involuntary coordination and control of ongoing body movements
White matter	**Arbor vitae**	Connects cerebellar cortex and nuclei with cerebellar peduncles
	Cerebellar peduncles	
	Superior	Link the cerebellum with midbrain, diencephalon, and cerebrum
	Middle	Contain transverse fibers and carry communications between the cerebellum and pons
	Inferior	Link the cerebellum with the medulla oblongata and spinal cord
	Transverse fibers	Interconnect pontine nuclei with the cerebellar hemisphere on the opposite side

thalamus on that side. Each **inferior colliculus** receives auditory data from nuclei in the medulla oblongata and pons. Some of this information may be forwarded to the medial geniculate on the same side. The superior colliculi control the reflex movements of the eyes, head, and neck in response to visual stimuli, such as a bright light. The inferior colliculi control reflex movements of the head, neck, and trunk in response to auditory stimuli, such as a loud noise.

The area anterior to the cerebral aqueduct is called the **tegmentum.** On each side, the tegmentum contains a red nucleus and the substantia nigra (**Figure 14–8a**). The **red nucleus** contains numerous blood vessels, which give it a rich red color. This nucleus, which receives information from the cerebrum and cerebellum, issues subconscious motor commands that affect upper limb position and background muscle tone. The **substantia nigra** (NĪ-gruh; *nigra*, black) is a nucleus that lies lateral to the red nucleus. The gray matter in this region contains darkly pigmented cells, giving it a black color.

The nerve fiber bundles on the ventrolateral surfaces of the midbrain (**Figures 14–5** and **14–8b**) are the **cerebral peduncles** (*peduncles*, little feet). They contain (1) descending fibers that go to the cerebellum by way of the pons and (2) descending fibers that carry voluntary motor commands issued by the cerebral hemispheres.

Figure 14–8 **The Midbrain.** ATLAS: Plates 7b; 9a–c; 11c; 12a,c



a A posterior view. The underlying nuclei are colored only on the right.

b A superior view of a transverse section at the level of the midbrain.

Table 14–4 Components and Functions of the Midbrain

Subdivision	Region/Nuclei	Function
Gray Matter		
Tectum (roof)	Superior colliculi	Integrate visual information with other sensory inputs; initiate reflex responses to visual stimuli
	Inferior colliculi	Relay auditory information to medial geniculate nuclei; initiate reflex responses to auditory stimuli
Walls and floor	Red nuclei Substantia nigra	Subconscious control of upper limb position and background muscle tone Regulates activity in the basal nuclei
	Reticular formation (headquarters)	Automatic processing of incoming sensations and outgoing motor commands; can initiate involuntary motor responses to stimuli; helps maintain consciousness (RAS)
	Other nuclei/centers	Nuclei associated with two cranial nerves (III, IV)
White Matter	Cerebral peduncles	Connect primary motor cortex with motor neurons in brain and spinal cord; carry ascending sensory information to thalamus

The midbrain also contains the headquarters of the *reticular activating system (RAS)*, a specialized component of the reticular formation. Stimulation of this region makes you more alert and attentive. We will consider the role of the RAS in the maintenance of consciousness in Chapter 16.

Checkpoint

14. **Identify the sensory nuclei within the corpora quadrigemina.**
15. **Which area of the midbrain controls reflexive movements of the eyes, head, and neck in response to visual stimuli?**

See the blue Answers tab at the back of the book.

14-7 The diencephalon integrates sensory information with motor output at the subconscious level

The diencephalon is a division of the brain that consists of the epithalamus, thalamus, and hypothalamus. **Figure 14–5** shows its position and its relationship to landmarks on the brain stem.

The *epithalamus* is the roof of the diencephalon superior to the third ventricle. The anterior portion of the epithalamus contains an extensive area of choroid plexus that extends through the interventricular foramina into the lateral ventricles. The posterior portion of the epithalamus contains the **pineal gland** (**Figure 14–5c**), an endocrine structure that secretes the hormone **melatonin.** Melatonin is important in the regulation of day–night cycles and also in the regulation of reproductive functions. (We will describe the role of melatonin in Chapter 18.)

Most of the neural tissue in the diencephalon is concentrated in the *left thalamus* and *right thalamus*, which form the lateral walls, and the *hypothalamus*, which forms the floor. Ascending sensory information from the spinal cord and cranial nerves (other than the olfactory tract) synapses in a nucleus in the left or right thalamus before reaching the cerebral cortex and our conscious awareness. The hypothalamus contains centers involved with emotions and visceral processes that affect the cerebrum as well as other components of the brain stem. It also controls a variety of autonomic functions and forms the link between the nervous and endocrine systems.

The Thalamus

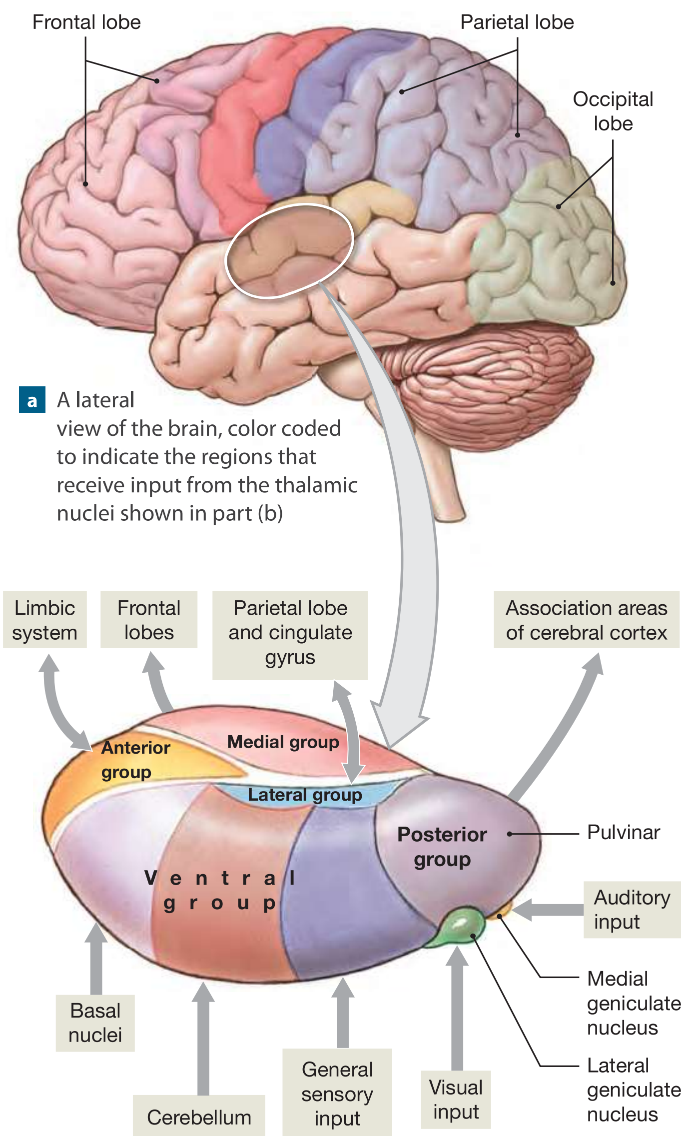
On each side of the diencephalon, the thalamus is the final relay point for ascending sensory information that will be projected to the primary sensory cortex. It acts as a filter, passing on only a small portion of the arriving sensory information. The thalamus also coordinates the activities of the basal nuclei and the cerebral cortex by relaying information between them.

The third ventricle separates the left thalamus and right thalamus. Each thalamus consists of a rounded mass of *thalamic nuclei* (**Figure 14–9**). Viewed in a midsagittal section through the brain (**Figure 14–10b**), each thalamus extends from the anterior commissure to the inferior base of the pineal gland. A projection of gray matter called an **interthalamic adhesion** extends into the ventricle from the thalamus on either side (**Figures 14–10** and **14–11**), although no fibers cross the midline.

Functions of Thalamic Nuclei

The thalamic nuclei deal primarily with the relay of sensory information to the basal nuclei and cerebral cortex. The five major groups of thalamic nuclei, shown in **Figure 14–9b** and

Figure 14–9 The Thalamus.



a A lateral view of the brain, color coded to indicate the regions that receive input from the thalamic nuclei shown in part (b)

b An enlarged view of the thalamic nuclei of the left side

14

Table 14–5 The Thalamus	
Group/Nuclei	**Function**
Anterior Group	Part of the limbic system
Medial Group	Integrates sensory information for projection to the frontal lobes
Ventral Group	Projects sensory information to the primary sensory cortex; relays information from cerebellum and basal nuclei to motor area of cerebral cortex
Posterior Group	
Pulvinar	Integrates sensory information for projection to association areas of cerebral cortex
Lateral geniculate nuclei	Project visual information to the visual cortex
Medial geniculate nuclei	Project auditory information to the auditory cortex
Lateral Group	Integrates sensory information and influences emotional states

listed in **Table 14–5**, are the anterior, medial, ventral, posterior, and lateral groups:

1. The *anterior group* includes the **anterior nuclei,** which are part of the *limbic system*. This system, which is involved with emotion and motivation, is discussed in a later section.
2. The nuclei of the *medial group* provide an awareness of emotional states by connecting emotional centers in the hypothalamus with the *frontal lobes* of the cerebral hemispheres. The medial group also receives and relays sensory information from other portions of the thalamus.
3. The nuclei of the *ventral group* relay information from the *basal nuclei* of the cerebrum and the cerebellum to somatic motor areas of the cerebral cortex. Ventral group nuclei also relay sensory information about touch, pressure, pain, temperature, and proprioception (position) to the sensory areas of the cerebral cortex.
4. The *posterior group* includes the pulvinar and the geniculate nuclei. The **pulvinar** integrates sensory information for projection to the cerebral cortex. The **lateral geniculate** (je-NIK-ū-lāt; *genicula*, little knee) **nucleus** of each thalamus receives visual information over the *optic tract*, which originates at the eyes. The output of the lateral geniculate nucleus goes to the *occipital lobes* of the cerebral hemispheres and to the midbrain. The **medial geniculate nucleus** relays auditory information to the appropriate area of the cerebral cortex from specialized receptors of the internal ear.
5. The nuclei of the *lateral group* form feedback loops with the limbic system and the *parietal lobes* of the cerebral hemispheres. The lateral group affects emotional states and the integration of sensory information.

The Hypothalamus

The hypothalamus (**Figure 14–10a**) extends from the area superior to the *optic chiasm*, a crossover where the optic tracts from the eyes arrive at the brain, to the posterior margins of the **mamillary** (*mamilla*, little breast) **bodies.** The mamillary bodies process sensory information, including olfactory sensations. They also contain motor nuclei that control reflex movements associated with eating, such as chewing, licking, and swallowing.

Immediately posterior to the optic chiasm, a narrow stalk called the **infundibulum** (in-fun-DIB-ū-lum; *infundibulum*, funnel) extends inferiorly, connecting the floor of the hypothalamus to the pituitary gland (**Figure 14–10b**).

The floor of the hypothalamus between the infundibulum and the mamillary bodies is the **tuberal area** (*tuber*, swelling). The tuberal area contains nuclei that are involved with the control of pituitary gland function.

Functions of the Hypothalamus

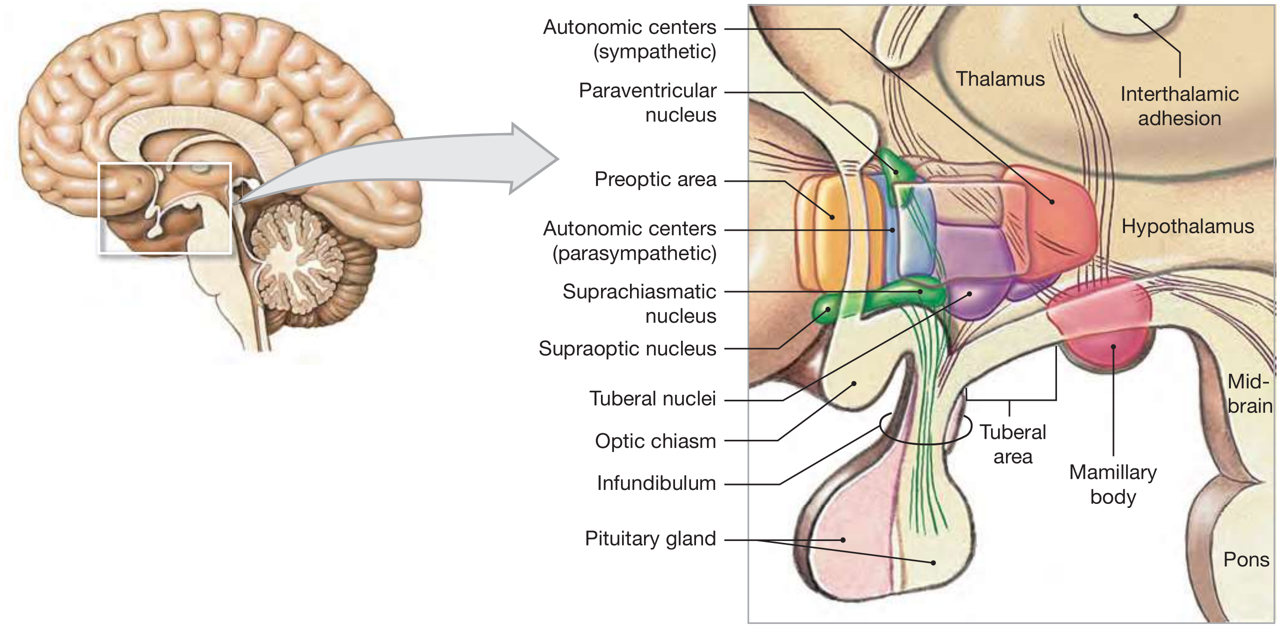
The hypothalamus contains important control and integrative centers, in addition to those associated with the limbic system. These centers are shown in **Figure 14–10a**, and their functions are summarized in **Table 14–6**. Hypothalamic centers may be stimulated by (1) sensory information from the cerebrum, brain stem, and spinal cord; (2) changes in the compositions of the CSF and interstitial fluid; or (3) chemical stimuli in the circulating blood that move rapidly across highly permeable capillaries to enter the hypothalamus (where there is no blood–brain barrier).

The hypothalamus performs the following functions:

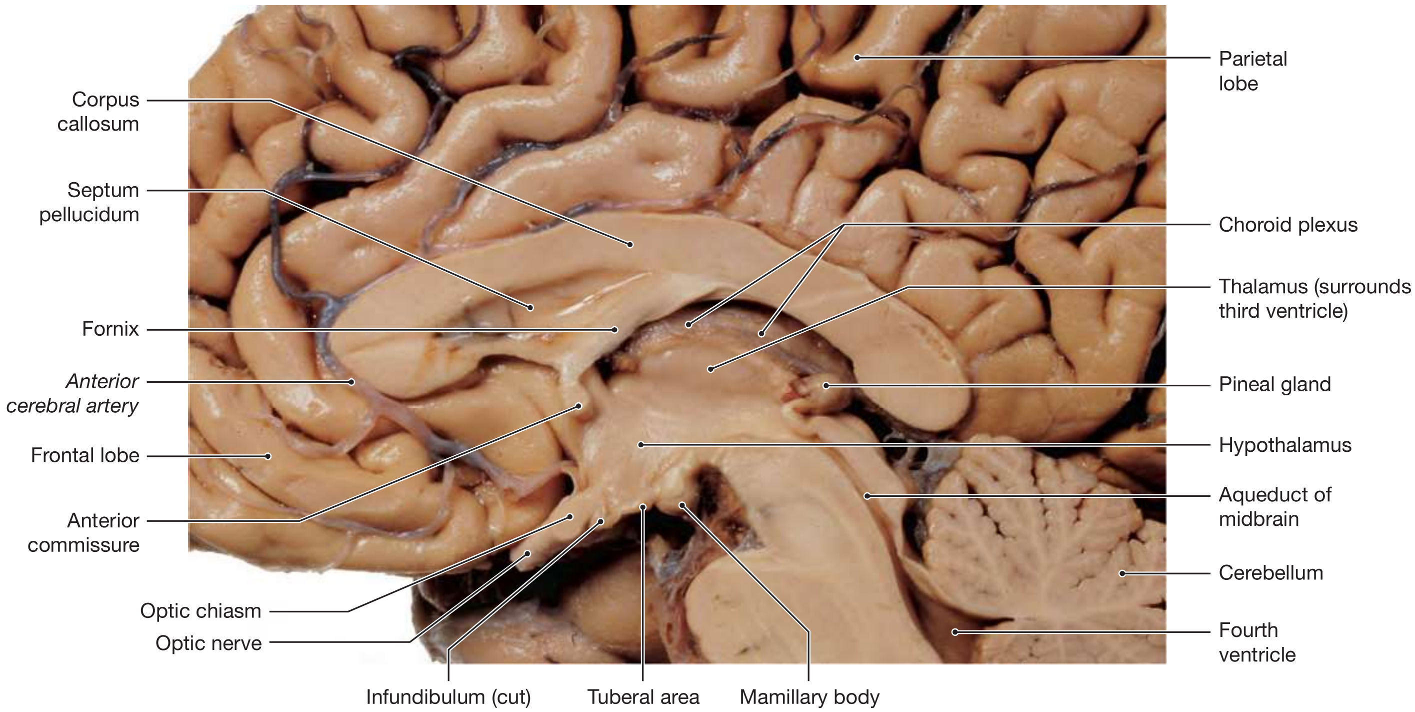
1. *The Subconscious Control of Skeletal Muscle Contractions.* The hypothalamus directs somatic motor patterns associated with rage, pleasure, pain, and sexual arousal by stimulating centers in other portions of the brain. For example, hypothalamic centers control the changes in facial expression that accompany rage and the basic movements associated with sexual activity.
2. *The Control of Autonomic Function.* The hypothalamus adjusts and coordinates the activities of autonomic centers in the pons and medulla oblongata that regulate heart rate, blood pressure, respiration, and digestive functions.
3. *The Coordination of Activities of the Nervous and Endocrine Systems.* The hypothalamus coordinates neural and endocrine activities by inhibiting or stimulating endocrine cells in the pituitary gland through the production of *regulatory hormones*. These hormones are produced at the tuberal area and are released into local capillaries for transport to the anterior lobe of the pituitary gland.

4. *The Secretion of Two Hormones.* The hypothalamus secretes *antidiuretic hormone* (ADH, also called vasopressin) and *oxytocin* (OXT). ADH is produced by the **supraoptic nucleus** and restricts water loss by the kidneys. Oxytocin is produced by the **paraventricular nucleus** and stimulates smooth muscle contractions in the uterus and mammary glands of females and the prostate gland of males. These hormones are transported along axons that pass through

Figure 14–10 The Hypothalamus in Sagittal Section.



a A diagrammatic view of the hypothalamus, showing the locations of major nuclei and centers



b The hypothalamus and adjacent portions of the brain

14

Table 14–6 Components and Functions of the Hypothalamus

Region/Nucleus	Function
Mamillary bodies	Control feeding reflexes (licking, swallowing, etc.)
Autonomic centers	Control medullary nuclei that regulate heart rate and blood pressure
Tuberal nuclei	Release hormones that control endocrine cells of the anterior pituitary gland (adenohypophysis)
Supraoptic nucleus	Secretes ADH, restricting water loss by the kidneys
Paraventricular nucleus	Secretes oxytocin
Preoptic areas	Regulate body temperature
Suprachiasmatic nucleus	Coordinates day–night cycles of activity

the infundibulum to the posterior lobe of the pituitary gland. There the hormones are released into the blood for distribution throughout the body.

