

CENTRAL NERVOUS SYSTEM, SPINAL NERVES, AND CRANIAL NERVES

did you know?

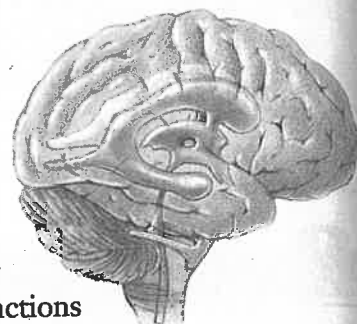
Athletes perform exercise training to stimulate physiological adaptations that lead to improved sports performance. Researchers now believe that a similar kind of training effect may occur in one of the most important organs in your body: the brain.

Just as muscles respond to strength training by increasing in size and becoming stronger, so does the brain respond by increasing the number of neural pathways, the connections between neurons that allow you to think and to remember. Undergoing years of “mental exercise” may be one of the reasons that people with college degrees have a lower risk of developing Alzheimer disease.



Focus on Wellness, page 257

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Now that you understand how the nervous system functions on the cellular level, in this chapter we will explore the structure and functions of the *central nervous system* (CNS), which consists of the brain and spinal cord. We will also examine spinal nerves and cranial nerves, which are part of the peripheral nervous system (PNS) (see Figure 9.1 on page 226).

looking back to move ahead . . .

- Skull and Hyoid Bone (page 125)
- Vertebral Column (page 133)
- Structures of the Nervous System (page 226)
- Structure of a Neuron (page 228)
- Gray and White Matter (page 228)

SPINAL CORD STRUCTURE

OBJECTIVES • Describe how the spinal cord is protected.

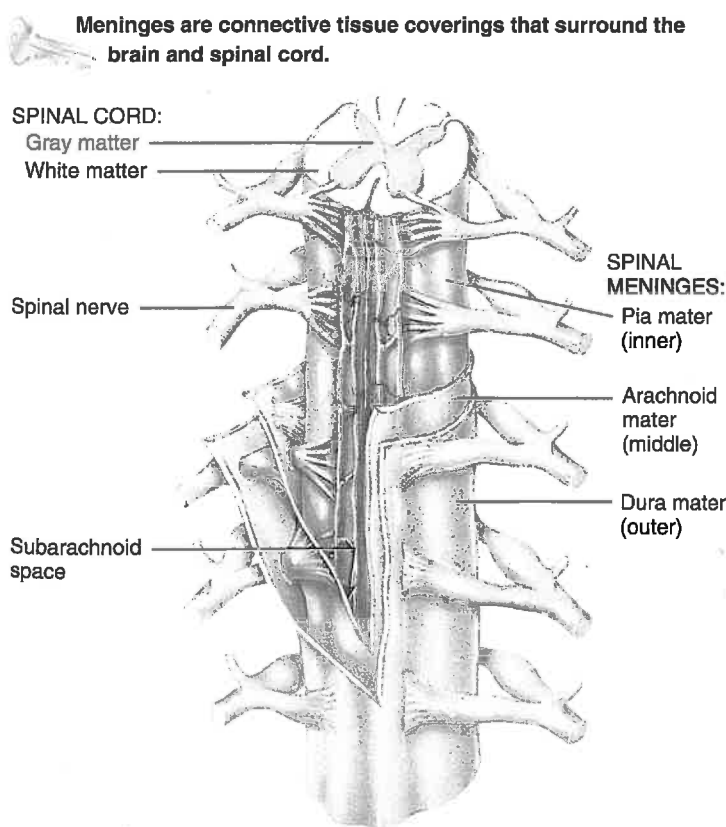
- Describe the structure of the spinal cord.

Protection and Coverings: Vertebral Canal and Meninges

The spinal cord is located within the vertebral cavity of the vertebral column. Because the wall of the vertebral cavity is essentially a ring of bone, the cord is well protected. The vertebral ligaments, meninges, and cerebrospinal fluid provide additional protection.

The **meninges** (me-NIN-jēz) are three layers of connective tissue coverings that extend around the spinal cord and brain. The meninges that protect the spinal cord, the **spinal meninges** (Figure 10.1), are continuous with those that protect the brain, the **cranial meninges** (see Figure 10.7). The outermost of the three layers of the meninges is called the **dura mater** (DOO-ra MĀter = tough mother). Its tough, dense irregular connective tissue helps protect the delicate struc-

Figure 10.1 Spinal meninges.



Anterior view and transverse section through spinal cord

In which meningeal space does cerebrospinal fluid circulate?

tures of the CNS. The tube of spinal dura mater extends to the second sacral vertebra, well beyond the spinal cord, which ends at about the level of the second lumbar vertebra. The spinal cord is also protected by a cushion of fat and connective tissue located in the **epidural space**, a space between the dura mater and vertebral column.

The middle layer of the meninges is called the **arachnoid mater** (a-RAK-noyd; *arachn-* = spider; *-oid* = similar to) because the arrangement of its collagen and elastic fibers resembles a spider's web. The inner layer, the **pia mater** (PĒ-a MĀ-ter; *pia* = delicate), is a transparent layer of collagen and elastic fibers that adheres to the surface of the spinal cord and brain. It contains numerous blood vessels. Between the arachnoid mater and the pia mater is the **subarachnoid space**, where cerebrospinal fluid circulates.

In a **spinal tap (lumbar puncture)**, a local anesthetic is given, and a long needle is inserted into the subarachnoid space. In adults, a spinal tap is normally performed between the third and fourth or fourth and fifth lumbar vertebrae. Because this region is inferior to the lowest portion of the spinal cord, it provides relatively safe access. The procedure is used to withdraw cerebrospinal fluid (CSF) for diagnostic purposes; to introduce antibiotics, contrast media for myelography, or anesthetics; to administer chemotherapy; to measure CSF pressure; and/or to evaluate the effects of treatment for diseases such as meningitis.

