NEUROSCIENCE

Exploring the Brain

Enhanced Fourth Edition

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INTRODUCTION

In previous chapters, we saw how individual neurons function and communicate. Now we are ready to assemble them into a nervous system that sees, hears, feels, moves, remembers, and dreams. Just as an understanding of neuronal structure is necessary for understanding neuronal function, we must understand nervous system structure in order to understand brain function.

Neuroanatomy has challenged generations of students—and for good reason: The human brain is extremely complicated. However, our brain is merely a variation on a plan that is common to the brains of all mammals (Figure 7.1). The human brain appears complicated because it is distorted as a result of the selective growth of some parts within the confines of the skull. But once the basic mammalian plan is understood, these specializations of the human brain become clear.

We begin by introducing the general organization of the mammalian brain and the terms used to describe it. Then we take a look at how the three-dimensional structure of the brain arises during embryological and fetal development. Following the course of development makes it easier to understand how the parts of the adult brain fit together. Finally, we explore the cerebral neocortex, a structure that is unique to mammals and proportionately the largest in humans. An Illustrated Guide to Human Neuroanatomy follows the chapter as an appendix.

The neuroanatomy presented in this chapter provides the canvas on which we will paint the sensory and motor systems in Chapters 8–14. Because you will encounter a lot of new terms, self-quizzes within this chapter provide an opportunity for review.

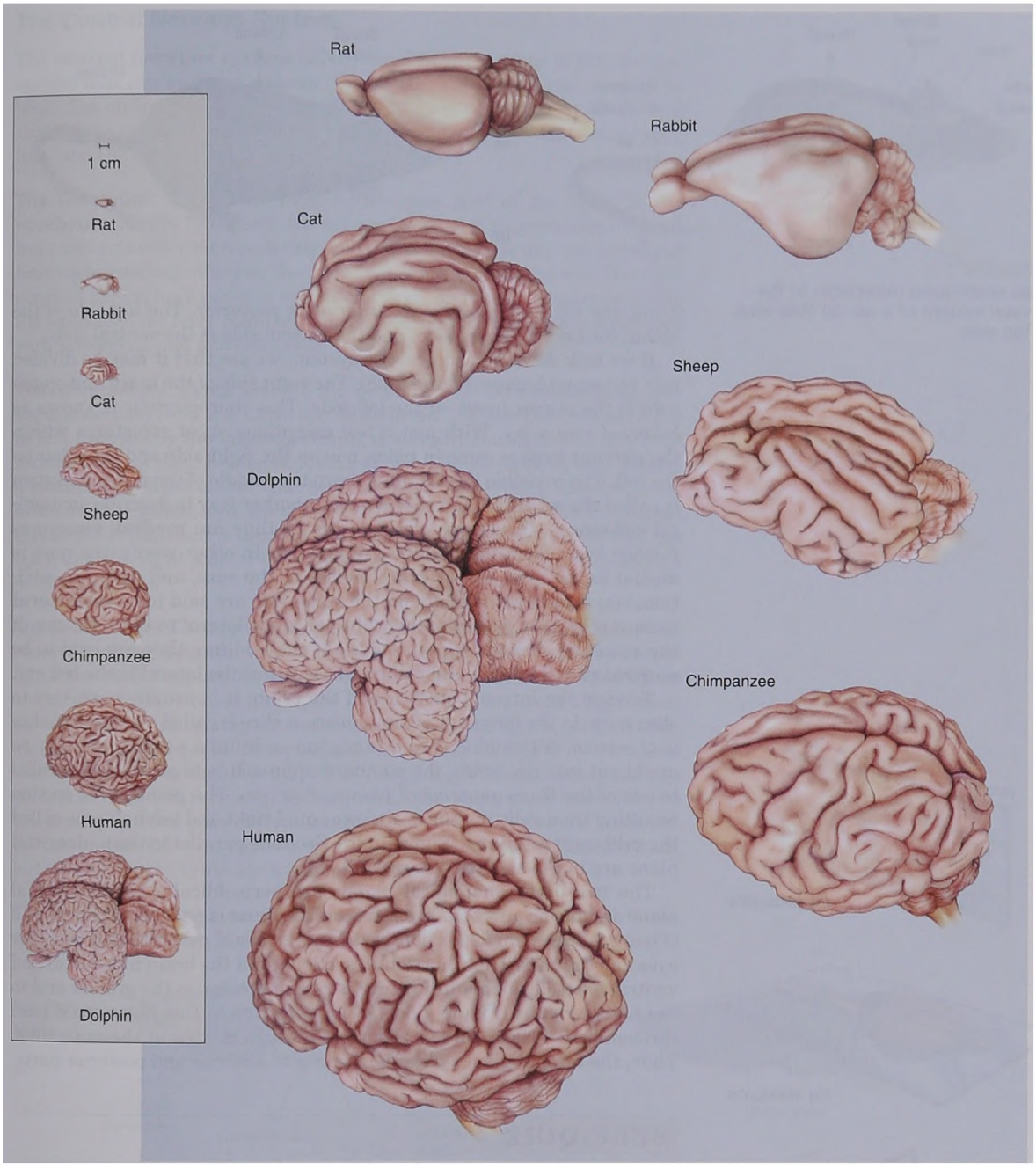
GROSS ORGANIZATION OF THE MAMMALIAN NERVOUS SYSTEM