5. *The Production of Emotions and Behavioral Drives.* Specific hypothalamic centers produce sensations that lead to conscious or subconscious changes in behavior. For example, stimulation of the **feeding center** produces the sensation of hunger, and stimulation of the **thirst center** produces the sensation of thirst. These unfocused "impressions" originating in the hypothalamus are called **drives.** The conscious sensations are only part of the hypothalamic response. For instance, the thirst center also orders the release of ADH by neurons in the supraoptic nucleus.
6. *Coordination between Voluntary and Autonomic Functions.* When you think about a dangerous or stressful situation, your heart rate and respiratory rate go up and your body prepares for an emergency. These autonomic adjustments are made by the hypothalamus.
7. *The Regulation of Body Temperature.* The **preoptic area** of the hypothalamus coordinates the activities of other CNS centers and regulates other physiological systems to maintain normal body temperature. If body temperature falls, the preoptic area communicates with the *vasomotor center*, an autonomic center in the medulla oblongata that controls blood flow by regulating the diameter of peripheral blood vessels. In response, the vasomotor center decreases the blood supply to the skin, reducing the rate of heat loss.
8. *The Control of Circadian Rhythms.* The **suprachiasmatic nucleus** coordinates daily cycles of activity that are linked to the 24-hour day–night cycle. This nucleus receives input from the retina of the eye, and its output adjusts the activities of other hypothalamic nuclei, the pineal gland, and the reticular formation.

14

Checkpoint

16. **Name the main components of the diencephalon.**
17. **Damage to the lateral geniculate nuclei of the thalamus would interfere with the functions of which special sense?**
18. **Which component of the diencephalon is stimulated by changes in body temperature?**

See the blue Answers tab at the back of the book.

14-8 The limbic system is a group of tracts and nuclei with various functions

The **limbic system** (*limbus*, border) includes nuclei and tracts along the border between the cerebrum and diencephalon. This system is a functional grouping rather than an anatomical one. Functions of the limbic system include (1) establishing emotional states; (2) linking the conscious, intellectual functions of the cerebral cortex with the unconscious and autonomic functions of the brain stem; and (3) facilitating memory storage and retrieval. Whereas the sensory cortex, motor cortex, and association areas of the cerebral cortex enable you to perform complex tasks, it is largely the limbic system that makes you *want* to do them. For this reason, the limbic system is also known as the *motivational system*.

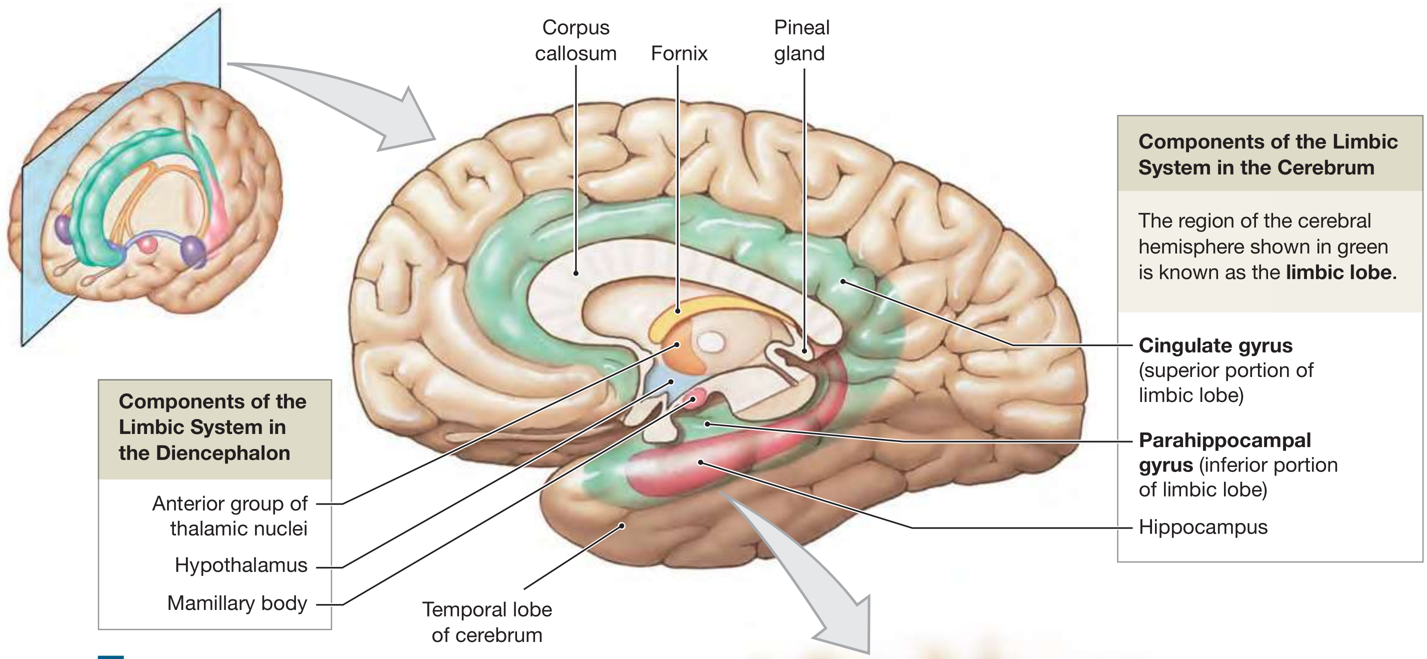
Figure 14–11 focuses on major components of the limbic system. The **amygdaloid** (ah-MIG-da-loyd; *amygdale*, almond) **body** (**Figure 14–11b**), commonly referred to as the amygdala, appears to act as an interface between the limbic system, the cerebrum, and various sensory systems. It plays a role in the regulation of heart rate, in the control of the "fight or flight" response by the sympathetic division of the ANS, and in linking emotions with specific memories. The **limbic lobe** of the cerebral hemisphere consists of the superficial folds, or *gyri*, and underlying structures adjacent to the diencephalon. The gyri curve along the *corpus callosum*, a fiber tract that links the two cerebral hemispheres, and continue on to the medial surface of the cerebrum lateral to the diencephalon (**Figure 14–11a**). There are three gyri in the limbic lobe. The **cingulate** (SIN-gū-lāt) **gyrus** (*cingulum*, girdle or belt) sits superior to the corpus callosum. The **dentate gyrus** and the **parahippocampal** (pa-ra-hip-ō-KAM-pal) **gyrus** form the posterior and inferior portions of the limbic lobe. These gyri conceal the **hippocampus,** a nucleus inferior to the floor of the lateral ventricle. To early anatomists, this structure resembled a sea horse (*hippocampus*); it is important in learning, especially in the storage and retrieval of new long-term memories.

The **fornix** (FOR-niks, arch) is a tract of white matter that connects the hippocampus with the hypothalamus (**Figures 14–11** and **14–14b**). From the hippocampus, the fornix curves medially, meeting its counterpart from the opposing hemisphere. The fornix proceeds anteriorly, inferior to the corpus callosum, before curving toward the hypothalamus. Many fibers of the fornix end in the mamillary bodies of the hypothalamus.

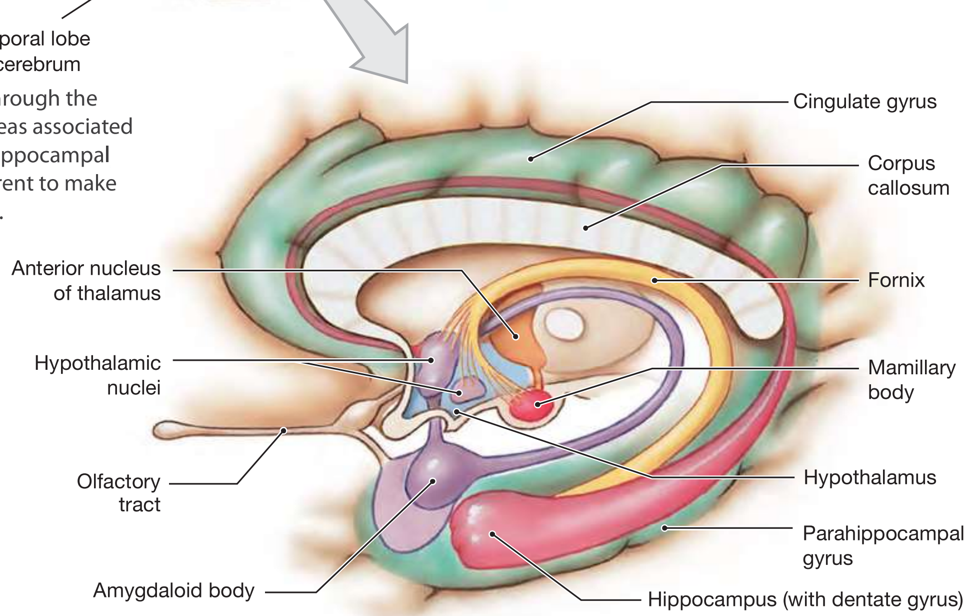
Several other nuclei in the wall (thalamus) and floor (hypothalamus) of the diencephalon are components of the limbic system. The *anterior nucleus* of the thalamus (**Figure 14–11b**) relays information from the mamillary body (of the hypothalamus) to the cingulate gyrus on that side. The boundaries between the hypothalamic nuclei of the limbic system are often poorly defined, but experimental stimulation has outlined a number of important hypothalamic centers responsible for the emotions of rage, fear, pain, sexual arousal, and pleasure. The stimulation of specific regions of the hypothalamus can also produce heightened alertness and a generalized excitement or generalized lethargy and sleep. These responses are caused by the stimulation or inhibition of the reticular formation. Although the reticular formation extends the length of the brain stem, its headquarters reside in the midbrain.

Table 14–7 summarizes the organization and functions of the limbic system.

Figure 14–11 The Limbic System.



a A diagrammatic sagittal section through the cerebrum, showing the cortical areas associated with the limbic system. The parahippocampal gyrus is shown as though transparent to make deeper limbic components visible.



b A three-dimensional reconstruction of the limbic system, showing the relationships among the major components.

Table 14–7 The Limbic System
FUNCTION
Processing of memories; creation of emotional states, drives, and associated behaviors
CEREBRAL COMPONENTS
Cortical areas: limbic lobe (cingulate gyrus, dentate gyrus, and parahippocampal gyrus)
Nuclei: hippocampus, amygdaloid body
Tracts: fornix
DIENCEPHALIC COMPONENTS
Thalamus: anterior nuclear group
Hypothalamus: centers concerned with emotions, appetites (thirst, hunger), and related behaviors (*see Table 14–6*)
OTHER COMPONENTS
Reticular formation: network of interconnected nuclei throughout brain stem

14

Checkpoint

19. **What are the primary functions of the limbic system?**
20. **Damage to the amygdaloid body would interfere with regulation of what division of the autonomic nervous system (ANS)?**

See the blue Answers tab at the back of the book.

14-9 The cerebrum, the largest region of the brain, contains motor, sensory, and association areas

The cerebrum is the largest region of the brain. Conscious thoughts and all intellectual functions originate in the cerebral hemispheres. Much of the cerebrum is involved in the processing of somatic sensory and motor information. Gray matter in the cerebrum is located in the *cerebral cortex* and in deeper *basal nuclei*. The white matter of the cerebrum lies deep to the cerebral cortex and around the basal nuclei.

The Cerebral Cortex

A layer of cerebral cortex ranging from 1 to 4.5 mm thick covers the paired cerebral hemispheres, which dominate the superior and lateral surfaces of the cerebrum. The gyri increase the surface area of the cerebral hemispheres, and thus the number of cortical neurons they contain; the total surface area of the cerebral hemispheres is roughly equivalent to 2200 cm^2 (2.5 ft^2) of flat surface. The entire brain has enlarged over the course of human evolution, but the cerebral hemispheres have enlarged at a much faster rate than has the rest of the brain, reflecting the large numbers of neurons needed for complex analytical and integrative functions. Since the neurons involved are in the superficial layer of cortex, it is there that the expansion has been most pronounced. The only solution available, other than an enlargement of the entire skull, was for the cortical layer to fold like a crumpled piece of paper.

Landmarks and features on the surface of one cerebral hemisphere are shown in **Figure 14–12a,b**. (The two cerebral hemispheres are almost completely separated by a deep **longitudinal fissure,** seen in **Figure 14–13b**.) Each cerebral hemisphere can be divided into *lobes*, or regions, named after the overlying bones of the skull. Your brain has a unique pattern of sulci and gyri, as individual as a fingerprint, but the boundaries between lobes are reliable landmarks. On each hemisphere, the **central sulcus,** a deep groove, divides the anterior **frontal lobe** from the more posterior **parietal lobe.** The horizontal **lateral sulcus** separates the frontal lobe from the **temporal lobe.** The **insula** (IN-sū-luh; *insula*, island), an "island" of cortex, lies medial to the lateral sulcus. The more posterior **parieto-occipital sulcus** separates the parietal lobe from the **occipital lobe** (**Figure 14–12c**).

Each lobe contains functional regions whose boundaries are less clearly defined. Some of these regions deal with sensory information and others with motor commands. Keep in mind three points about the cerebral lobes:

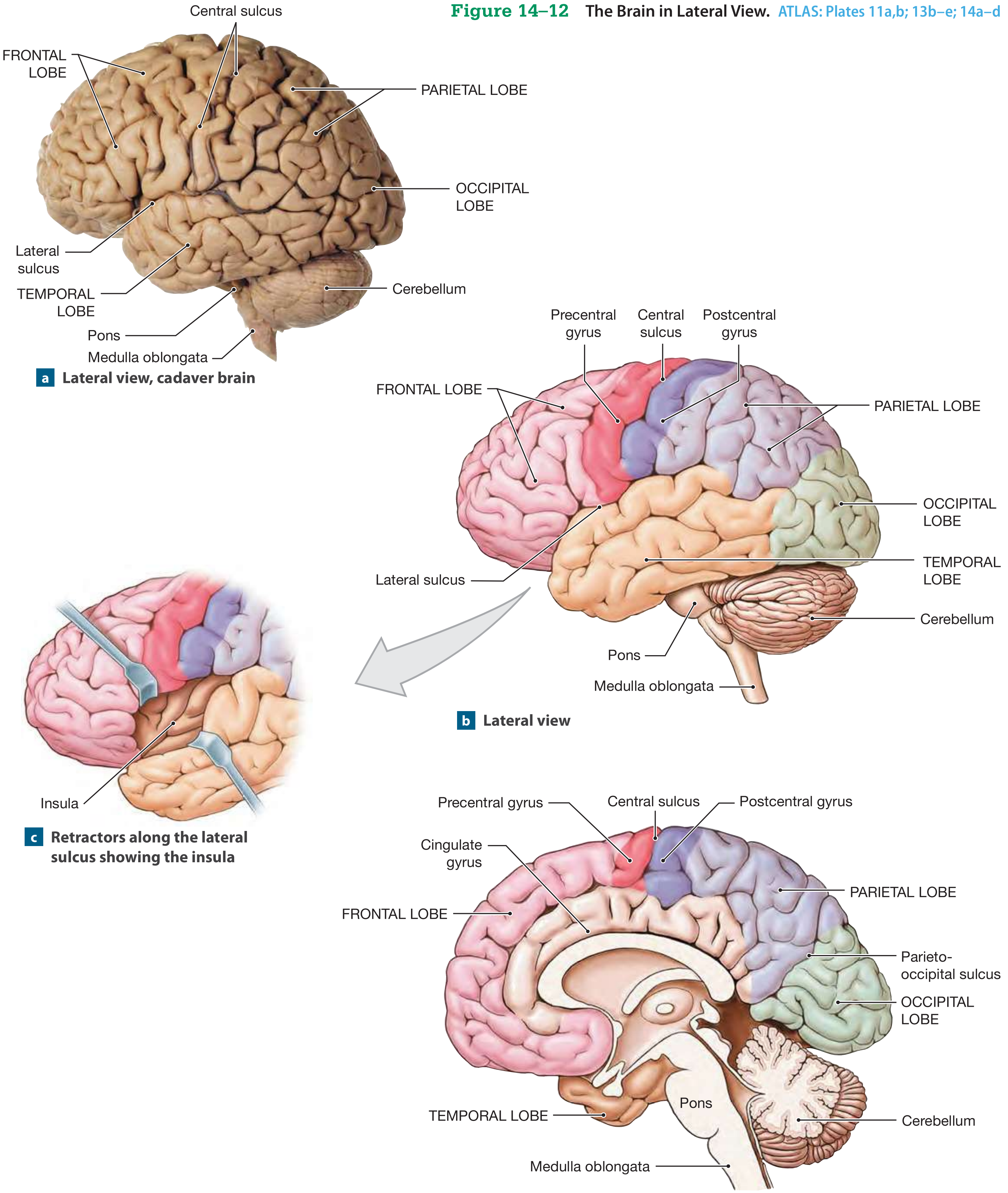
1. *Each cerebral hemisphere receives sensory information from, and sends motor commands to, the opposite side of the body.* For example, the motor areas of the left cerebral hemisphere control muscles on the right side, and the right cerebral hemisphere controls muscles on the left side. This crossing over has no known functional significance.
2. *The two hemispheres have different functions, even though they look almost identical.* We discuss these differences in a later section.
3. *The correspondence between a specific function and a specific region of the cerebral cortex is imprecise.* Because the boundaries are indistinct and have considerable overlap, one region may have several functions. Some aspects of cortical function, such as consciousness, cannot easily be assigned to any single region. However, we know that normal individuals use all portions of the brain.

The White Matter of the Cerebrum

The interior of the cerebrum consists mostly of white matter. The axons can be classified as association fibers, commissural fibers, and projection fibers (**Figure 14–13**).

- **Association fibers** interconnect areas of cerebral cortex within a single cerebral hemisphere. Shorter association fibers are called **arcuate** (AR-kū-āt) **fibers,** because they curve in an arc to pass from one gyrus to another. Longer association fibers are organized into discrete bundles, or *fasciculi*. The **longitudinal fasciculi** connect the frontal lobe to the other lobes of the same hemisphere.