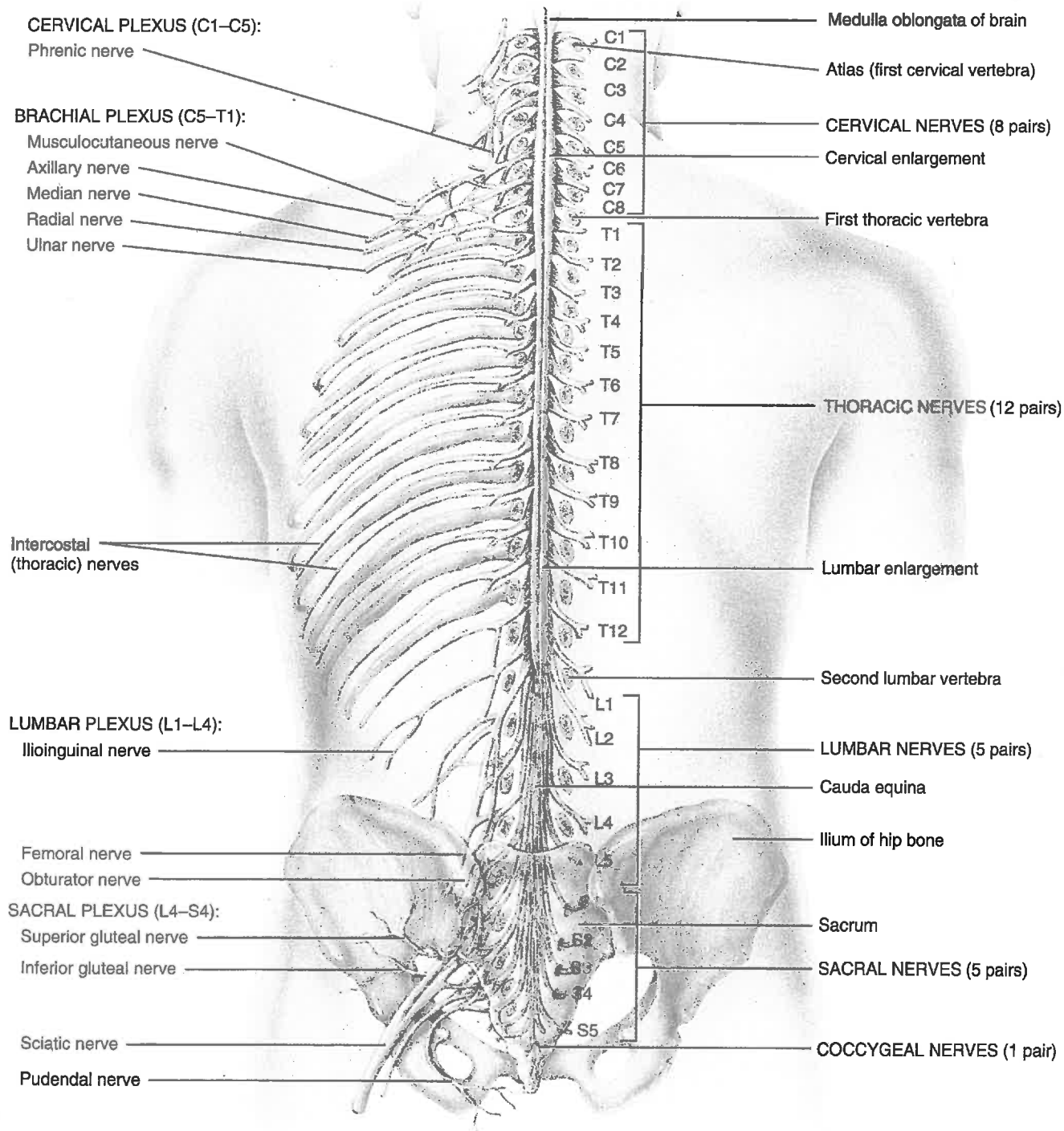
Gross Anatomy of the Spinal Cord

The length of the adult **spinal cord** ranges from 42 to 45 cm (16 to 18 in.). It extends from the lowest part of the brain, the medulla oblongata, to the upper border of the second lumbar vertebra in the vertebral column (Figure 10.2). Because the spinal cord is shorter than the vertebral column, nerves that arise from the lumbar, sacral, and coccygeal regions of the spinal cord do not leave the vertebral column at the same level they exit the cord. The roots of these spinal nerves angle down the vertebral cavity like wisps of flowing hair. They are appropriately named the **cauda equina** (KAW-da ē-KWĪ-na), meaning horse's tail. The spinal cord has two conspicuous enlargements: The **cervical enlargement** contains nerves that supply the upper limbs, and the **lumbar enlargement** contains nerves supplying the lower limbs. Each of 31 **spinal segments** of the spinal cord gives rise to a pair of spinal nerves (Figure 10.2).

Two grooves, the deep **anterior median fissure** and the shallow **posterior median sulcus**, divide the spinal cord into right and left halves (see Figure 10.3). In the spinal cord, white matter surrounds a centrally located H-shaped mass of gray matter. In the center of the gray matter is the **central canal**, a small space that extends the length of the cord and contains cerebrospinal fluid.

Figure 10.2 Spinal cord and spinal nerves. Selected nerves are labeled on the left side of the figure. Together, the lumbar and sacral plexuses are called the lumbosacral plexus.

The spinal cord extends from the base of the skull to the superior border of the second lumbar vertebra.



Posterior view of entire spinal cord and portions of spinal nerves and their branches

Are spinal nerves part of the CNS or the PNS?

Internal Structure of the Spinal Cord

The gray matter of the spinal cord contains neuronal cell bodies, dendrites, unmyelinated axons, axon terminals, and neuroglia. On each side of the spinal cord, the gray matter is subdivided into regions called **horns**, named relative to their location: anterior, lateral, and posterior (Figure 10.3). The **anterior (ventral) gray horns** contain cell bodies of somatic motor neurons, which provide the nerve impulses that cause contraction of skeletal muscles. The **posterior (dorsal) gray horns** contain somatic and autonomic sensory neurons. Between the anterior and posterior gray horns are the **lateral gray horns**, which are present only in the thoracic, upper lumbar, and sacral segments of the cord. The lateral horns contain the cell bodies of autonomic motor neurons that regulate the activity of smooth muscle, cardiac muscle, and glands.

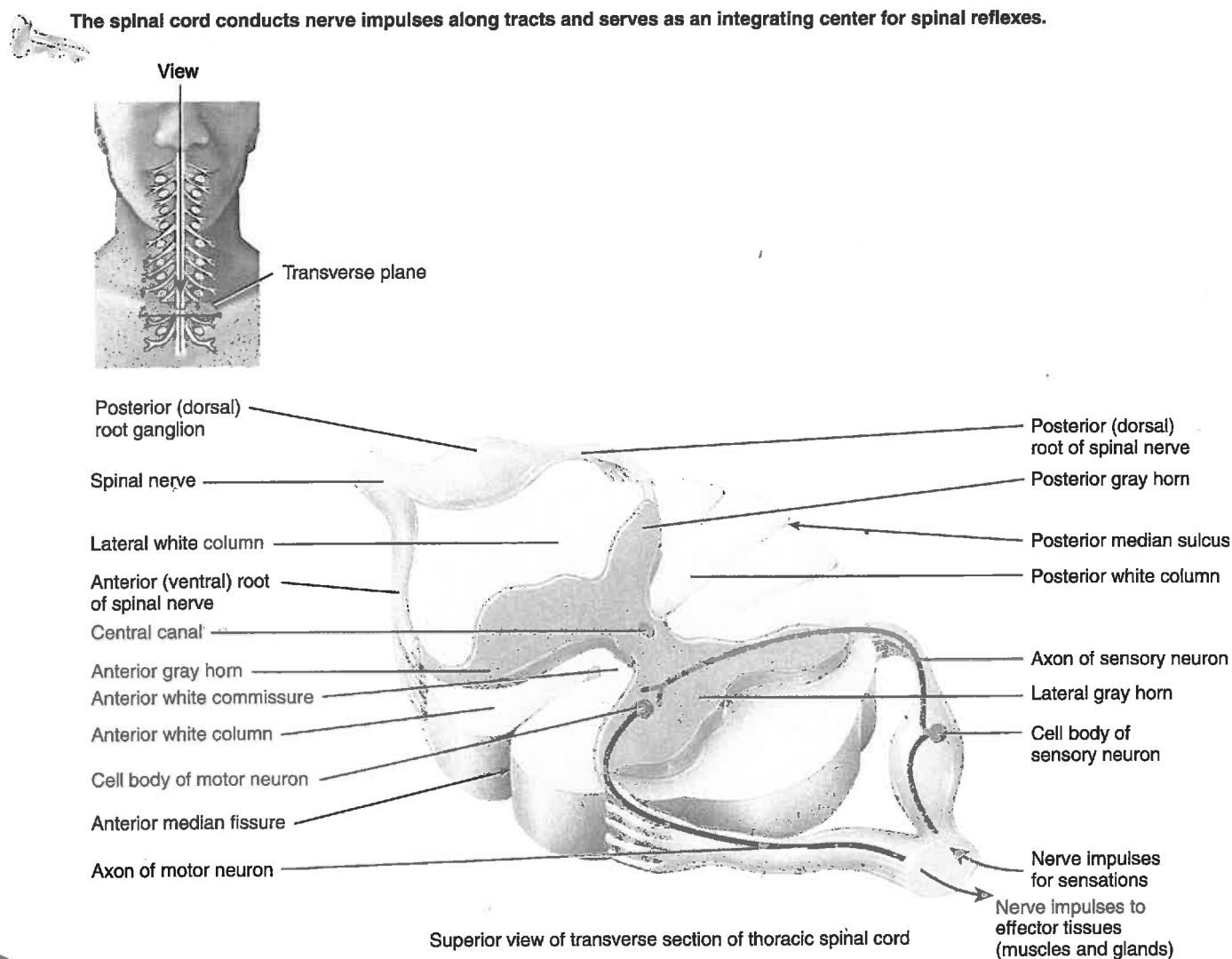
The white matter of the spinal cord consists primarily of myelinated axons of neurons and is organized into regions called anterior, lateral, and posterior **white columns**. Each column con-

tains one or more **tracts**, which are distinct bundles of axons having a common origin or destination and carrying similar information. **Sensory (ascending) tracts** consist of axons that conduct nerve impulses toward the brain. Tracts consisting of axons that carry nerve impulses down the spinal cord are called **motor (descending) tracts**. Sensory and motor tracts of the spinal cord are continuous with sensory and motor tracts in the brain. Often, the name of a tract indicates its position in the white matter, where it begins and ends, and the direction of nerve impulse conduction. For example, the anterior spinothalamic tract is located in the **anterior white column**; it begins in the **spinal cord**, and it ends in the **thalamus** (a region of the brain) (see Figure 10.14b).

CHECKPOINT

1. How is the spinal cord protected?
2. What body regions are served by nerves from the cervical and lumbar enlargements?
3. Distinguish between a horn and a column in the spinal cord.

Figure 10.3 Internal structure of the spinal cord. Columns of white matter surround the gray matter.



? What is the difference between a **horn** and a **column** in the spinal cord?

SPINAL NERVES

OBJECTIVE • Describe the composition, coverings, and distribution of spinal nerves.

Spinal nerves are the paths of communication between the spinal cord and the nerves that serve specific regions of the body. Two bundles of axons, called **roots**, connect each spinal nerve to a segment of the cord (Figure 10.3). The **posterior (dorsal) root** contains only sensory axons, which conduct nerve impulses for sensations from the skin, muscles, and internal organs into the central nervous system. Each posterior root also has a swelling, the **posterior (dorsal) root ganglion**, that contains the cell bodies of sensory neurons. The other point of attachment of a spinal nerve to the cord is the **anterior (ventral) root**. It contains axons of **somatic motor neurons**, which conduct nerve impulses from the CNS to skeletal muscles, and **autonomic motor neurons**, which conduct impulses to smooth muscle, cardiac muscle, and glands. A spinal nerve thus contains both sensory and motor axons and therefore is a **mixed nerve**.