Figure 14–12 The Brain in Lateral View. ATLAS: Plates 11a,b; 13b–e; 14a–d



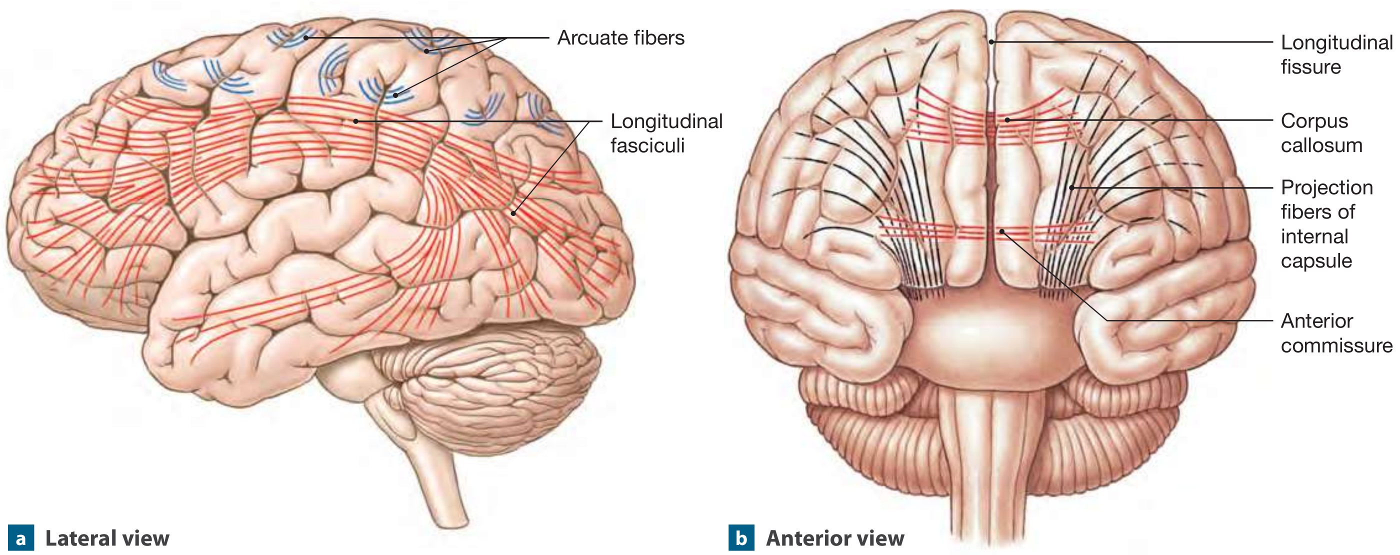
a Lateral view, cadaver brain

b Lateral view

c Retractors along the lateral sulcus showing the insula

d Midsagittal section

Figure 14–13 Fibers of the White Matter of the Cerebrum.



14

- **Commissural** (kom-i-SŪR-ul; *commissura*, crossing over) **fibers** interconnect and permit communication between the cerebral hemispheres. Bands of commissural fibers linking the hemispheres include the **corpus callosum** and the **anterior commissure.** The corpus callosum alone contains more than 200 million axons, carrying some 4 billion impulses per second!
- **Projection fibers** link the cerebral cortex to the diencephalon, brain stem, cerebellum, and spinal cord. All projection fibers must pass through the diencephalon, where axons heading to sensory areas of the cerebral cortex pass among the axons descending from motor areas of the cortex. In gross dissection, the ascending fibers and descending fibers look alike. The entire collection of projection fibers is known as the **internal capsule.**

The Basal Nuclei

While your cerebral cortex is consciously directing a complex movement or solving some intellectual puzzle, other centers of your cerebrum, diencephalon, and brain stem are processing sensory information and issuing motor commands outside your conscious awareness. Many of these activities, which occur at the subconscious level, are directed by the basal nuclei.

Anatomy of the Basal Nuclei

The **basal nuclei** are masses of gray matter that lie within each hemisphere deep to the floor of the lateral ventricle (**Figure 14–14**). They are embedded in the white matter of the cerebrum, and the radiating projection fibers and commissural fibers travel around or between these nuclei. Historically, the basal nuclei have been considered part of a larger functional group known as the *basal ganglia*. This group included the basal nuclei of the cerebrum and the associated motor nuclei in the diencephalon and midbrain. Although we will consider the functional interactions among these components in Chapter 15, we will avoid the term "basal ganglia" because ganglia are otherwise restricted to the PNS.

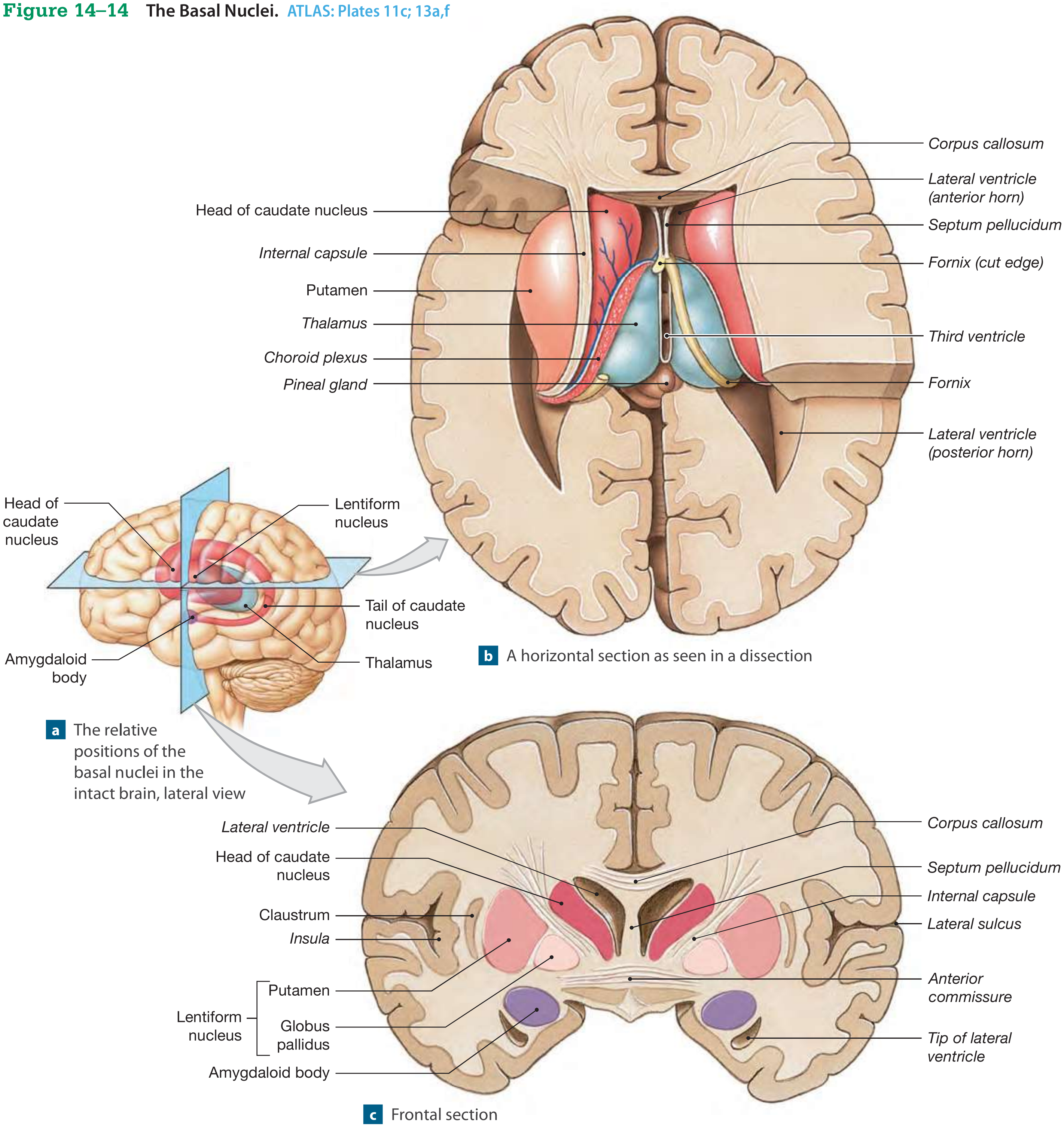
The **caudate nucleus** has a massive head and a slender, curving tail that follows the curve of the lateral ventricle. The head of the caudate nucleus lies anterior to the **lentiform nucleus.** The lentiform nucleus consists of a medial **globus pallidus** (GLŌ-bus PAL-i-dus; pale globe) and a lateral **putamen** (pū-TĀ-men). The term *corpus striatum* (striated body) has been used to refer to the caudate and lentiform nuclei, or to the caudate nucleus and putamen. The name refers to the striated (striped) appearance of the internal capsule as its fibers pass among these nuclei. The amygdaloid body, part of the limbic system, lies anterior to the tail of the caudate nucleus and inferior to the lentiform nucleus.

Functions of the Basal Nuclei

The basal nuclei are involved with the subconscious control of skeletal muscle tone and the coordination of learned movement patterns. Under normal conditions, these nuclei do not initiate particular movements. But once a movement is under way, the basal nuclei provide the general pattern and rhythm, especially for movements of the trunk and proximal limb muscles.

Information arrives at the caudate nucleus and putamen from sensory, motor, and integrative areas of the cerebral cortex. Processing occurs in these nuclei and in the adjacent globus pallidus. Most of the output of the basal nuclei leaves the globus pallidus and synapses in the thalamus. Nuclei in the thalamus

Figure 14–14 The Basal Nuclei. ATLAS: Plates 11c; 13a,f



a The relative positions of the basal nuclei in the intact brain, lateral view

b A horizontal section as seen in a dissection

c Frontal section

14

then project the information to appropriate areas of the cerebral cortex. The basal nuclei alter the motor commands issued by the cerebral cortex through this feedback loop. For example:

- When you walk, the basal nuclei control the cycles of arm and thigh movements that occur between the time you decide to "start" walking and the time you give the "stop" order.
- As you begin a voluntary movement, the basal nuclei control and adjust muscle tone, particularly in the appendicular muscles, to set your body position. When you

decide to pick up a pencil, you consciously reach and grasp with your forearm, wrist, and hand while the basal nuclei operate at the subconscious level to position your shoulder and stabilize your arm.

Activity of the basal nuclei is inhibited by neurons in the substantia nigra of the midbrain, which release the neurotransmitter *dopamine*. ⮌ p. 404 If the substantia nigra is damaged or the neurons secrete less dopamine, basal nuclei become more active. The result is a gradual, generalized increase in muscle tone and the appearance of symptoms characteristic of *Parkinson's disease*. ⮌ p. 103 People with Parkinson's disease have difficulty starting voluntary movements, because opposing muscle groups do not relax; they must be overpowered. Once a movement is under way, every aspect must be voluntarily controlled through intense effort and concentration.

Motor and Sensory Areas of the Cortex

The major motor and sensory regions of the cerebral cortex are listed in **Table 14–8** and shown in **Figure 14–15**. The central sulcus separates the motor and sensory areas of the cortex. The **precentral gyrus** of the frontal lobe forms the anterior border of the central sulcus. The surface of this gyrus is the **primary motor cortex.** Neurons of the primary motor cortex direct voluntary movements by controlling somatic motor neurons in the brain stem and spinal cord. These cortical neurons are called **pyramidal cells,** because their cell bodies resemble little pyramids.

The primary motor cortex is like the keyboard of a piano. If you strike a specific piano key, you produce a specific sound; if you stimulate a specific motor neuron in the primary motor cortex, you generate a contraction in a specific skeletal muscle.

Like the monitoring gauges in the dashboard of a car, the sensory areas of the cerebral cortex report key information. At each location, sensory information is reported in the pattern of neuron activity in the cortex. The **postcentral gyrus** of the parietal lobe forms the posterior border of the central sulcus, and its surface contains the **primary sensory cortex.** Neurons in this region receive somatic sensory information from receptors for touch, pressure, pain, vibration, taste, or temperature. We are aware of these sensations only when nuclei in the thalamus relay the information to the primary sensory cortex.

Sensations of sight, sound, smell, and taste arrive at other portions of the cerebral cortex (**Figure 14–15a**). The **visual cortex** of the occipital lobe receives visual information, and the **auditory cortex** and **olfactory cortex** of the temporal lobe receive information about hearing and smell, respectively. The **gustatory cortex,** which receives information from taste receptors of the tongue and pharynx, lies in the anterior portion of the insula and adjacent portions of the frontal lobe.

Table 14–8 The Cerebral Cortex

Lobe/Region	Function
FRONTAL LOBE	
Primary motor cortex	Voluntary control of skeletal muscles
PARIETAL LOBE	
Primary sensory cortex	Conscious perception of touch, pressure, pain, vibration, taste, and temperature
OCCIPITAL LOBE	
Visual cortex	Conscious perception of visual stimuli
TEMPORAL LOBE	
Auditory cortex and olfactory cortex	Conscious perception of auditory (hearing) and olfactory (smell) stimuli
ALL LOBES	
Association areas	Integration and processing of sensory data; processing and initiation of motor activities

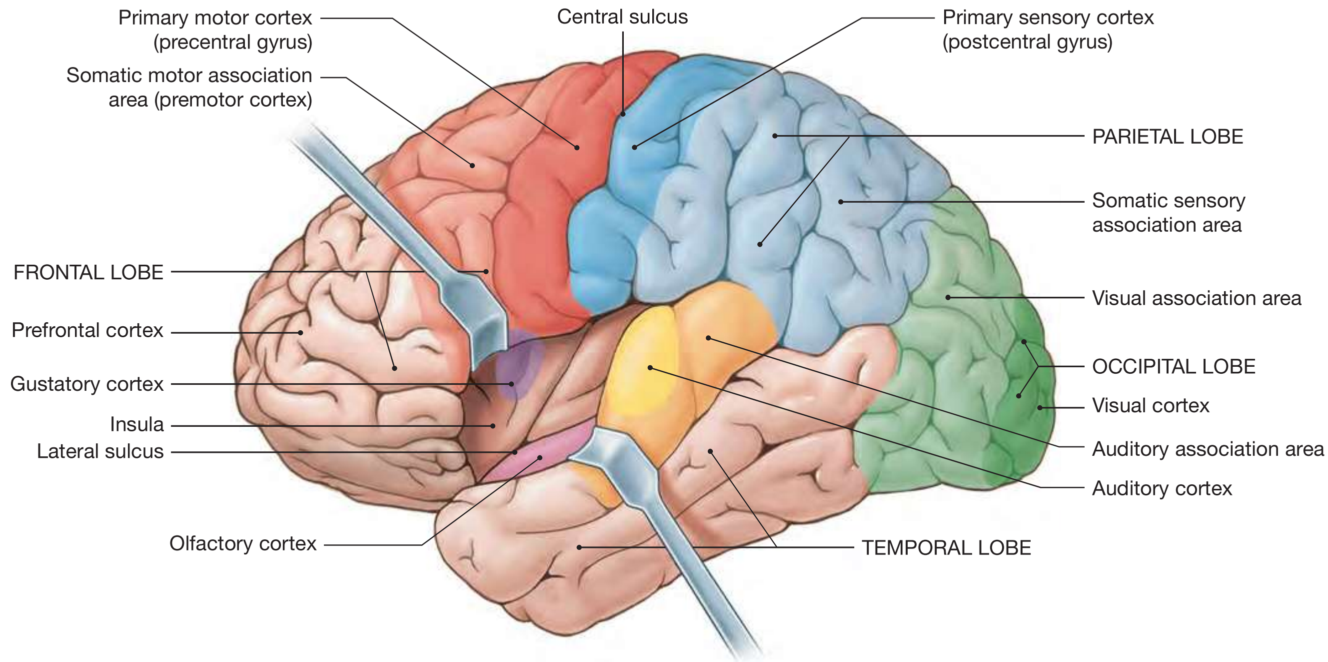
Association Areas

The sensory and motor regions of the cortex are connected to nearby **association areas,** regions of the cortex that interpret incoming data or coordinate a motor response (**Figure 14–15a**). Like the information provided by the gauges in a car, the arriving information must be noticed and interpreted before the driver can take appropriate action. *Sensory association areas* are cortical regions that monitor and interpret the information that arrives at the sensory areas of the cortex. Examples include the somatic sensory association area, visual association area, and auditory association area.

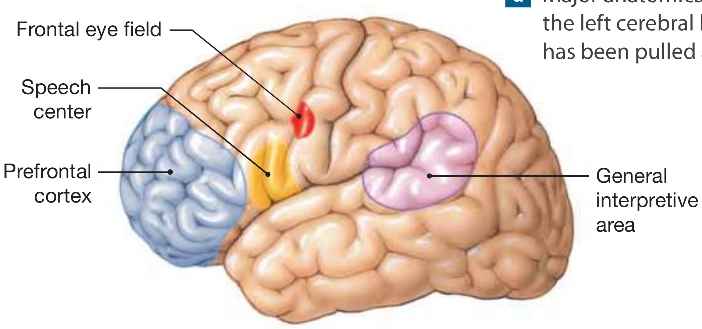
The **somatic sensory association area** monitors activity in the primary sensory cortex. It is the somatic sensory association area that allows you to recognize a touch as light as the arrival of a mosquito on your arm (and gives you a chance to swat the mosquito before it bites).

The special senses of smell, sight, and hearing involve separate areas of the sensory cortex, and each has its own association area. These areas monitor and interpret arriving sensations. For example, the **visual association area** monitors the patterns of activity in the visual cortex and interprets the results. You see the symbols *c*, *a*, and *r* when the stimulation of receptors in your eyes leads to the stimulation of neurons in your visual cortex. Your visual association area recognizes that these are letters and that $c + a + r = car$. An individual with a damaged visual association area could scan the lines of a printed page and see rows of symbols that are clear, but would perceive no meaning from the symbols. Similarly, the **auditory association area** monitors sensory activity in the auditory cortex; word recognition occurs in this association area.

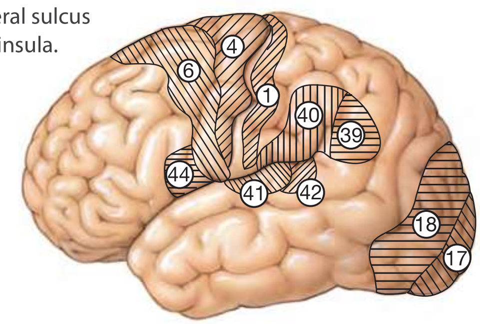
Figure 14–15 **Motor and Sensory Regions of the Cerebral Cortex.**



a Major anatomical landmarks on the surface of the left cerebral hemisphere. The lateral sulcus has been pulled apart to expose the insula.



b The left hemisphere generally contains the general interpretive area and the speech center. The prefrontal cortex of each hemisphere is involved with conscious intellectual functions.



c Regions of the cerebral cortex as determined by histological analysis. Several of the 47 Brodmann areas are shown for comparison with the results of functional mapping.

The **premotor cortex,** or **somatic motor association area,** is responsible for the coordination of learned movements. The primary motor cortex does nothing on its own, any more than a piano keyboard can play itself. The neurons in the primary motor cortex must be stimulated by neurons in other parts of the cerebrum. When you perform a voluntary movement, the instructions are relayed to the primary motor cortex by the premotor cortex. With repetition, the proper pattern of stimulation becomes stored in your premotor cortex. You can then perform the movement smoothly and easily by triggering the *pattern* rather than by controlling the individual neurons. This principle applies to any learned movement, from something as simple as picking up a glass to something as complex as playing the piano. One area of the premotor cortex, the *frontal eye field*, controls learned eye movements, such as when you scan these lines of type. Individuals with damage to the frontal eye field can understand written letters and words but cannot read, because their eyes cannot follow the lines on a printed page.