Spinal nerves and the nerves that branch from them are part of the peripheral nervous system (PNS). They connect the CNS to sensory receptors, muscles, and glands in all parts of the body. The 31 pairs of spinal nerves are named and numbered according to the region and level of the vertebral column from which they emerge (see Figure 10.2). There are 8 pairs of cervical nerves, 12 pairs of thoracic nerves, 5 pairs of lumbar nerves, 5 pairs of sacral nerves, and 1 pair of coccygeal nerves. The first cervical pair emerges above the atlas. All other spinal nerves leave the vertebral column by passing through the **intervertebral foramina**, the holes between vertebrae.

Spinal Nerve Coverings

Each spinal nerve (and cranial nerve) contains layers of protective connective tissue coverings (Figure 10.4). Individual axons, whether myelinated or unmyelinated, are wrapped in **endoneurium** (en'-dō-NOO-rē-um; *endo*- = within or inner). Groups of axons with their endoneurium are arranged in bundles, called **fascicles**, each of which is wrapped in **perineurium** (per'-i-NOO-rē-um; *peri*- = around). The superficial covering over the entire nerve is the **epineurium** (ep'-i-NOO-rē-um; *epi*- = over). The dura mater of the spinal meninges fuses with the epineurium as a spinal nerve passes through the intervertebral foramen. Note the presence of many blood vessels, which nourish nerves, within the perineurium and epineurium.

Distribution of Spinal Nerves

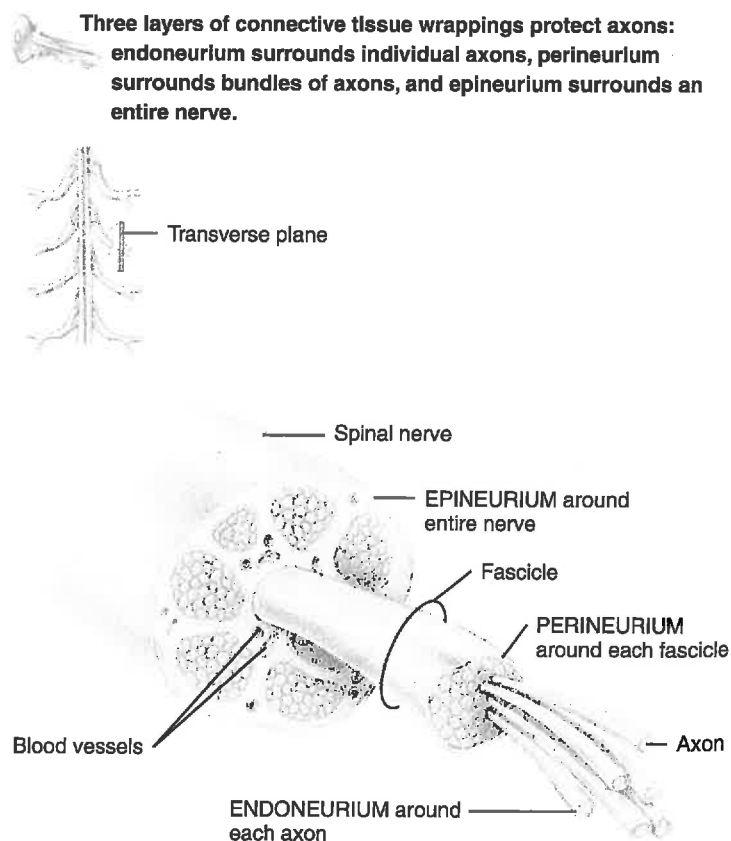
Plexuses

A short distance after passing through its intervertebral foramen, a spinal nerve divides into several branches. Many of the spinal nerve branches do not extend directly to the body structures they supply. Instead, they form networks on either

side of the body by joining with axons from adjacent nerves. Such a network is called a **plexus** (= braid or network). Emerging from the plexuses are nerves bearing names that are often descriptive of the general regions they supply or the course they take. Each of the nerves, in turn, may have several branches named for the specific structures they supply.

The major plexuses are the cervical plexus, brachial plexus, lumbar plexus, and sacral plexus (see Figure 10.2). The **cervical plexus** supplies the skin and muscles of the posterior head, neck, upper part of the shoulders, and the diaphragm. The phrenic nerves, which stimulate the diaphragm to contract, arise from the cervical plexus. Damage to the spinal cord above the origin of the phrenic nerves may cause respiratory failure. The **brachial plexus** constitutes the nerve supply for the upper limbs and several neck and shoulder muscles. Among the nerves that arise from the brachial plexus are the musculocutaneous, axillary, median, radial, and ulnar nerves. The **lumbar plexus** supplies the abdominal wall, external genitals, and part of the lower limbs. Arising from this plexus are the ilioinguinal, femoral, and obturator nerves. The **sacral plexus** supplies the buttocks, perineum,

Figure 10.4 Composition and connective tissue coverings of a spinal nerve.



Transverse section showing the coverings of a spinal nerve

Why are all spinal nerves classified as mixed nerves?

and lower limbs. Among the nerves that arise from this plexus are the gluteal, sciatic, and pudendal nerves. The sciatic nerve is the longest nerve in the body.

Spinal nerves T2 to T11 do not form plexuses. They are known as *intercostal nerves* and extend directly to the structures they supply, including the muscles between ribs, abdominal muscles, and skin of the chest and back (see Figure 10.2).

■ CHECKPOINT

4. How do spinal nerves connect to the spinal cord?
5. Which regions of the body are supplied by plexuses, and which are served by intercostal nerves?

SPINAL CORD FUNCTIONS

OBJECTIVES • Describe the functions of the spinal cord.

• Describe the components of a reflex arc.

The spinal cord white matter and gray matter have two major functions in maintaining homeostasis. (1) The white matter of the spinal cord consists of tracts that serve as highways for nerve impulse conduction. Along these highways, sensory impulses travel toward the brain and motor impulses travel from the brain toward skeletal muscles and other effector tissues. The route that nerve impulses follow from a neuron in one part of the body to other neurons elsewhere in the body is called a *pathway*. After describing the functions of various regions of the brain, we will depict some important pathways that connect the spinal cord and brain (see Figures 10.14 and 10.15). (2) The gray matter of the spinal cord receives and integrates incoming and outgoing information and is a site for integration of reflexes. A *reflex* is a fast, involuntary sequence of actions that occurs in response to a particular stimulus. Some reflexes are inborn, such as pulling your hand away from a hot surface before you even feel that it is hot (a *withdrawal reflex*). Other reflexes are learned or acquired, such as the many reflexes you learn while acquiring driving skills. When integration takes place in the spinal cord gray matter, the reflex is a *spinal reflex*. By contrast, if integration occurs in the brain stem rather than the spinal cord, the reflex is a *cranial reflex*. An example is the tracking movements of your eyes as you read this sentence.

The pathway followed by nerve impulses that produce a reflex is known as a *reflex arc*. Using the *patellar reflex* (knee jerk reflex) as an example, the basic components of a reflex arc are as follows (Figure 10.5):

- 1 **Sensory receptor.** The distal end of a sensory neuron (or sometimes a separate receptor cell) serves as a *sensory receptor*. Sensory receptors respond to a specific type of stimulus by generating one or more nerve impulses. In the patellar reflex, sensory receptors known as *muscle*

spindles detect slight stretching of the quadriceps femoris (anterior thigh) muscle when the patellar (knee cap) ligament is tapped with a reflex hammer.

- 2 **Sensory neuron.** The nerve impulses conduct from the sensory receptor along the axon of a *sensory neuron* to its axon terminals, which are located in the CNS gray matter. Axon branches of the sensory neuron also relay nerve impulses to the brain, allowing conscious awareness that the reflex has occurred.
- 3 **Integrating center.** One or more regions of gray matter in the CNS act as an *integrating center*. In the simplest type of reflex, such as the patellar reflex, the integrating center is a single synapse between a sensory neuron and a motor neuron. In other types of reflexes, the integrating center includes one or more interneurons.
- 4 **Motor neuron.** Impulses triggered by the integrating center pass out of the spinal cord (or brain stem, in the case of a cranial reflex) along a *motor neuron* to the part of the body that will respond. In the patellar reflex, the axon of the motor neuron extends to the quadriceps femoris muscle.
- 5 **Effector.** The part of the body that responds to the motor nerve impulse, such as a muscle or gland, is the *effector*. Its action is a reflex. If the effector is skeletal muscle, the reflex is a *somatic reflex*. If the effector is smooth muscle, cardiac muscle, or a gland, the reflex is an *autonomic (visceral) reflex*. For example, the acts of swallowing, urinating, and defecating all involve autonomic reflexes. The patellar reflex is a somatic reflex because its effector is the quadriceps femoris muscle, which contracts and thereby relieves the stretching that initiated the reflex. In sum, the patellar reflex causes extension of the knee by contraction of the quadriceps femoris muscle in response to tapping the patellar ligament.

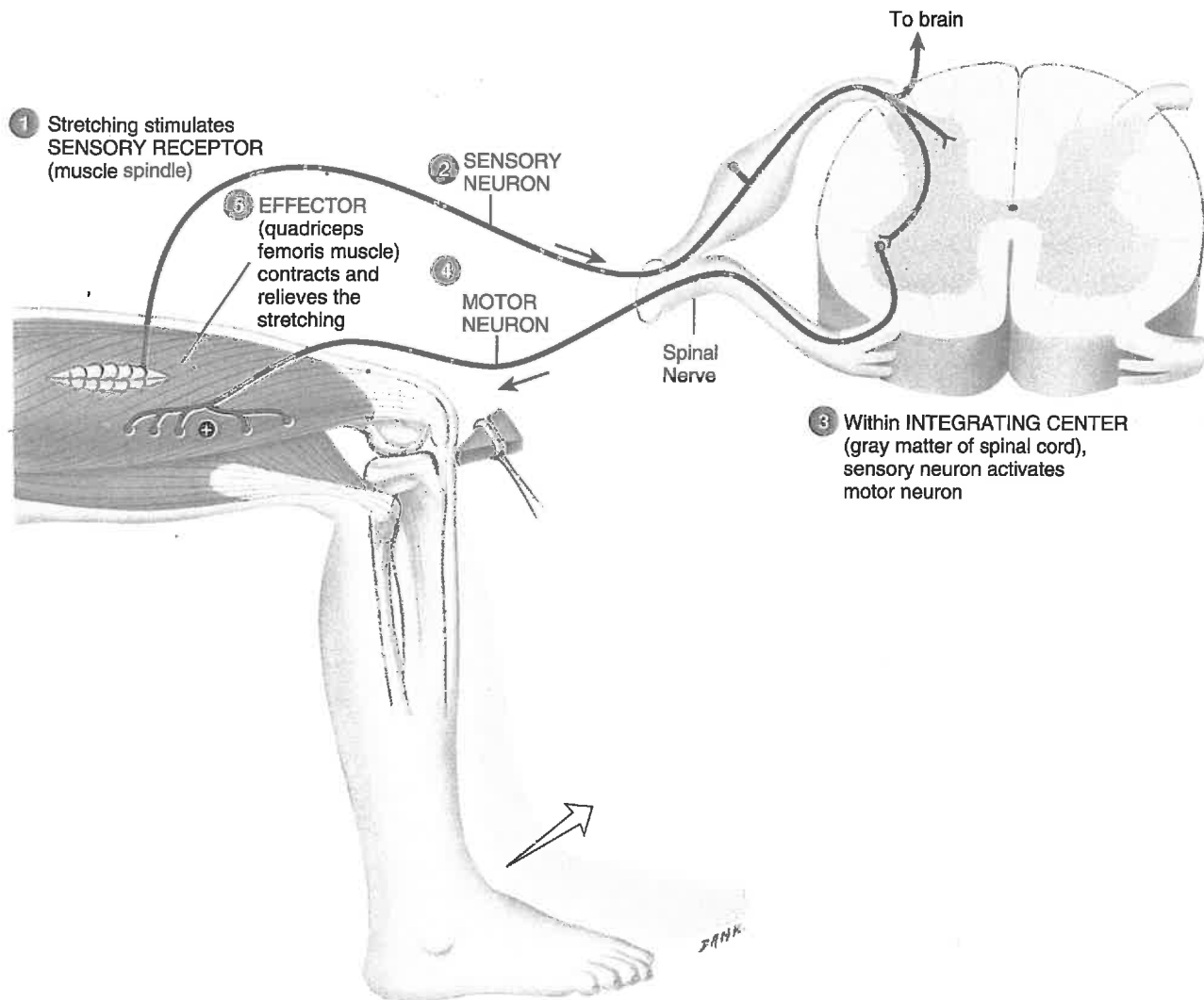
Damage or disease anywhere along a reflex arc can cause the reflex to be absent or abnormal. For example, **absence of the patellar reflex** could indicate damage of the sensory or motor neurons, or a spinal cord injury, in the lumbar region. Somatic reflexes generally can be tested simply by tapping or stroking the body surface. Most autonomic reflexes, by contrast, are not practical diagnostic tools because it is difficult to stimulate visceral receptors, which are deep inside the body. An exception is the pupillary light reflex, in which the pupils of both eyes decrease in diameter when either eye is exposed to light. Because the reflex arc includes synapses in lower parts of the brain, the **absence of a normal pupillary light reflex** may indicate brain damage or injury.