Integrative Centers

Integrative centers are areas that receive information from many association areas and direct extremely complex motor activities. These centers also perform complicated analytical functions. For example, the *prefrontal cortex* of the frontal lobe (**Figure 14–15b**) integrates information from sensory association areas and performs abstract intellectual functions, such as predicting the consequences of possible responses.

Integrative centers are located in the lobes and cortical areas of both cerebral hemispheres. Integrative centers concerned with the performance of complex processes, such as speech, writing, mathematical computation, and understanding spatial relationships, are restricted to either the left or the right hemisphere. These centers include the *general interpretive area* and the *speech center*. The corresponding regions on the opposite hemisphere are also active, but their functions are less well defined.

The General Interpretive Area. The **general interpretive area,** also called the *Wernicke's area* (**Figure 14–15b**), receives information from all the sensory association areas. This analytical center is present in only one hemisphere (typically the left). This region plays an essential role in your personality by integrating sensory information and coordinating access to complex visual and auditory memories. Damage to the general interpretive area affects the ability to interpret what is seen or heard, even though the words are understood as individual entities. For example, if your general interpretive area were damaged, you might still understand the meaning of the spoken words *sit* and *here*, because word recognition occurs in the auditory association areas. But you would be totally bewildered by the request *sit here*. Damage to another portion of the general interpretive area might leave you able to see a chair clearly, and to know that you recognize it, but you would be unable to name it because the connection to your visual association area has been disrupted.

Clinical Note

Disconnection Syndrome

The functional differences between the hemispheres become apparent if the corpus callosum is cut, a procedure sometimes performed to treat epileptic seizures that cannot be controlled by other methods. This surgery produces symptoms of **disconnection syndrome.** In this condition, the two hemispheres function independently, each "unaware" of stimuli or motor commands that involve its counterpart.

Individuals with this syndrome exhibit some rather interesting changes in their mental abilities. For example, objects touched by the left hand can be recognized but not verbally identified, because the sensory information arrives at the right hemisphere but the speech center is on the left. The object can be verbally identified if felt with the right hand, but the person cannot say whether it is the same object previously touched with the left hand. Sensory information from the left side of the body arrives at the right hemisphere and cannot reach the general interpretive area. Thus, conscious decisions are made without regard to sensations from the left side.

Two years after a surgical sectioning of the corpus callosum, the most striking behavioral abnormalities have disappeared and the person may test normally. In addition, individuals born without a functional corpus callosum do not have sensory, motor, or intellectual problems. In some way, the CNS adapts to these situations, probably by increasing the amount of information transferred across the anterior commissure.

The Speech Center. Some of the neurons in the general interpretive area innervate the **speech center,** also called the *Broca's area* or the *motor speech area* (**Figure 14–15b**). This center lies along the edge of the premotor cortex in the same hemisphere as the general interpretive area (usually the left). The speech center regulates the patterns of breathing and vocalization needed for normal speech. This regulation involves coordinating the activities of the respiratory muscles, the laryngeal and pharyngeal muscles, and the muscles of the tongue, cheeks, lips, and jaws. A person with a damaged speech center can make sounds but not words.

The motor commands issued by the speech center are adjusted by feedback from the auditory association area, also called the *receptive speech area*. Damage to the related sensory areas can cause a variety of speech-related problems. (See the discussion of *aphasia* on p. 476.) Some affected individuals have difficulty speaking although they know exactly which words to use; others talk constantly but use all the wrong words.

The Prefrontal Cortex. The **prefrontal cortex** of the frontal lobe (**Figure 14–15b**) coordinates information relayed from the association areas of the entire cortex. In doing so, it performs such abstract intellectual functions as predicting the consequences of events or actions. Damage to the prefrontal cortex leads to difficulties in estimating temporal relationships between events. Questions such as "How long ago did this happen?" or "What happened first?" become difficult to answer.

The prefrontal cortex has extensive connections with other cortical areas and with other portions of the brain. Feelings of frustration, tension, and anxiety are generated at the prefrontal cortex as it interprets ongoing events and makes predictions about future situations or consequences. If the connections between the prefrontal cortex and other brain regions are severed, the frustrations, tensions, and anxieties are removed. During the middle of the 20th century, this rather drastic procedure, called **prefrontal lobotomy,** was used to "cure" a variety of mental illnesses, especially those associated with violent or antisocial behavior. After a lobotomy, the patient would no longer be concerned about what had previously been a major problem, whether psychological (hallucinations) or physical (severe pain). However, the individual was often equally unconcerned about tact, decorum, and toilet training. Drugs that target specific pathways and regions of the CNS have been developed, so lobotomies are no longer used to change behavior.

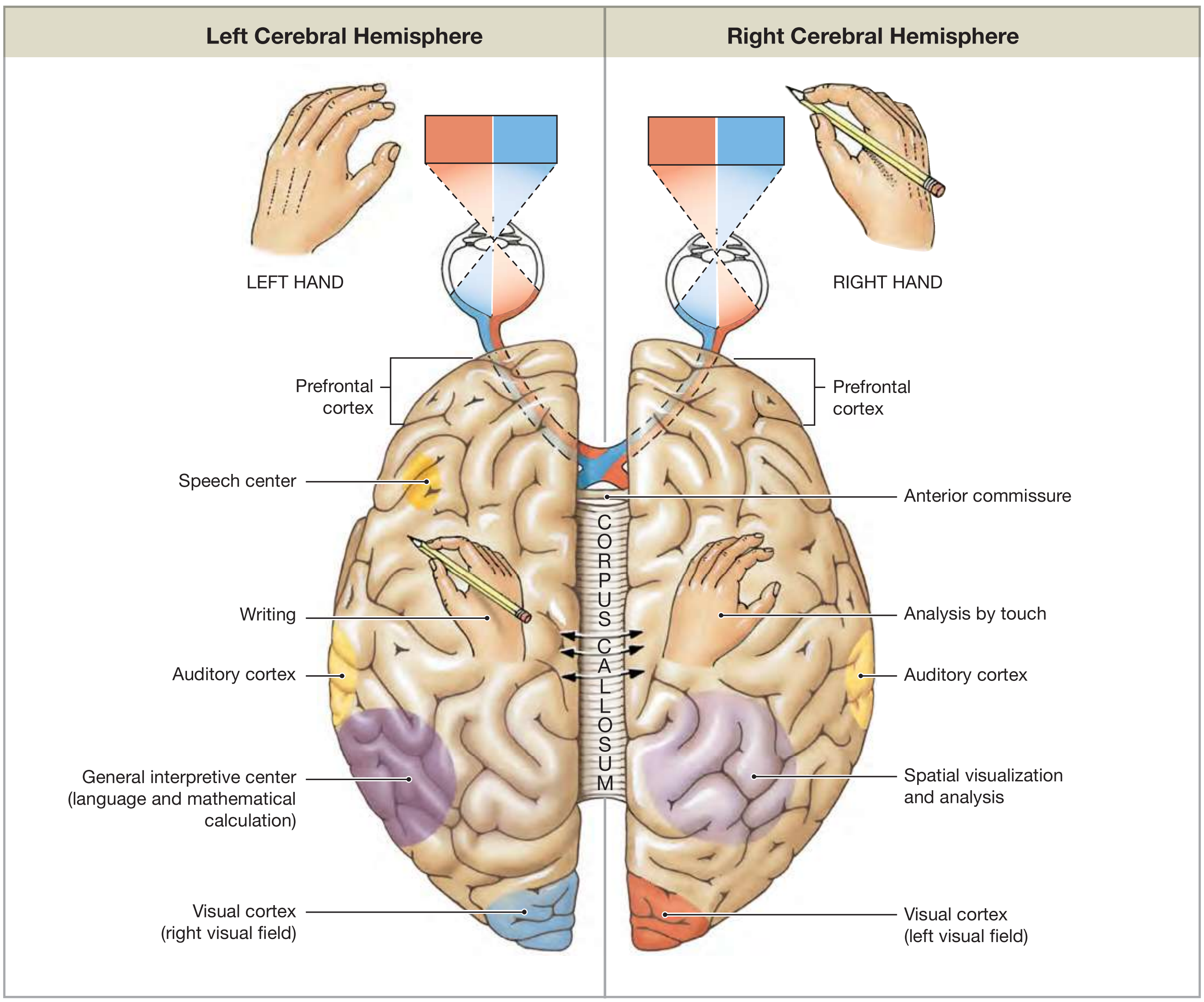
Brodmann Areas. Early in the 20th century, numerous researchers attempted to describe and classify regional differences in the histological organization of the cerebral cortex. They hoped to correlate the patterns of cellular organization with specific functions. By 1919, at least 200 patterns had been described, but most of the classification schemes have since been abandoned. However, the cortical map prepared by Korbinian Brodmann in 1909 has proved useful to neuroanatomists. Brodmann, a German neurologist, described 47 patterns of cellular organization in the cerebral cortex. Several of these *Brodmann areas* are shown in **Figure 14–15c**. Some correspond to known functional areas. For example, Brodmann area 44 corresponds to the speech center, and area 41 to the auditory cortex; area 4 follows the contours of the primary motor cortex. In other cases, the correspondence is less precise. For instance, Brodmann area 42 forms only a small portion of the auditory association area.

Hemispheric Lateralization

Each of the two cerebral hemispheres is responsible for specific functions that are not ordinarily performed by the opposite hemisphere. This regional specialization is called *hemispheric lateralization*. **Figure 14–16** indicates the major functional differences between the hemispheres. In most people, the left hemisphere contains the general interpretive and speech centers and is responsible for language-based skills. For example, reading, writing, and speaking are dependent on processing done in the left cerebral hemisphere. In addition, the premotor cortex involved with the control of hand movements is larger on the left side for right-handed individuals than for left-handed ones. The left hemisphere is also important in performing analytical tasks, such as mathematical calculations and logical decision-making. For these reasons, the left cerebral hemisphere has been called the *dominant hemisphere*.

The right cerebral hemisphere analyzes sensory information and relates the body to the sensory environment. Interpretive centers in this hemisphere permit you to identify familiar objects

Figure 14–16 **Hemispheric Lateralization.** Functional differences between the left and right cerebral hemispheres.



14

Clinical Note — Aphasia and Dyslexia

Can't get the **words** out or get what's there

Aphasia (*a*-, without + *phasia*, speech) is a disorder affecting the ability to speak or read. *Global aphasia* results from extensive damage to the general interpretive area or to the associated sensory tracts. Affected individuals are unable to speak, read, or understand the speech of others. Global aphasia often accompanies a severe stroke or tumor that affects a large area of cortex, including the speech and language areas. Recovery is possible when the condition results from edema or hemorrhage, but the process often takes months or even years.

Dyslexia (*dys*-, difficult, faulty + *lexis*, diction) is a disorder affecting the comprehension and use of written words. *Developmental dyslexia* affects children; estimates indicate that up to 15 percent of children in the United States have some degree of dyslexia. Children with dyslexia have difficulty reading and writing, although their other intellectual functions may be normal or above normal. Their writing looks uneven and disorganized; letters are typically written in the wrong order (*dig* becomes *gid*) or reversed (*E* becomes Ǝ). Recent evidence suggests that at least some forms of dyslexia result from problems in processing, sorting, and integrating visual or auditory information.

by touch, smell, sight, taste, or feel. For example, the right hemisphere plays a dominant role in recognizing faces and in understanding three-dimensional relationships. It is also important in analyzing the emotional context of a conversation—for instance, distinguishing between the threat "Get lost!" and the question "Get lost?" Individuals with a damaged right hemisphere may be unable to add emotional inflections to their own words.

Left-handed people represent 9 percent of the human population; in most cases, although the primary motor cortex of the right hemisphere controls motor function for the dominant hand, the centers involved with speech and analytical function are in the left hemisphere. Interestingly, an unusually high percentage of musicians and artists are left-handed. The complex motor activities performed by these individuals are directed by the primary motor cortex and association areas of the right cerebral hemisphere, near the association areas involved with spatial visualization and emotions.

Monitoring Brain Activity: The Electroencephalogram

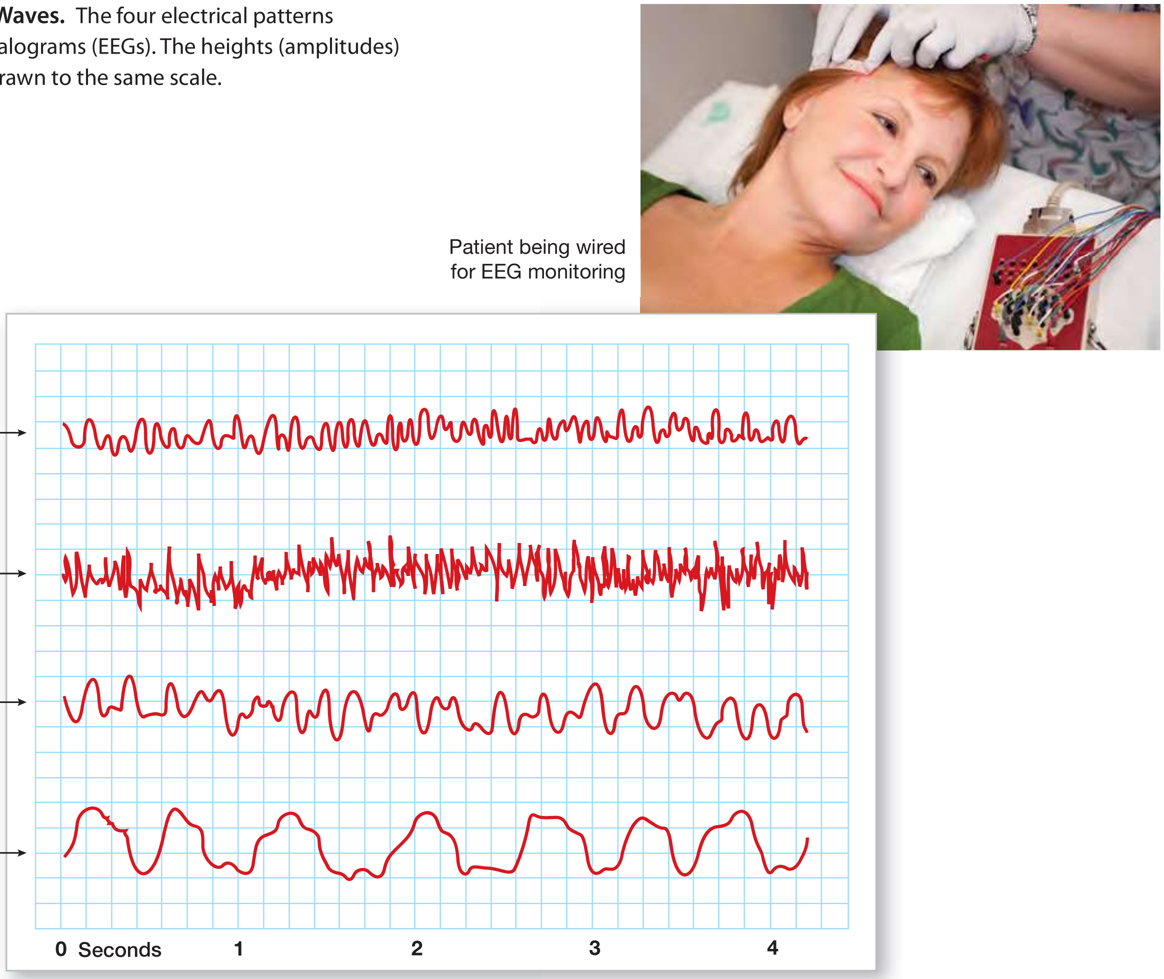
The primary sensory cortex and the primary motor cortex have been mapped by direct stimulation in patients undergoing brain surgery. The functions of other regions of the cerebrum can be revealed by the behavioral changes that follow localized injuries or strokes, and the activities of specific regions can be examined by a PET scan or sequential MRI scans.

The electrical activity of the brain is commonly monitored to assess brain activity. Neural function depends on electrical events within the plasma membrane of neurons. The brain contains billions of neurons, and their activity generates an electrical field that can be measured by placing electrodes on the brain or on the outer surface of the skull. The electrical activity changes constantly, as nuclei and cortical areas are stimulated or they quiet down. A printed report of the electrical activity of the brain is called an **electroencephalogram (EEG).** The electrical patterns observed are called *brain waves*.

Typical brain waves are shown in **Figure 14–17a–d**. **Alpha waves** occur in the brains of healthy, awake adults who are resting with their eyes closed. Alpha waves disappear during sleep, but they also vanish when the individual begins to concentrate on some specific task. During attention to stimuli or tasks, alpha waves are replaced by higher-frequency **beta waves.** Beta waves are typical of individuals who are either concentrating on a task, under stress, or in a state of psychological tension. **Theta waves** may appear transiently during sleep in normal adults but are most often observed in children and in intensely frustrated adults. The presence of theta waves under other circumstances may indicate the presence of a brain disorder, such as a tumor. **Delta waves** are very-large-amplitude, low-frequency waves. They are normally seen during deep sleep in individuals of all ages. Delta waves are also seen in the brains of infants (in whom cortical development is still incomplete) and in awake adults when a tumor, vascular blockage, or inflammation has damaged portions of the brain.

Electrical activity in the two hemispheres is generally synchronized by a "pacemaker" mechanism that appears to involve the thalamus. Asynchrony between the hemispheres

Figure 14–17 Brain Waves. The four electrical patterns revealed by electroencephalograms (EEGs). The heights (amplitudes) of the four waves are not drawn to the same scale.



can therefore indicate localized damage or other cerebral abnormalities. For example, a tumor or injury affecting one hemisphere typically changes the pattern in that hemisphere, and the patterns of the two hemispheres are no longer aligned. A **seizure** is a temporary cerebral disorder accompanied by abnormal movements, unusual sensations, inappropriate behavior, or some combination of these symptoms. Clinical conditions characterized by seizures are known as seizure disorders, or *epilepsies*. Seizures of all kinds are accompanied by a marked change in the pattern of electrical activity recorded in an electroencephalogram. The change begins in one portion of the cerebral cortex but may subsequently spread across the entire cortical surface, like a wave on the surface of a pond.

The nature of the signs and symptoms produced depends on the region of the cortex involved. If a seizure affects the primary motor cortex, movements will occur; if it affects the auditory cortex, the individual will hear strange sounds.

Checkpoint

21. What name is given to fibers carrying information between the brain and spinal cord, and through which brain regions do they pass?
22. What symptoms would you expect to observe in an individual who has damage to the basal nuclei?
23. A patient suffers a head injury that damages her primary motor cortex. Where is this area located?
24. Which senses would be affected by damage to the temporal lobes of the cerebrum?
25. After suffering a stroke, a patient is unable to speak. He can understand what is said to him, and he can understand written messages, but he cannot express himself verbally. Which part of his brain has been affected by the stroke?
26. A patient is having a difficult time remembering facts and recalling long-term memories. Which part of his cerebrum is probably involved?