■ CHECKPOINT

6. What is the significance of the white matter tracts of the spinal cord?
7. How are somatic and autonomic reflexes similar and different?

Figure 10.5 Patellar reflex, showing general components of a reflex arc. The arrows show the direction of nerve impulse conduction.

A reflex is a fast, involuntary sequence of actions that occurs in response to a particular stimulus.



? Which attachment of a spinal nerve to the spinal cord contains axons of sensory neurons? Which attachment contains axons of motor neurons?

BRAIN

OBJECTIVES • Discuss how the brain is protected and supplied with blood.

- Name the major parts of the brain and explain the function of each part.
- Describe three somatic sensory and somatic motor pathways.

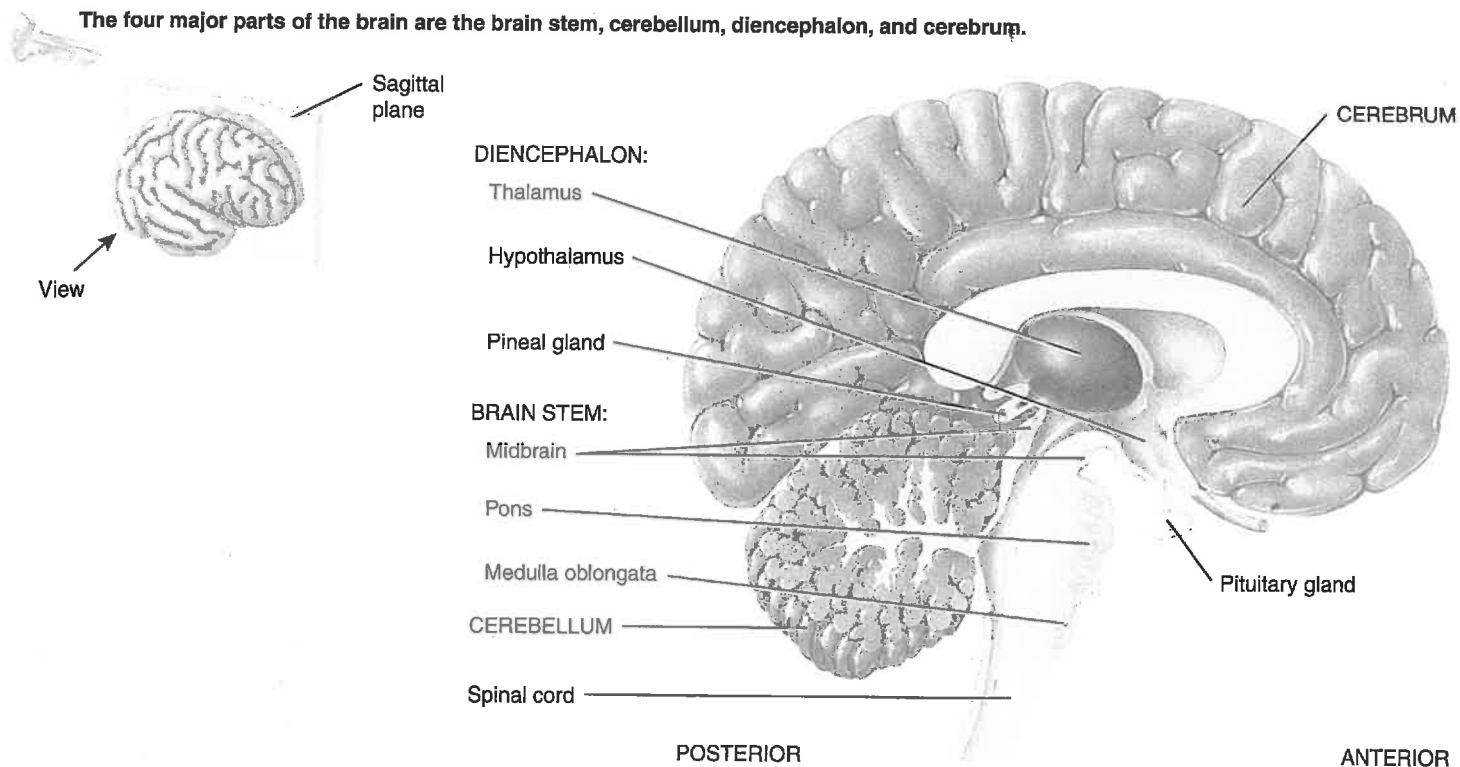
Next, we will consider the major parts of the brain, how the brain is protected, and how it is related to the spinal cord and cranial nerves.