See the blue Answers tab at the back of the book.

Focus Cranial Nerves

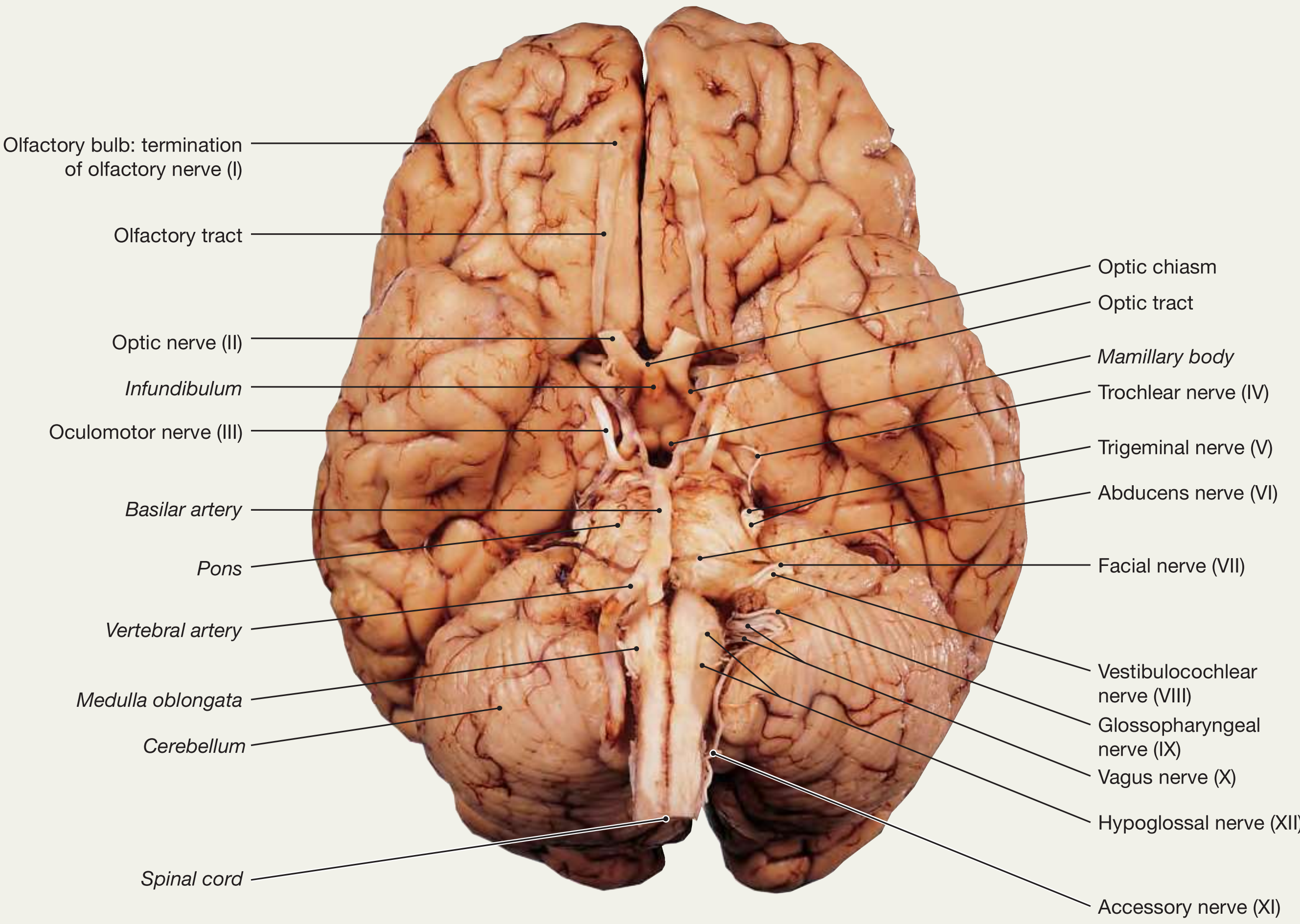
Cranial nerves are PNS components that connect directly to the brain. The 12 pairs of cranial nerves are visible on the ventral surface of the brain (**Figure 14–18**); each has a name related to its appearance or its function.

The number assigned to a cranial nerve corresponds to the nerve's position along the longitudinal axis of the brain, beginning at the cerebrum. Roman numerals preceded by the letter N are usually used. (You may sometimes encounter these numerals preceded by the letters CN.)

Each cranial nerve attaches to the brain near the associated sensory or motor nuclei. The sensory nuclei act as switching centers, with the postsynaptic neurons relaying the information to other nuclei or to processing centers in the cerebral or cerebellar cortex. In a similar way, the motor nuclei receive convergent inputs from higher centers or from other nuclei along the brain stem.

In this section, we classify cranial nerves as primarily sensory, special sensory, motor, or mixed (sensory and motor). In this classification, sensory nerves carry somatic sensory information, including touch, pressure, vibration, temperature, or pain. Special sensory nerves carry the sensations of smell, sight, hearing, or balance. Motor nerves are dominated by the axons of somatic motor neurons; mixed nerves have a mixture of sensory and motor fibers. This is a useful classification scheme, but it is based

Figure 14–18 **Origins of the Cranial Nerves.** An inferior view of the brain.



on the primary function, and a cranial nerve can have important secondary functions. Three examples are worth noting:

1. The olfactory receptors, the visual receptors, and the receptors of the internal ear are innervated by cranial nerves that are dedicated almost entirely to carrying special sensory information. The sensation of taste, considered to be one of the special senses, is carried by axons that form only a small part of large cranial nerves that have other primary functions.
2. As elsewhere in the PNS, a nerve containing tens of thousands of motor fibers that lead to a skeletal muscle will also contain sensory fibers from muscle spindles and Golgi tendon organs in that muscle. We assume that these sensory fibers are present but ignore them in the classification of the nerve.
3. Regardless of their other functions, several cranial nerves (III, VII, IX, and X) distribute autonomic fibers to peripheral ganglia, just as spinal nerves deliver them to ganglia along the spinal cord. We will note the presence of small numbers of autonomic fibers (and will discuss them further in Chapter 16) but ignore them in the classification of the nerve.

Tips & Tricks

Two useful mnemonics for remembering the names of the cranial nerves in order are "**O**h **O**h **O**h, **T**o **T**ouch **A**nd **F**eel **V**ery **G**reen **V**egetables, **A**h **H**eaven!" and "**O**h, **O**nce **O**ne **T**akes **T**he **A**natomy **F**inal, **V**ery **G**ood **V**acations **A**re **H**eavenly!" Another to assist with remembering cranial nerve function is "N III, N IV, N V keep the diaphragm alive."

The Olfactory Nerves (I)

Primary function: Special sensory (smell)

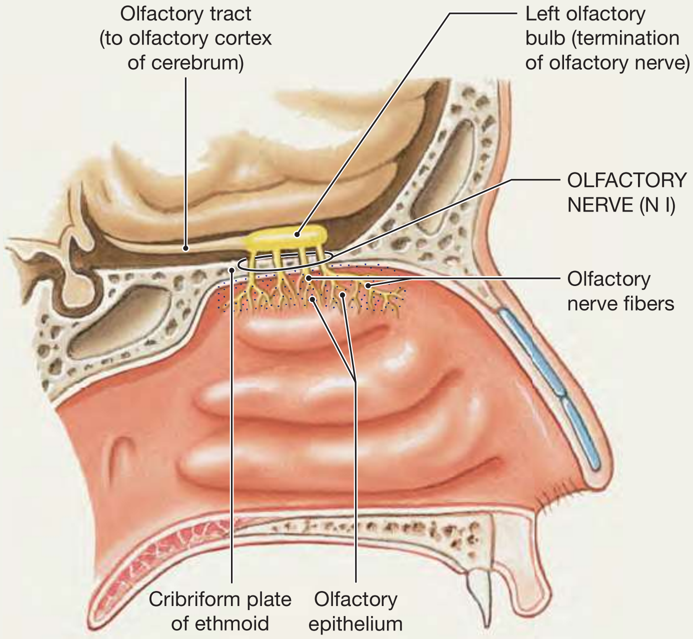
Origin: Receptors of olfactory epithelium

Pass through: Olfactory foramina in cribriform plate of ethmoid pp. 203, 208

Destination: Olfactory bulbs

The first pair of cranial nerves (**Figure 14–19**) carries special sensory information responsible for the sense of smell. The olfactory receptors are specialized neurons in the epithelium covering the roof of the nasal cavity, the superior nasal conchae, and the superior parts of the nasal septum. Axons from these sensory neurons collect to form 20 or more bundles that

Figure 14–19 **The Olfactory Nerve.**



penetrate the cribriform plate of the ethmoid bone. These bundles are components of the **olfactory nerves** (I). Almost at once these bundles enter the **olfactory bulbs,** neural masses on either side of the crista galli. The olfactory afferents synapse within the olfactory bulbs. The axons of the postsynaptic neurons proceed to the cerebrum along the slender **olfactory tracts** (**Figures 14–18** and **14–19**).

Because the olfactory tracts look like typical peripheral nerves, anatomists about a century ago misidentified these tracts as the first cranial nerve. Later studies demonstrated that the olfactory tracts and bulbs are part of the cerebrum, but by then the numbering system was already firmly established. Anatomists were left with a forest of tiny olfactory nerve bundles lumped together as cranial nerve I.

The olfactory nerves are the only cranial nerves attached directly to the cerebrum. The rest originate or terminate within nuclei of the diencephalon or brain stem, and the ascending sensory information synapses in the thalamus before reaching the cerebrum.

The Optic Nerves (II)

Primary function: Special sensory (vision)

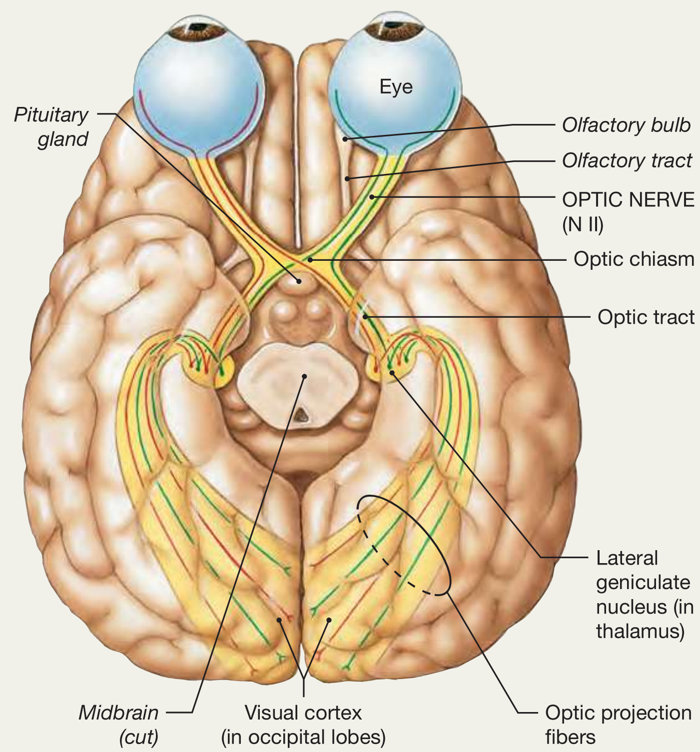
Origin: Retina of eye

Pass through: Optic canals of sphenoid ⮌ p. 207

Destination: Diencephalon via the optic chiasm

The **optic nerves** (II) carry visual information from special sensory ganglia in the eyes. These nerves (**Figure 14–20**) contain about 1 million sensory nerve fibers. The optic nerves pass through the optic canals of the sphenoid. Then they converge at the ventral, anterior margin of the diencephalon, at the **optic chiasm** (*chiasma*, a crossing). At the optic chiasm, fibers from the medial half of each retina cross over to the opposite side of the brain.

Figure 14–20 **The Optic Nerve.**



The reorganized axons continue toward the lateral geniculate nuclei of the thalamus as the **optic tracts** (**Figures 14–18** and **14–20**). After synapsing in the lateral geniculates, projection fibers deliver the information to the visual cortex of the occipital lobes. With this arrangement, each cerebral hemisphere receives visual information from the lateral half of the retina of the eye on that side and from the medial half of the retina of the eye of the opposite side (**Figure 14–16**). A few axons in the optic tracts bypass the lateral geniculate nuclei and synapse in the superior colliculi of the midbrain. We will consider that pathway in Chapter 17.

The Oculomotor Nerves (III)

Primary function: Motor (eye movements)

Origin: Midbrain

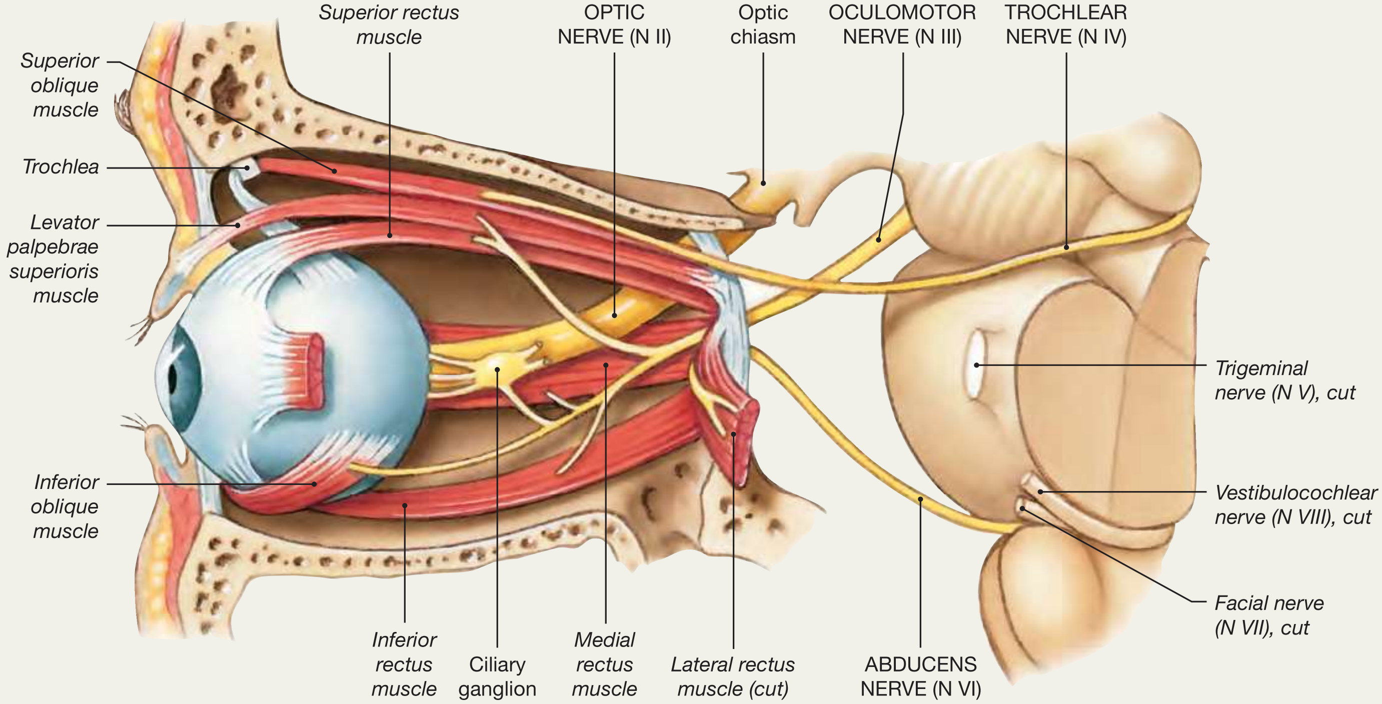
Pass through: Superior orbital fissures of sphenoid ⮌ pp. 202, 207, 210, 214

Destination: *Somatic motor*: superior, inferior, and medial rectus muscles; inferior oblique muscle; levator palpebrae superioris muscle. *Visceral motor*: intrinsic eye muscles

The midbrain contains the motor nuclei controlling the third and fourth cranial nerves. Each **oculomotor nerve** (III) innervates four of the six extrinsic muscles that move the eye, and the levator palpebrae superioris muscle, which raises the upper eyelid (**Figure 14–21**). On each side of the brain, nerve III emerges from the ventral surface of the midbrain and penetrates the posterior wall of the orbit at the superior orbital fissure. Individuals with damage to this nerve often complain of pain over the eye, droopy eyelids, and double vision, because the movements of the left and right eyes cannot be coordinated properly.

The oculomotor nerve also delivers preganglionic autonomic fibers to neurons of the **ciliary ganglion**. The neurons of the ciliary ganglion control intrinsic eye muscles. These muscles change the diameter of the pupil, adjusting the amount of light entering the eye, and change the shape of the lens to focus images on the retina.

Figure 14–21 **Cranial Nerves Controlling the Exrinsic Eye Muscles.** ATLAS: Plates 16a,b



The Trochlear Nerves (IV)

Primary function: Motor (eye movements)

Origin: Midbrain

Pass through: Superior orbital fissures of sphenoid pp. 202, 207, 210, 214

Destination: Superior oblique muscle

A **trochlear** (TRŌK-lē-ar; *trochlea*, a pulley) **nerve** (IV), the smallest cranial nerve, innervates the superior oblique muscle of each eye (**Figure 14–21**). The trochlea is a pulley-shaped, ligamentous sling. Each superior oblique muscle passes through a trochlea on its way to its insertion on the surface of the eye. An individual with damage to cranial nerve IV or to its nucleus will have difficulty looking down and to the side.

The Abducens Nerves (VI)

Primary function: Motor (eye movements)

Origin: Pons

Pass through: Superior orbital fissures of sphenoid pp. 202, 207, 210, 214

Destination: Lateral rectus muscle

The **abducens** (ab-DŪ-senz) **nerves** (VI) innervate the lateral rectus muscles, the sixth pair of extrinsic eye muscles. Contraction of the lateral rectus muscle makes the eye look to the side; in essence, the *abducens* causes *abduction* of the eye. Each abducens nerve emerges from the inferior surface of the brain stem at the border between the pons and the medulla oblongata (**Figure 14–21**). Along with the oculomotor and trochlear nerves from that side, it reaches the orbit through the superior orbital fissure.

The Trigeminal Nerves (V)

Primary function: Mixed (sensory and motor) to face

Origin: *Ophthalmic branch* (sensory): orbital structures, cornea, nasal cavity, skin of forehead, upper eyelid, eyebrow, nose (part). *Maxillary branch* (sensory): lower eyelid, upper lip, gums, and teeth; cheek; nose, palate, and pharynx (part). *Mandibular branch* (mixed): sensory from lower gums, teeth, and lips; palate and tongue (part); motor from motor nuclei of pons

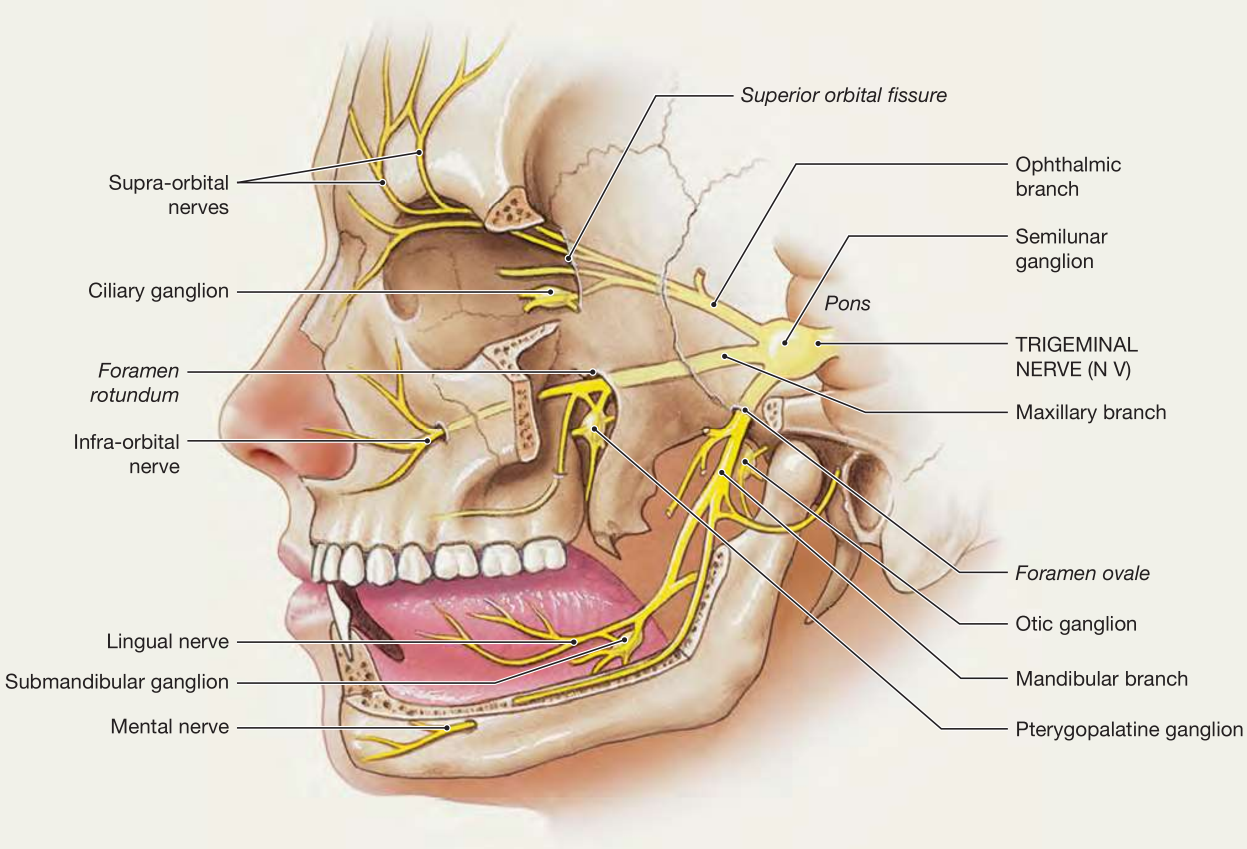
Pass through (on each side): Ophthalmic branch through superior orbital fissure, maxillary branch through foramen rotundum, mandibular branch through foramen ovale ⮌ pp. 202, 203, 207, 214

Destination: Ophthalmic, maxillary, and mandibular branches to sensory nuclei in pons; mandibular branch also innervates muscles of mastication ⮌ p. 336

The pons contains the nuclei associated with three cranial nerves (V, VI, and VII) and contributes to a fourth (VIII). The **trigeminal** (trī-JEM-i-nal) **nerves** (V), the largest cranial nerves, are mixed nerves. Each provides both somatic sensory information from the head and face, and motor control over the muscles of mastication. Sensory (dorsal) and motor (ventral) roots originate on the lateral surface of the pons (**Figure 14–22**). The sensory branch is larger, and the enormous **semilunar ganglion** contains the cell bodies of the sensory neurons. As the name implies, the trigeminal has three major branches; the small motor root contributes to only one of the three. **Tic douloureux** (doo-luh-ROO; *douloureux*, painful), or *trigeminal neuralgia*, is a painful condition affecting the area innervated by the maxillary and mandibular branches of the trigeminal nerve. Sufferers complain of debilitating pain triggered by contact with the lip, tongue, or gums. The cause of the condition is unknown.

The trigeminal nerve branches are associated with the *ciliary*, *sphenopalatine*, *submandibular*, and *otic ganglia*. These are autonomic (parasympathetic) ganglia whose neurons innervate structures of the face. However, although its nerve fibers may pass around or through these ganglia, the trigeminal nerve does not contain visceral motor fibers. We discussed the ciliary ganglion on page 480 and will describe the other ganglia next, with the branches of the *facial nerves* (VII) and the *glossopharyngeal nerves* (IX).

Figure 14–22 **The Trigeminal Nerve.**



The Facial Nerves (VII)

Primary function: Mixed (sensory and motor) to face

Origin: *Sensory*: taste receptors on anterior two-thirds of tongue. *Motor*: motor nuclei of pons

Pass through: Internal acoustic meatus to canals leading to the stylomastoid foramina ⮌ pp. 202, 203, 207

Destination: *Sensory*: sensory nuclei of pons. *Somatic motor*: muscles of facial expression. ⮌ p. 332 *Visceral motor*: lacrimal (tear) gland and nasal mucous glands by way of the pterygopalatine ganglion; submandibular and sublingual salivary glands by way of the submandibular ganglion

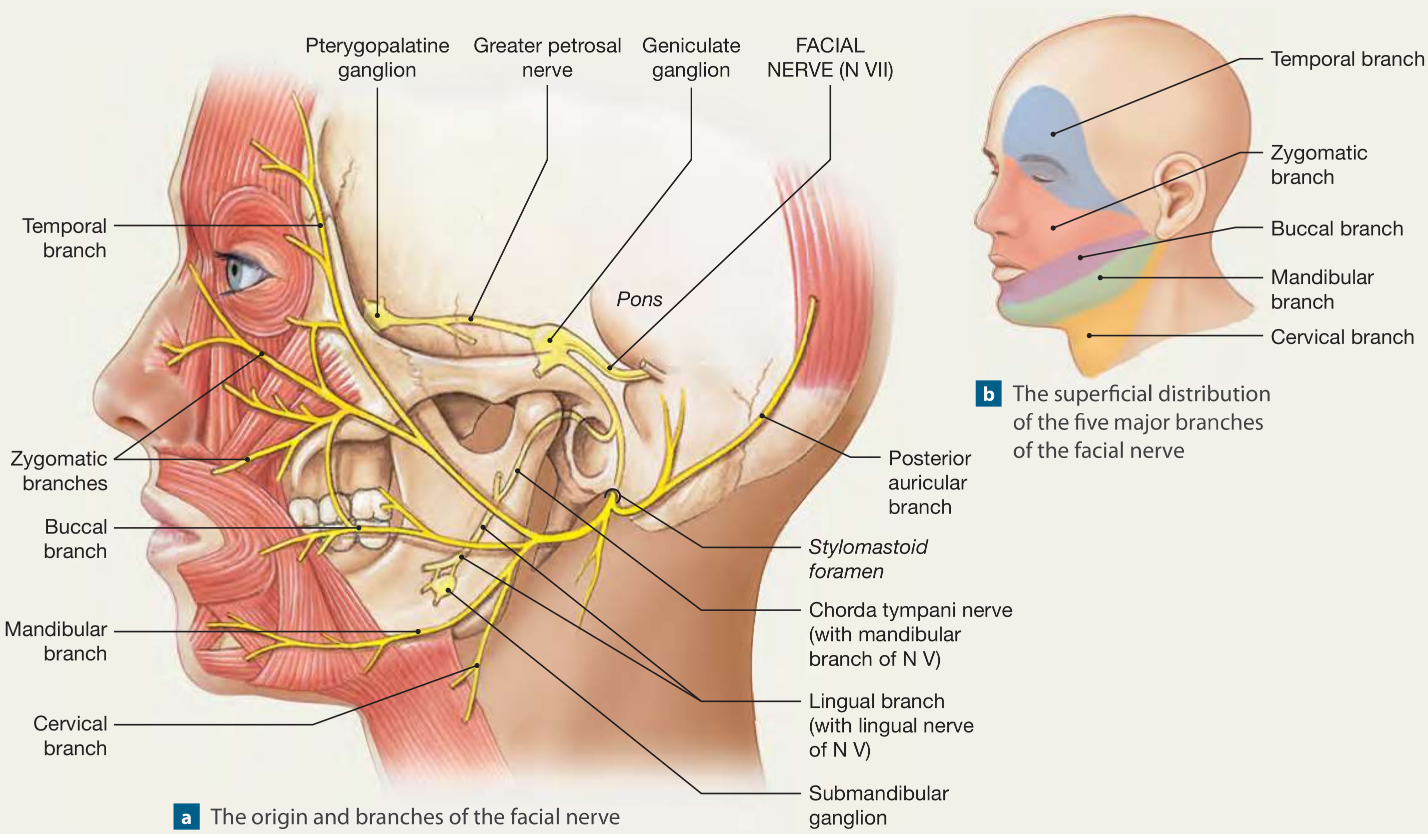
The **facial nerves** (VII) are mixed nerves. The cell bodies of the sensory neurons are located in the **geniculate ganglia,** and the motor nuclei are in the pons. On each side, the sensory and motor roots emerge from the pons and enter the internal acoustic meatus of the temporal bone. Each facial nerve then passes through the facial canal to reach the face by way of the stylomastoid foramen. The nerve then splits to form the temporal, zygomatic, buccal, mandibular, and cervical branches (**Figure 14–23**).

The sensory neurons monitor proprioceptors in the facial muscles, provide deep pressure sensations over the face, and receive taste information from receptors along the anterior two-thirds of the tongue. Somatic motor fibers control the superficial muscles of the scalp and face and deep muscles near the ear.

The facial nerves carry preganglionic autonomic fibers to the pterygopalatine and submandibular ganglia. Postganglionic fibers from the **pterygopalatine ganglia** innervate the lacrimal glands and small glands of the nasal cavity and pharynx. The **submandibular ganglia** innervate the *submandibular* and *sublingual* (*sub-*, under + *lingual*, pertaining to the tongue) *salivary glands*.

Bell's palsy is a cranial nerve disorder that results from an inflammation of a facial nerve. The condition is probably due to a viral infection. Signs and symptoms include paralysis of facial muscles on the affected side and loss of taste sensations from the anterior two-thirds of the tongue. The condition is usually painless and in most cases the symptoms fade after a few weeks or months.

Figure 14–23 **The Facial Nerve.**



a The origin and branches of the facial nerve

b The superficial distribution of the five major branches of the facial nerve

The Vestibulocochlear Nerves (VIII)

Primary function: Special sensory: balance and equilibrium (vestibular branch) and hearing (cochlear branch)

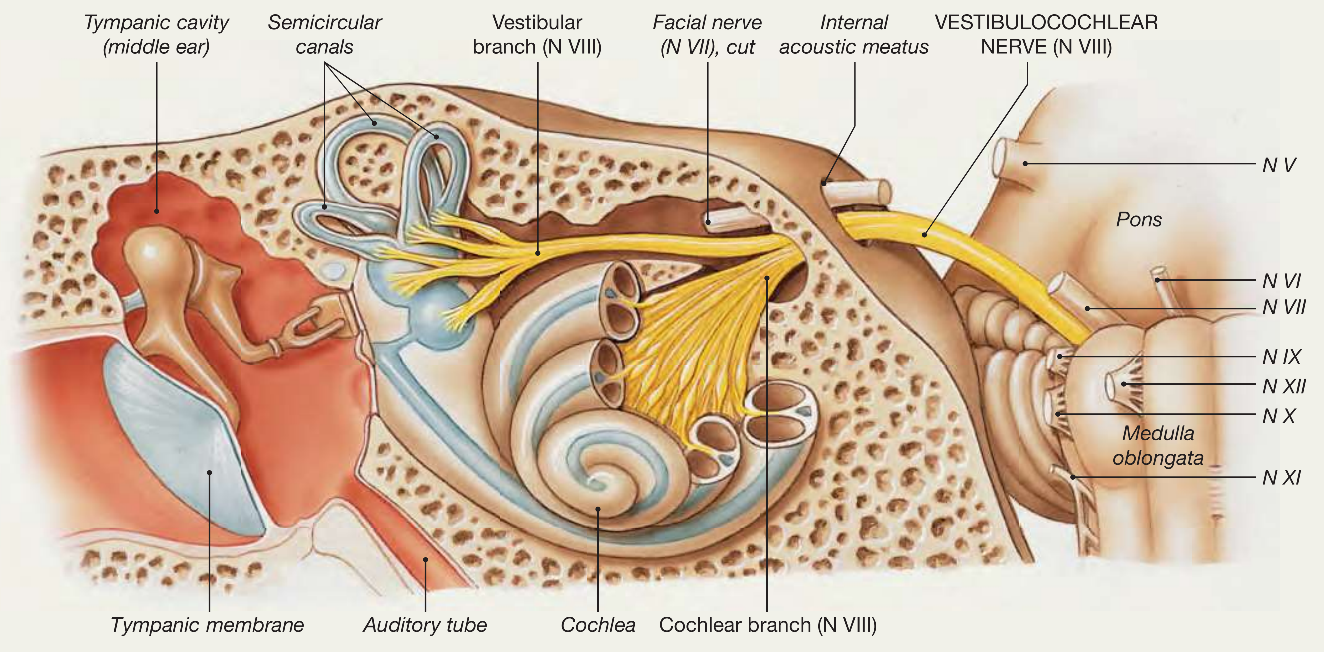
Origin: Monitor receptors of the internal ear (vestibule and cochlea)

Pass through: Internal acoustic meatus of temporal bones pp. 203, 207

Destination: Vestibular and cochlear nuclei of pons and medulla oblongata

The **vestibulocochlear nerves** (VIII) are also known as the *acoustic nerves*, the *auditory nerves*, and the *stato-acoustic nerves*. We will use *vestibulocochlear*, because this term indicates the names of the two major branches: the vestibular branch and the cochlear branch. Each vestibulocochlear nerve lies posterior to the origin of the facial nerve, straddling the boundary between the pons and the medulla oblongata (**Figure 14–24**). This nerve reaches the sensory receptors of the internal ear by entering the internal acoustic meatus in company with the facial nerve. Each vestibulocochlear nerve has two distinct bundles of sensory fibers. The **vestibular** (*vestibulum*, cavity) **branch** originates at the receptors of the *vestibule*, the portion of the internal ear concerned with balance sensations. The sensory neurons are located in an adjacent sensory ganglion, and their axons target the **vestibular nuclei** of the pons and medulla oblongata. These afferents convey information about the orientation and movement of the head. The **cochlear** (*cochlea*, snail shell) **branch** monitors the receptors in the *cochlea*, the portion of the internal ear that provides the sense of hearing. The cell bodies of the sensory neurons are located within a peripheral ganglion (the *spiral ganglion*), and their axons synapse within the **cochlear nuclei** of the pons and medulla oblongata. Axons leaving the vestibular and cochlear nuclei relay the sensory information to other centers or initiate reflexive motor responses. We discuss balance and the sense of hearing in Chapter 17.

Figure 14–24 **The Vestibulocochlear Nerve.**



The Glossopharyngeal Nerves (IX)

Primary function: Mixed (sensory and motor) to head and neck

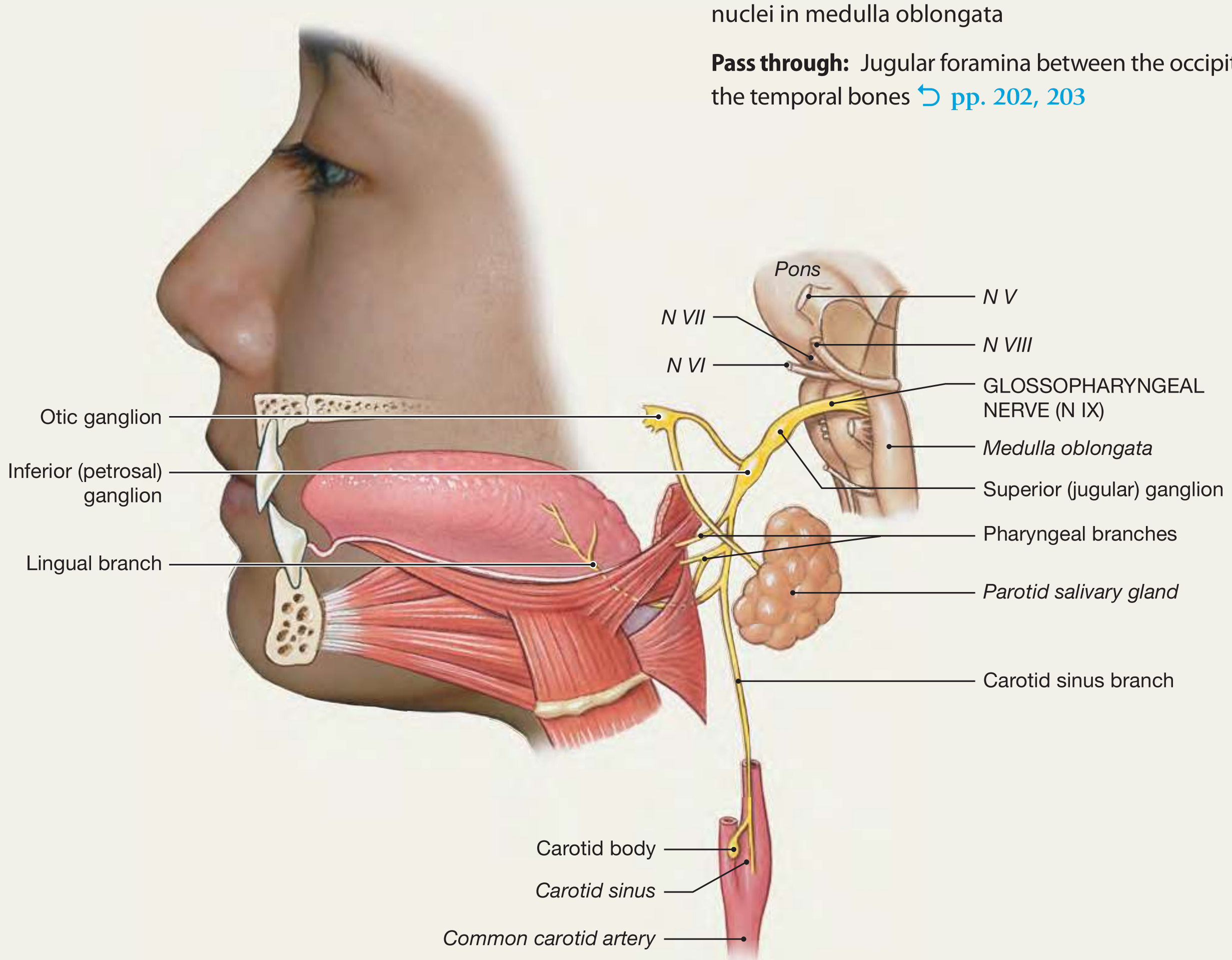
Origin: *Sensory*: posterior one-third of the tongue, part of the pharynx and palate, carotid arteries of the neck. *Motor*: motor nuclei of medulla oblongata

Pass through: Jugular foramina between the occipital bone and the temporal bones pp. 202, 203

Destination: *Sensory*: sensory nuclei of medulla oblongata. *Somatic motor*: pharyngeal muscles involved in swallowing. *Visceral motor*: parotid salivary gland by way of the otic ganglion

The medulla oblongata contains the sensory and motor nuclei of cranial nerves IX, X, XI, and XII, in addition to the vestibular nucleus of nerve VIII. The **glossopharyngeal** (glos-ō-fah-RIN-jē-al; *glossum*, tongue) **nerves** (IX) innervate the tongue and pharynx. Each glossopharyngeal nerve penetrates the cranium within the jugular foramen, with cranial nerves X and XI.