Major Parts and Protective Coverings

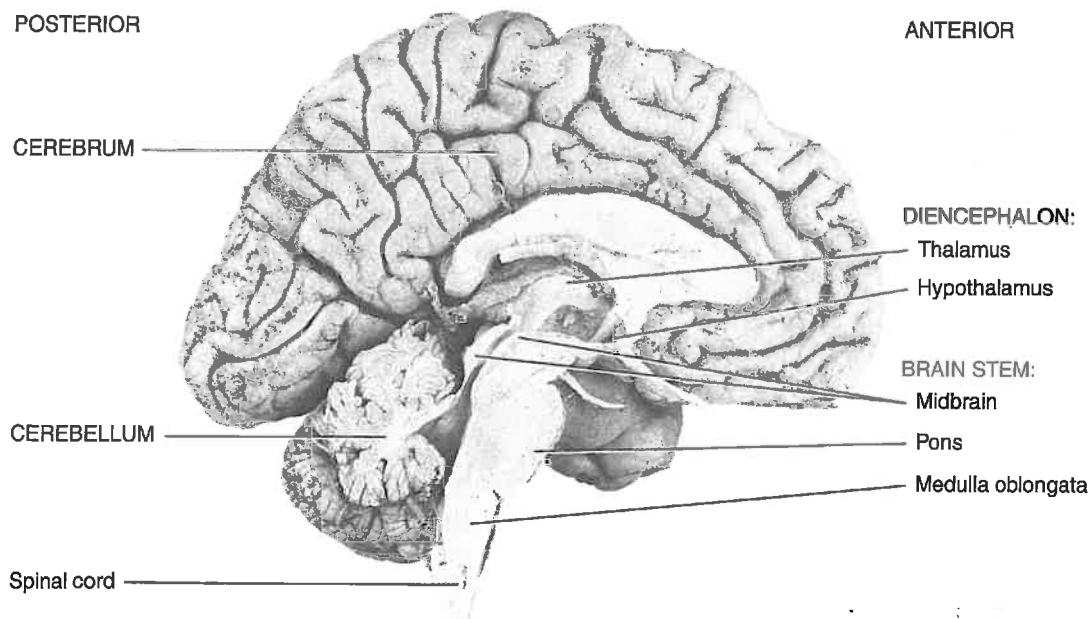
The **brain** is one of the largest organs of the body, consisting of about 100 billion neurons and 10–50 trillion neuroglia with a mass of about 1300 g (almost 3 lb). The four major parts are the brain stem, diencephalon, cerebrum, and cerebellum (Figure 10.6). The **brain stem** is continuous with the spinal cord and consists of the medulla oblongata, pons, and midbrain. Above the brain stem is the **diencephalon** (dī'en-SEF-a-lon; *di-* = through; *-encephalon* = brain), consisting mostly of the thalamus, hypothalamus, and pineal gland. Supported on the diencephalon and brain stem and forming the bulk of the brain is the **cerebrum** (se-RĒ-brum = brain).

Figure 10.6 Brain. The pituitary gland is discussed together with the endocrine system in Chapter 13.

The four major parts of the brain are the brain stem, cerebellum, diencephalon, and cerebrum.



(a) Sagittal section, medial view



(b) Sagittal section, medial view



Which part of the brain attaches to the spinal cord?

The surface of the cerebrum is composed of a thin layer of gray matter, the *cerebral cortex* (*cortex* = rind or bark), beneath which lies the cerebral white matter. Posterior to the brain stem is the *cerebellum* (ser'-e-BEL-um = little brain).

As you learned earlier in the chapter, the brain is protected by the cranium and cranial meninges. The *cranial meninges* have the same names as the spinal meninges: the outermost *dura mater*, middle *arachnoid mater*, and innermost *pia mater* (Figure 10.7).

Brain Blood Supply and the Blood–Brain Barrier

Although the brain constitutes only about 2% of total body weight, it requires about 20% of the body's oxygen supply. If blood flow to the brain stops, even briefly, unconsciousness may result. Brain neurons that are totally deprived of oxygen for four or more minutes may be permanently injured. Blood supplying the brain also contains glucose, the main source of energy for brain cells. Because virtually no glucose is stored in the brain, the supply of glucose also must be continuous. If blood entering the brain has a low level of glucose, mental confusion, dizziness, convulsions, and loss of consciousness may occur.

The existence of a *blood–brain barrier (BBB)* protects brain cells from harmful substances and pathogens by preventing passage of many substances from blood into brain tissue. This barrier consists basically of very tightly sealed blood capillaries (microscopic blood vessels) in the brain. However, lipid-soluble substances such as oxygen, carbon dioxide, alcohol, and most anesthetic agents, easily cross the blood-brain barrier. Trauma, certain toxins, and inflammation can cause a breakdown of the blood–brain barrier.

Cerebrospinal Fluid

The spinal cord and brain are further protected against chemical and physical injury by *cerebrospinal fluid (CSF)*. CSF is a clear, colorless liquid that carries oxygen, glucose, and other needed chemicals from the blood to neurons and neuroglia and removes wastes and toxic substances produced by brain and spinal cord cells. CSF circulates through the subarachnoid space (between the arachnoid mater and pia mater), around the brain and spinal cord, and through cavities in the brain known as *ventricles* (VEN-tri-kuls = little cavities). There are four ventricles: two *lateral ventricles*, one *third ventricle*, and one *fourth ventricle* (Figure 10.7). Openings connect them with one another, with the central canal of the spinal cord, and with the subarachnoid space.

The sites of CSF production are the *choroid plexuses* (KÖ-royd = membranelike), which are specialized networks of capillaries in the walls of the ventricles (Figure 10.7). Covering the choroid plexus capillaries are ependymal cells, which form cerebrospinal fluid from blood plasma by filtra-

tion and secretion. From the fourth ventricle, CSF flows into the central canal of the spinal cord and into the subarachnoid space around the surface of the brain and spinal cord. CSF is gradually reabsorbed into the blood through *arachnoid villi*, which are fingerlike extensions of the arachnoid mater. The CSF drains primarily into a vein called the *superior sagittal sinus* (Figure 10.7). Normally, the volume of CSF remains constant at 80 to 150 mL (3 to 5 oz) because it is absorbed as rapidly as it is formed.

Abnormalities in the brain—tumors, inflammation, or developmental malformation—can interfere with the drainage of CSF from the ventricles into the subarachnoid space. When *excess* CSF accumulates in the ventricles, the CSF pressure rises. Elevated CSF pressure causes a condition called **hydrocephalus** (hī'-drō-SEF-a-lus; *hydro-* = water; *cephal-* = head). In a baby in whom the fontanels have not yet closed, the head bulges due to the increased pressure. If the condition persists, the fluid buildup compresses and damages the delicate nervous tissue. Hydrocephalus is relieved by draining the excess CSF. A neurosurgeon may implant a drain line, called a shunt, into the lateral ventricle to divert CSF into the superior vena cava or abdominal cavity, where it can be absorbed by the blood. In adults, hydrocephalus may occur after head injury, meningitis, or subarachnoid hemorrhage. This condition can quickly become life-threatening and requires immediate intervention; since the adult skull bones have already fused, nervous tissue damage occurs quickly.

Brain Stem

The brain stem is the part of the brain between the spinal cord and the diencephalon. It consists of three regions: (1) the medulla oblongata, (2) pons, and (3) midbrain. Extending through the brain stem is the reticular formation, a region where gray and white matter are intermingled.

Medulla Oblongata

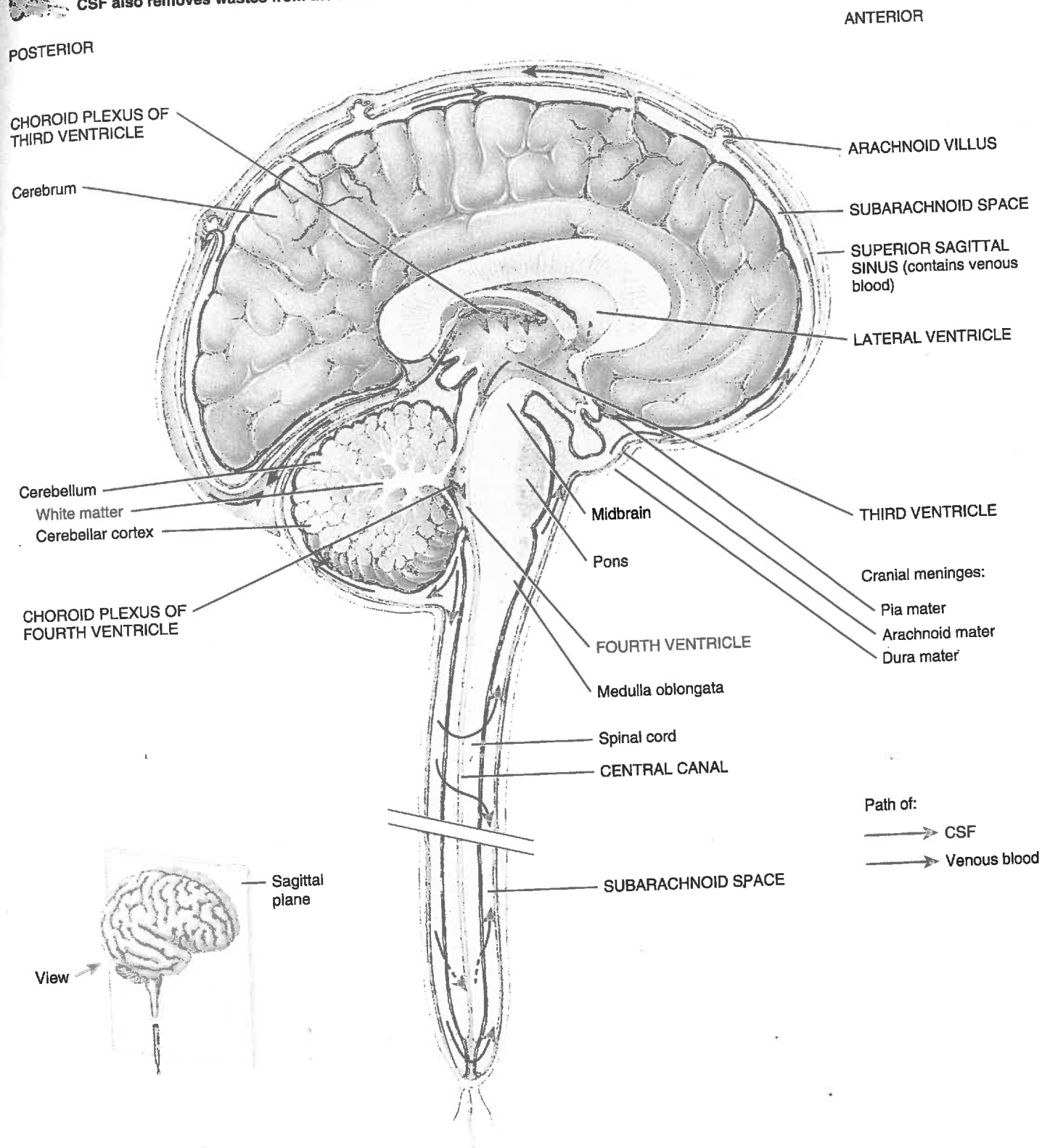
The *medulla oblongata* (me-DOOL-la ob'-long-GA-ta), or simply *medulla*, is a continuation of the spinal cord (see Figure 10.6). It forms the inferior part of the brain stem (Figure 10.8 on page 252). Within the medulla's white matter are all sensory (ascending) and motor (descending) tracts extending between the spinal cord and other parts of the brain.

The medulla also contains several nuclei, which are masses of gray matter where neurons form synapses with one another. Two major nuclei are the *cardiovascular center*, which regulates the rate and force of the heartbeat and the diameter of blood vessels (see Figure 15.9 on page 377), and the *medullary rhythmicity area*, which adjusts the basic rhythm of breathing (see Figure 18.12 on page 462). Nuclei associated with sensations of touch and vibration are located



Figure 10.7 Meninges and ventricles of the brain.

Cerebrospinal fluid (CSF) protects the brain and spinal cord and delivers nutrients from the blood to the brain and spinal cord; CSF also removes wastes from the brain and spinal cord to the blood.



Sagittal section of brain and spinal cord

Where is CSF formed and absorbed?