Figure 14–25 **The Glossopharyngeal Nerve.**



The glossopharyngeal nerves are mixed nerves, but sensory fibers are most abundant. The sensory neurons on each side are in the **superior** *(jugular)* **ganglion** and **inferior** *(petrosal)* **ganglion** (**Figure 14–25**). The sensory fibers carry general sensory information from the lining of the pharynx and the soft palate to a nucleus in the medulla oblongata. These nerves also provide taste sensations from the posterior third of the tongue and have special receptors that monitor the blood pressure and dissolved gas concentrations in the carotid arteries, major blood vessels in the neck.

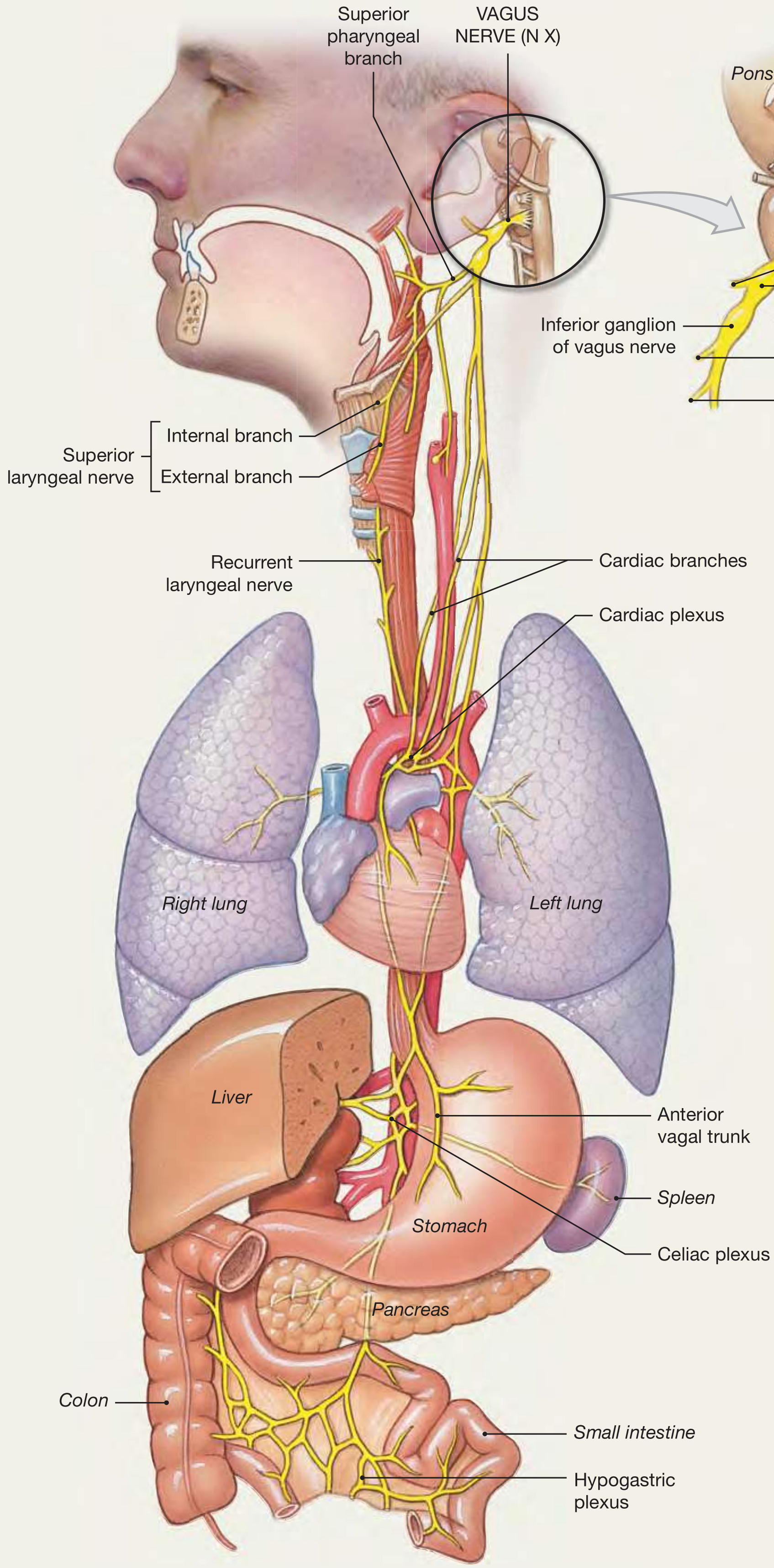
The somatic motor fibers control the pharyngeal muscles involved in swallowing. Visceral motor fibers synapse in the **otic ganglion,** and postganglionic fibers innervate the parotid salivary gland of the cheek.

The Vagus Nerves (X)

Primary function: Mixed (sensory and motor), widely distributed in the thorax and abdomen

Origin: *Sensory*: pharynx (part), auricle and external acoustic meatus (a portion of the exterior ear), diaphragm, and visceral organs in thoracic and abdominopelvic cavities. *Motor*: motor nuclei in medulla oblongata

Pass through: Jugular foramina between the occipital bone and the temporal bones pp. 202, 203



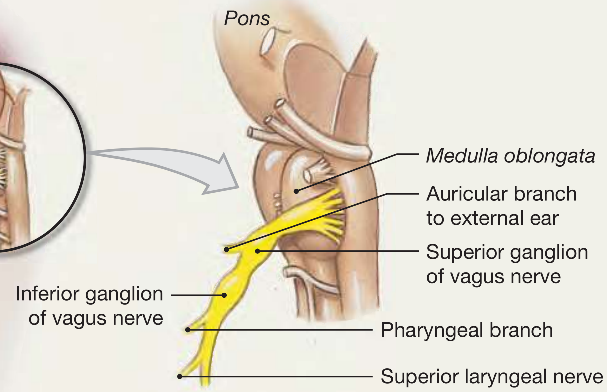


Figure 14–26 **The Vagus Nerve.**

Destination: *Sensory*: sensory nuclei and autonomic centers of medulla oblongata. *Visceral motor*: muscles of the palate, pharynx, digestive, respiratory, and cardiovascular systems in the thoracic and abdominal cavities

The **vagus** (VĀ-gus) **nerves** (X) arise immediately posterior to the attachment of the glosso-pharyngeal nerves. Many small rootlets contribute to their formation, and developmental studies indicate that these nerves probably represent the fusion of several smaller cranial nerves during our evolutionary history. *Vagus* means wandering, and the vagus nerves branch and radiate extensively. The adjacent **Figure 14–26** shows only the general pattern of distribution.

Sensory neurons are located in the **superior** (jugular) **ganglion** and the **inferior** (nodose; NŌ-dōs) **ganglion.** Each vagus nerve provides somatic sensory information about the external acoustic meatus and the diaphragm, and special sensory information from pharyngeal taste receptors. But most of the vagal afferents carry visceral sensory information from receptors along the esophagus, respiratory tract, and abdominal viscera as distant as the last portions of the large intestine. This visceral sensory information is vital to the autonomic control of visceral function.

The motor components of the vagus are equally diverse. Each vagus nerve carries preganglionic autonomic (parasympathetic) fibers that affect the heart and control smooth muscles and glands within the areas monitored by its sensory fibers, including the stomach, intestines, and gallbladder. Difficulty in swallowing is one of the most common signs of damage to either nerve IX or X, because damage to either one prevents the coordination of the swallowing reflex.

The Accessory Nerves (XI)

Primary function: Motor to muscles of the neck and upper back

Origin: Motor nuclei of spinal cord and medulla oblongata

Pass through: Jugular foramina between the occipital bone and the temporal bones ⮌ pp. 202, 203

Destination: Internal branch innervates voluntary muscles of palate, pharynx, and larynx; external branch controls sternocleidomastoid and trapezius muscles

The **accessory nerves** (XI) are also known as the *spinal accessory nerves* or the *spinoaccessory nerves*. Unlike other cranial nerves, each accessory nerve has some motor fibers that originate in the lateral part of the anterior gray horns of the first five cervical segments of the spinal cord (**Figure 14–27**). These somatic motor fibers form the **spinal root** of nerve XI. They enter the cranium through the foramen magnum. They then join the motor fibers of the **cranial root,** which originates at a nucleus in the medulla oblongata. The composite nerve leaves the cranium through the jugular foramen and divides into two branches.

The **internal branch** of nerve XI joins the vagus nerve and innervates the voluntary swallowing muscles of the soft palate and pharynx and the intrinsic muscles that control the vocal cords. The **external branch** of nerve XI controls the sternocleidomastoid and trapezius muscles of the neck and back. ⮌ pp. 339, 350 The motor fibers of this branch originate in the lateral gray part of the anterior horns of cervical spinal nerves C_1 to C_5.

The Hypoglossal Nerves (XII)

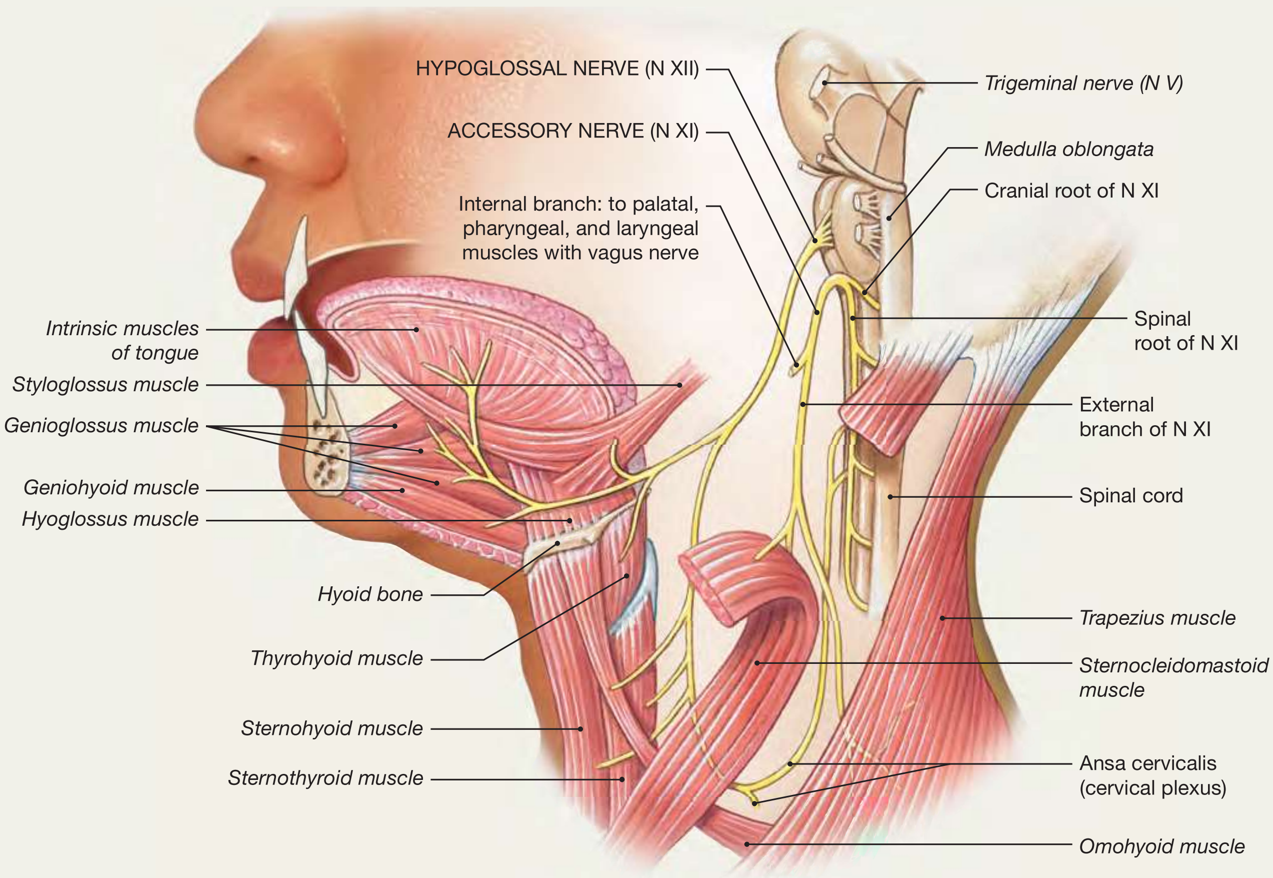
Primary function: Motor (tongue movements)

Origin: Motor nuclei of medulla oblongata

Pass through: Hypoglossal canals of occipital bone ⮌ pp. 202, 203, 204

Destination: Muscles of the tongue ⮌ p. 337

Figure 14–27 **The Accessory and Hypoglossal Nerves.** ATLAS: Plates 18a–c; 25



Each **hypoglossal** (hī-pō-GLOS-al) **nerve** (XII) leaves the cranium through the hypoglossal canal. The nerve then curves to reach the skeletal muscles of the tongue (**Figure 14–27**). This cranial nerve provides voluntary motor control over movements of the tongue. Its condition is checked by having you stick out your tongue. Damage to one hypoglossal nerve or to its associated nuclei causes the tongue to veer toward the affected side. **Table 14–9** summarizes the basic distribution and function of each cranial nerve.

Cranial nerves are clinically important, in part because they can provide clues to underlying CNS problems. A number of standardized tests are used to assess cranial nerve function.

Table 14–9 Cranial Nerve Branches and Functions

Cranial Nerve (Number)	Sensory Ganglion	Branch	Primary Function	Foramen	Innervation
Olfactory (N I)			Special sensory	Olfactory foramina of ethmoid	Olfactory epithelium
Optic (N II)			Special sensory	Optic canal	Retina of eye
Oculomotor (N III)			Motor	Superior orbital fissure	Inferior, medial, superior rectus, inferior oblique and levator palpebrae superioris muscles; intrinsic eye muscles
Trochlear (N IV)			Motor	Superior orbital fissure	Superior oblique muscle
Trigeminal (N V)	Semilunar		Mixed	Superior orbital fissure	Areas associated with the jaws
		Ophthalmic	Sensory	Superior orbital fissure	Orbital structures, nasal cavity, skin of forehead, upper eyelid, eyebrows, nose (part)
		Maxillary	Sensory	Foramen rotundum	Lower eyelid; superior lip, gums, and teeth; cheek, nose (part), palate, and pharynx (part)
		Mandibular	Mixed	Foramen ovale	*Sensory*: inferior gums, teeth, lips, palate (part), and tongue (part) *Motor*: muscles of mastication
Abducens (N VI)			Motor	Superior orbital fissure	Lateral rectus muscle
Facial (N VII)	Geniculate		Mixed	Internal acoustic meatus to facial canal; exits at stylomastoid foramen	*Sensory*: taste receptors on anterior 2/3 of tongue *Motor*: muscles of facial expression, lacrimal gland, submandibular gland, sublingual salivary glands
Vestibulocochlear (N VIII)		Cochlear Vestibular	Special sensory	Internal acoustic meatus	Cochlea (receptors for hearing) Vestibule (receptors for motion and balance)
Glossopharyngeal (N IX)	Superior (jugular) and inferior (petrosal)		Mixed	Jugular foramen	*Sensory*: posterior 1/3 of tongue; pharynx and palate (part); receptors for blood pressure, pH, oxygen, and carbon dioxide concentrations *Motor*: pharyngeal muscles and parotid salivary gland
Vagus (N X)	Superior (jugular) and inferior (nodose)		Mixed	Jugular foramen	*Sensory*: pharynx; auricle and external acoustic meatus; diaphragm; visceral organs in thoracic and abdominopelvic cavities *Motor*: palatal and pharyngeal muscles and visceral organs in thoracic and abdominopelvic cavities
Accessory (N XI)		Internal	Motor	Jugular foramen	Skeletal muscles of palate, pharynx, and larynx (with vagus nerve)
		External	Motor	Jugular foramen	Sternocleidomastoid and trapezius muscles
Hypoglossal (N XII)			Motor	Hypoglossal canal	Tongue musculature

14-10 ◗ Cranial reflexes involve sensory and motor fibers of cranial nerves

Cranial reflexes are monosynaptic and polysynaptic reflex arcs that involve the sensory and motor fibers of cranial nerves. Numerous examples of cranial reflexes will be encountered in later chapters, and this section will simply provide an overview and general introduction.

Table 14–10 lists representative examples of cranial reflexes and their functions. These reflexes are clinically important because they provide a quick and easy method for observing the condition of cranial nerves and specific nuclei and tracts in the brain. The somatic reflexes mediated by the cranial nerves are seldom more complex than the somatic reflexes of the spinal cord that were discussed in Chapter 13. ⮌ p. 437 Table 14–10 includes four representative somatic reflexes: the corneal reflex, the tympanic reflex, the auditory reflexes, and the vestibulo-ocular reflexes. These cranial reflexes are often used to check for damage to the cranial nerves or the associated processing centers in the brain.

The brain stem contains many reflex centers that control visceral motor activity. The motor output of these reflexes is distributed by the autonomic nervous system. As you will see in Chapter 16, the cranial nerves carry most of the commands issued by the parasympathetic division of the ANS, whereas spinal nerves T_1–L_2 carry the sympathetic commands. Many of the centers that coordinate autonomic reflexes are located in the medulla oblongata. These centers can direct very complex visceral motor responses that are essential to the control of respiratory, digestive, and cardiovascular functions.

Checkpoint

27. **What are cranial reflexes?**

See the blue Answers tab at the back of the book.

Table 14–10 Cranial Reflexes

Reflex	Stimulus	Afferents	Central Synapse	Efferents	Response
SOMATIC REFLEXES					
Corneal reflex	Contact with corneal surface	N V (trigeminal)	Motor nucleus for N VII (facial)	N VII (facial)	Blinking of eyelids
Tympanic reflex	Loud noise	N VIII (vestibulocochlear)	Inferior colliculus	N VII (facial)	Reduced movement of auditory ossicles
Auditory reflexes	Loud noise	N VIII (vestibulocochlear)	Motor nuclei of brain stem and spinal cord	N III, IV, VI, VII, X, and cervical nerves	Eye and/or head movements triggered by sudden sounds
Vestibulo-ocular reflexes	Rotation of head	N VIII (vestibulocochlear)	Motor nuclei controlling eye muscles	N III, IV, VI	Opposite movement of eyes to stabilize field of vision
VISCERAL REFLEXES					
Direct light reflex	Light striking photoreceptors	N II (optic)	Superior colliculus	N III (oculomotor)	Constriction of ipsilateral pupil
Consensual light reflex	Light striking photoreceptors	N II (optic)	Superior colliculus	N III (oculomotor)	Constriction of contralateral pupil

Related Clinical Terms

attention deficit hyperactivity disorder (ADHD): Disorder occurring mainly in children characterized by hyperactivity, inability to concentrate, and impulsive or inappropriate behavior.

autism: Any of a range of behavioral disorders occurring primarily in children, including such symptoms as poor concentration, hyperactivity, and impulsivity.

concussion: A brain injury often caused by a hit to the head that may result in a bad headache, altered levels of alertness, loss of memory, or unconsciousness.

Creutzfeldt-Jakob disease (CJD): A rare, degenerative, invariably fatal brain disorder that is marked by rapid mental deterioration. The disease, which is caused by a prion (an infectious protein particle), typically starts by causing mental and emotional problems, then progresses to affect motor skills, such as walking and talking.

delirium: An acutely disturbed state of mind that occurs in fever, intoxication, and other disorders and is characterized by restlessness, illusions, and incoherence of thought and speech.

dementia: A chronic or persistent disorder of the mental processes caused by brain disease or injury and marked by memory disorders, personality changes, and impaired reasoning.

Glasgow coma scale: The most widely used scoring system to quantify the level of consciousness of a victim of a traumatic brain injury. It rates three functions: eye opening, verbal response, and motor response.

migraine: A type of headache marked by severe debilitating head pain lasting several hours or longer.
myoclonus: A quick, involuntary muscle jerk or contraction; persistent myoclonus usually indicates a nervous system disorder.
pallidectomy: The destruction of all or part of the globus pallidus by chemicals or freezing; used in the treatment of Parkinson's disease.
prosopagnosia: The inability to recognize other humans by their faces.
psychosis: A severe mental disorder in which thought and emotions are so impaired that contact with reality is lost.
stupor: A state of near-unconsciousness or insensibility.
transient ischemic attack (TIA): An episode in which a person has stroke-like symptoms that last less than 24 hours and result in no permanent injury to the brain, but may be a warning sign of the potential for a major stroke.

Chapter Review

Study Outline

14

An Introduction to the Brain and Cranial Nerves p. 449

1. The adult human brain contains almost 97 percent of the body's neural tissue and averages 1.4 kg (3 lb) in weight and 1200 mL (71 in.^{3}) in volume.

14-1 The brain has several principal structures, each with specific functions p. 449

2. The six regions in the adult brain are the **cerebrum, cerebellum, diencephalon**, **midbrain** (mesencephalon), **pons,** and **medulla oblongata.** *(Figure 14–1)*
3. The brain contains extensive areas of **neural cortex,** a layer of gray matter on the surfaces of the cerebrum (**cerebral cortex**) and cerebellum.
4. The brain forms from three swellings at the superior tip of the developing *neural tube*: the *prosencephalon*, the *mesencephalon*, and the *rhombencephalon*. The prosencephalon ("forebrain") forms the **telencephalon** (which becomes the cerebrum) and diencephalon; the rhombencephalon ("hindbrain") forms the **metencephalon** (cerebellum and pons) and **myelencephalon** (medulla oblongata). *(Table 14–1)*
5. The central passageway of the brain expands to form chambers called **ventricles,** which contain cerebrospinal fluid. *(Figure 14–2)*

14-2 The brain is protected and supported by the cranial meninges, cerebrospinal fluid, and the blood–brain barrier p. 452

6. The cranial meninges (the *dura mater*, *arachnoid mater*, and *pia mater*) are continuous with those of the spinal cord.
7. Folds of dura mater, including the **falx cerebri, tentorium cerebelli,** and **falx cerebelli,** stabilize the position of the brain. *(Figure 14–3)*
8. Cerebrospinal fluid (CSF) (1) protects delicate neural structures, (2) supports the brain, and (3) transports nutrients, chemical messengers, and waste products.
9. Cerebrospinal fluid is produced at the **choroid plexus,** reaches the subarachnoid space through the **lateral** and **median apertures,** and diffuses across the **arachnoid granulations** into the **superior sagittal sinus.** *(Figure 14–4)*
10. The **blood–brain barrier (BBB)** isolates neural tissue from the general circulation.
11. The blood–brain barrier is incomplete in parts of the **hypothalamus,** the **pituitary gland,** the **pineal gland,** and the **choroid plexus.**

14-3 The medulla oblongata, which is continuous with the spinal cord, contains vital centers p. 456

12. The medulla oblongata connects the brain and spinal cord. It contains relay stations such as the **olivary nuclei,** and **reflex centers,** including the **cardiovascular** and **respiratory rhythmicity centers.** The **reticular formation** begins in the medulla oblongata and extends into more superior portions of the brain stem. *(Figures 14–5, 14–6; Table 14–2)*

14-4 The pons contains nuclei and tracts that carry or relay sensory and motor information p. 459

13. The pons contains (1) sensory and motor nuclei for four cranial nerves; (2) nuclei that help control respiration; (3) nuclei and tracts linking the cerebellum with the brain stem, cerebrum, and spinal cord; and (4) ascending, descending, and transverse tracts. *(Figure 14–6; Table 14–2)*

14-5 The cerebellum coordinates learned and reflexive patterns of muscular activity at the subconscious level p. 460

14. The cerebellum adjusts postural muscles and programs and tunes ongoing movements. The **cerebellar hemispheres** consist of the **anterior** and **posterior lobes,** the **vermis,** and the **flocculonodular lobe.** *(Figure 14–7; Table 14–3)*
15. The **superior, middle,** and **inferior cerebellar peduncles** link the cerebellum with the brain stem, diencephalon, cerebrum, and spinal cord and interconnect the two cerebellar hemispheres.

14-6 The midbrain regulates auditory and visual reflexes and controls alertness p. 460

16. The **tectum** (roof of the midbrain) contains the **corpora quadrigemina** (**superior colliculi** and **inferior colliculi**). The tegmentum contains the **red nucleus,** the **substantia nigra,** the **cerebral peduncles,** and the headquarters of the reticular activating system (RAS). *(Figure 14–8; Table 14–4)*

14-7 The diencephalon integrates sensory information with motor output at the subconscious level p. 463

17. The diencephalon is composed of the epithalamus, the hypothalamus, and the thalamus. *(Figures 14–9, 14–10)*
18. The thalamus is the final relay point for ascending sensory information and coordinates the activities of the basal nuclei and cerebral cortex. *(Figures 14–9, 14–10; Table 14–5)*
19. The hypothalamus can (1) control somatic motor activities at the subconscious level, (2) control autonomic function, (3) coordinate activities of the nervous and endocrine systems, (4) secrete hormones, (5) produce emotions and behavioral **drives,** (6) coordinate voluntary and autonomic functions, (7) regulate body temperature, and (8) coordinate circadian cycles of activity. *(Figure 14–10; Table 14–6)*

14-8 The limbic system is a group of tracts and nuclei with various functions p. 466

20. The **limbic system**, or *motivational system*, includes the **amygdaloid body, cingulate gyrus, dentate gyrus, parahippocampal gyrus, hippocampus,** and **fornix.** The functions of the limbic system involve emotional states and related behavioral drives *(Figure 14–11; Table 14–7)*

14-9 The cerebrum, the largest region of the brain, contains motor, sensory, and association areas p. 468

21. The cortical surface contains **gyri** (elevated ridges) separated by **sulci** (shallow depressions) or **fissures** (deeper grooves). The **longitudinal fissure** separates the two **cerebral hemispheres.** The **central sulcus** separates the **frontal** and **parietal lobes.** Other sulci form the boundaries of the **temporal** and **occipital lobes.** *(Figure 14–12)*
22. The white matter of the cerebrum contains **association fibers**, **commissural fibers,** and **projection fibers.** *(Figure 14–13)*
23. The **basal nuclei** include the **caudate nucleus**, **globus pallidus**, and **putamen;** they control muscle tone and coordinate learned movement patterns and other somatic motor activities. *(Figure 14–14)*
24. The **primary motor cortex** of the **precentral gyrus** directs voluntary movements. The **primary sensory cortex** of the **postcentral gyrus** receives somatic sensory information from touch, pressure, pain, vibration, taste, and temperature receptors. *(Figure 14–15; Table 14–8)*
25. **Association areas**, such as the **somatic sensory association area, visual association area,** and **premotor cortex (somatic motor association area),** control our ability to understand sensory information and coordinate a motor response. *(Figure 14–15)*
26. The **general interpretive area** receives information from all the sensory association areas. It is present in only one hemisphere—generally the left. *(Figure 14–15)*
27. The **speech center** regulates the patterns of breathing and vocalization needed for normal speech. *(Figure 14–15)*
28. The **prefrontal cortex** coordinates information from the secondary and special association areas of the entire cortex and performs abstract intellectual functions. *(Figure 14–15)*
29. The left hemisphere typically contains the general interpretive and speech centers and is responsible for language-based skills. The right hemisphere is typically responsible for spatial relationships and analyses. *(Figure 14–16)*
30. Brain activity is measured using an **electroencephalogram. Alpha waves** appear in healthy resting adults; **beta waves** occur when adults are concentrating; **theta waves** appear in children; and **delta waves** are normal during sleep. *(Figure 14–17)*

Focus: Cranial Nerves p. 478

31. We have 12 pairs of cranial nerves. Except for N I and N II, each nerve attaches to the ventrolateral surface of the brain stem near the associated sensory or motor nuclei. *(Figure 14–18)*
32. The **olfactory nerves** (N I) carry sensory information responsible for the sense of smell. The olfactory afferents synapse within the **olfactory bulbs.** *(Figures 14–18, 14–19)*
33. The **optic nerves** (N II) carry visual information from special sensory receptors in the eyes. *(Figures 14–18, 14–20)*
34. The **oculomotor nerves** (N III) are the primary source of innervation for four of the extrinsic eye muscles. *(Figure 14–21)*
35. The **trochlear nerves** (N IV), the smallest cranial nerves, innervate the superior oblique muscles of the eyes. *(Figure 14–21)*
36. The **trigeminal nerves** (N V), the largest cranial nerves, are mixed nerves with *ophthalmic*, *maxillary*, and *mandibular branches*. *(Figure 14–22)*
37. The **abducens nerves** (N VI) innervate the lateral rectus muscles. *(Figure 14–21)*
38. The **facial nerves** (N VII) are mixed nerves that control muscles of the scalp and face. They provide pressure sensations over the face and receive taste information from the tongue. *(Figure 14–23)*
39. The **vestibulocochlear nerves** (N VIII) contain the **vestibular branch,** which monitors sensations of balance, position, and movement, and the **cochlear branch,** which monitors hearing receptors. *(Figure 14–24)*
40. The **glossopharyngeal nerves** (N IX) are mixed nerves that innervate the tongue and pharynx and control the action of swallowing. *(Figure 14–25)*
41. The **vagus nerves** (N X) are mixed nerves that are vital to the autonomic control of visceral function. *(Figure 14–26)*
42. The **accessory nerves** (N XI) have **internal branches,** which innervate voluntary swallowing muscles of the soft palate and pharynx, and **external branches,** which control muscles associated with the pectoral girdle. *(Figure 14–27)*
43. The **hypoglossal nerves** (N XII) provide voluntary motor control over tongue movements. *(Figure 14–27)*
44. The branches and functions of the cranial nerves are summarized in *Table 14–9*.

14-10 Cranial reflexes involve sensory and motor fibers of cranial nerves p. 489

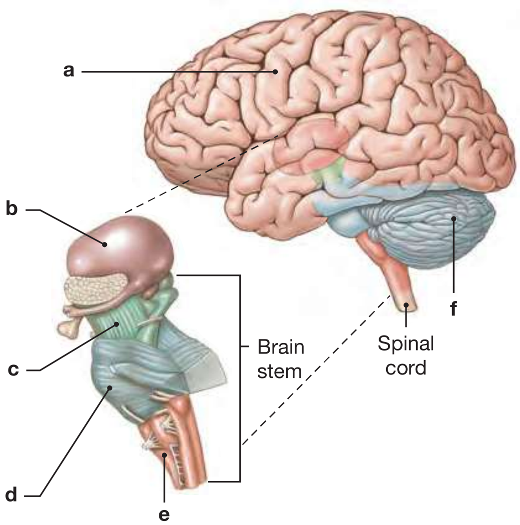
45. Cranial reflexes are monosynaptic and polysynaptic reflex arcs that involve sensory and motor fibers of cranial nerves. *(Table 14–10)*

Review Questions

See the blue Answers tab at the back of the book.

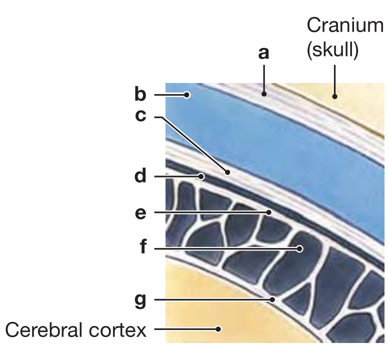
LEVEL 1 Reviewing Facts and Terms

1. Identify the six principal parts of the brain in the following diagram.



(a) __________ (b) __________
(c) __________ (d) __________
(e) __________ (f) __________

2. Identify the layers of the cranial meninges in the following diagram.



(a) __________ (b) __________
(c) __________ (d) __________
(e) __________ (f) __________
(g) __________

3. The term *higher brain centers* refers to those areas of the brain involved in higher-order functions. These centers would probably include nuclei, centers, and cortical areas of
   (a) the cerebrum.
   (b) the cerebellum.
   (c) the diencephalon.
   (d) all of these.
   (e) a and c only.

4. Which of the following is the site of cerebrospinal fluid production?
   (a) dural sinus
   (b) choroid plexus
   (c) falx cerebri
   (d) tentorium cerebelli
   (e) insula
5. The pons contains
   (a) sensory and motor nuclei for six cranial nerves.
   (b) nuclei concerned with control of blood pressure.
   (c) tracts that link the cerebellum with the brain stem.
   (d) no ascending or descending tracts.
   (e) both a and b.
6. The dural fold that divides the two cerebellar hemispheres is the
   (a) transverse sinus.
   (b) falx cerebri.
   (c) tentorium cerebelli.
   (d) falx cerebelli.
7. Cerebrospinal fluid is produced and secreted by
   (a) neurons.
   (b) ependymal cells.
   (c) Purkinje cells.
   (d) basal nuclei.
8. The primary purpose of the blood–brain barrier (BBB) is to
   (a) provide the brain with oxygenated blood.
   (b) drain venous blood via the internal jugular veins.
   (c) isolate neural tissue in the CNS from the general circulation.
   (d) do all of these.
9. The centers in the pons that modify the activity of the respiratory rhythmicity centers in the medulla oblongata are the
   (a) apneustic and pneumotaxic centers.
   (b) inferior and superior peduncles.
   (c) cardiac and vasomotor centers.
   (d) nucleus gracilis and nucleus cuneatus.
10. The final relay point for ascending sensory information that will be projected to the primary sensory cortex is the
   (a) hypothalamus.
   (b) thalamus.
   (c) spinal cord.
   (d) medulla oblongata.
11. The establishment of emotional states is a function of the
   (a) limbic system.
   (b) tectum.
   (c) mamillary bodies.
   (d) thalamus.
12. Coordination of learned movement patterns at the subconscious level is performed by
   (a) the cerebellum.
   (b) the substantia nigra.
   (c) association fibers.
   (d) the hypothalamus.

14

13. The two cerebral hemispheres are functionally different, even though anatomically they appear the same.
    (a) true
    (b) false
14. What are the three important functions of the CSF?
15. Which three areas in the brain are not isolated from the general circulation by the blood–brain barrier?
16. Using the mnemonic device "Oh, Once One Takes The Anatomy Final, Very Good Vacations Are Heavenly," list the names of the 12 pairs of cranial nerves.

LEVEL 2 Reviewing Concepts

17. Why can the brain respond to stimuli with greater versatility than the spinal cord?
18. Briefly summarize the overall function of the cerebellum.
19. The only cranial nerves that are attached to the cerebrum are the ___________ nerves.
    (a) optic
    (b) oculomotor
    (c) trochlear
    (d) olfactory
    (e) abducens
20. If symptoms characteristic of Parkinson's disease appear, which part of the midbrain is inhibited from secreting a neurotransmitter? Which neurotransmitter is it?
21. What varied roles does the hypothalamus play in the body?
22. Stimulation of which part of the brain would produce sensations of hunger and thirst?
23. Which structure in the brain would your A&P instructor be referring to when talking about a nucleus that resembles a sea horse and that appears to be important in the storage and retrieval of long-term memories? In which functional system of the brain is it located?
24. What are the principal functional differences between the right and left hemispheres of the cerebrum?
25. Damage to the vestibular nucleus would lead to
    (a) loss of sight.
    (b) loss of hearing.
    (c) inability to sense pain.
    (d) difficulty in maintaining balance.
    (e) inability to swallow.
26. A cerebrovascular accident occurs when
    (a) the reticular activating system fails to function.
    (b) the prefrontal lobe is damaged.
    (c) the blood supply to a portion of the brain is cut off.
    (d) a descending tract in the spinal cord is severed.
    (e) brain stem nuclei hypersecrete serotonin.
27. What kinds of problems are associated with the presence of lesions in the Wernicke's area and the Broca's area?

LEVEL 3 Critical Thinking and Clinical Applications

28. Smelling salts can sometimes help restore consciousness after a person has fainted. The active ingredient of smelling salts is ammonia, and it acts by irritating the lining of the nasal cavity. Propose a mechanism by which smelling salts would raise a person from the unconscious state to the conscious state.
29. A police officer has just stopped Bill on suspicion of driving while intoxicated. The officer asks Bill to walk the yellow line on the road and then to place the tip of his index finger on the tip of his nose. How would these activities indicate Bill's level of sobriety? Which part of the brain is being tested by these activities?
30. Colleen falls down a flight of stairs and bumps her head several times. Soon after, she develops a headache and blurred vision. Diagnostic tests at the hospital reveal an epidural hematoma in the temporoparietal area. The hematoma is pressing against the brain stem. What other signs and symptoms might she experience as a result of the injury?
31. Cerebral meningitis is a condition in which the meninges of the brain become inflamed as the result of viral or bacterial infection. This condition can be life threatening. Why?
32. Infants have little to no control of the movements of their head. One of the consequences of this is that they are susceptible to shaken baby syndrome, caused by vigorous shaking of an infant or young child by the arms, legs, chest, or shoulders. Forceful shaking can cause brain damage leading to mental retardation, speech and learning disabilities, paralysis, seizures, hearing loss, and even death. Damage to which areas of the brain would account for the clinical signs observed in this syndrome?