The nervous system of all mammals has two divisions: the central nervous system (CNS) and the peripheral nervous system (PNS). Here we identify some of the important components of the CNS and the PNS. We also discuss the membranes that surround the brain and the fluid-filled ventricles within the brain. We'll then explore some new methods of examining the structure of the brain. But first, we need to review some anatomical terminology.

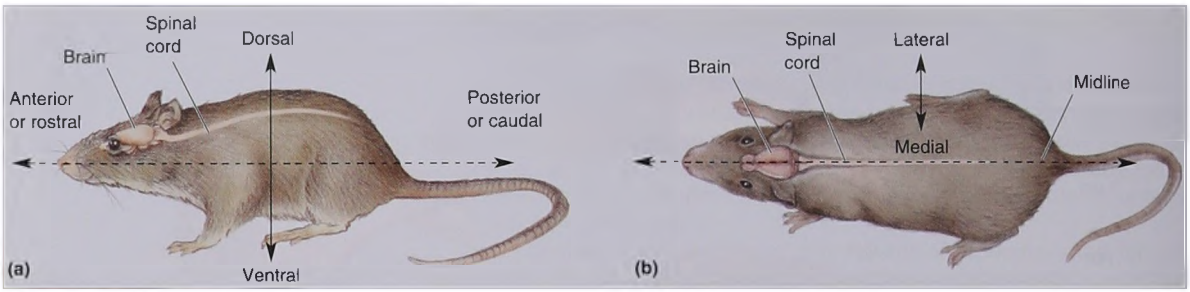
Anatomical References

Getting to know your way around the brain is like getting to know your way around a city. To describe your location in the city, you would use points of reference such as north, south, east, and west and up and down. The same is true for the brain, except that the terms—called *anatomical references*—are different.

Consider the nervous system of a rat (Figure 7.2a). We begin with the rat because it is a simplified version that has all the general features of mammalian nervous system organization. In the head lies the brain, and the spinal cord runs down inside the backbone toward the tail. The direction, or anatomical reference, pointing toward the rat's nose is known as **anterior** or **rostral** (from the Latin for "beak"). The direction pointing toward the rat's tail is **posterior** or **caudal** (from the Latin for "tail"). The direction pointing up is known as **dorsal** (from the Latin for "back"), and the direction pointing down is **ventral** (from the Latin for "belly").



▲ FIGURE 7.1
Mammalian brains. Despite differences in complexity, the brains of all these species have many features in common. The brains have been drawn to appear approximately the same size; their relative sizes are shown in the inset on the left.



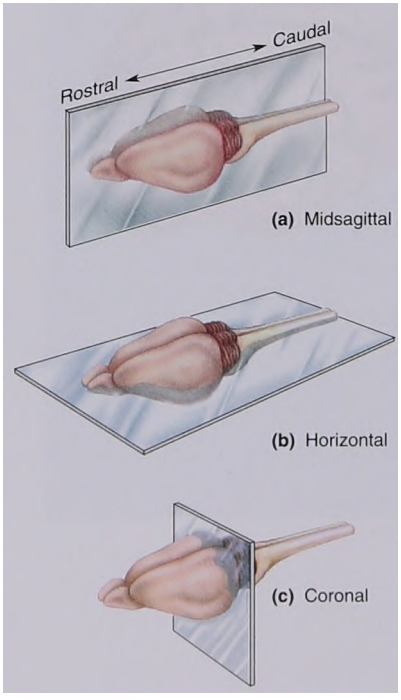
▲ FIGURE 7.2
Basic anatomical references in the nervous system of a rat. (a) Side view. (b) Top view.

Thus, the rat spinal cord runs anterior to posterior. The top side of the spinal cord is the dorsal side, and the bottom side is the ventral side.

If we look down on the nervous system, we see that it may be divided into two equal halves (Figure 7.2b). The right side of the brain and spinal cord is the mirror image of the left side. This characteristic is known as *bilateral symmetry*. With just a few exceptions, most structures within the nervous system come in pairs, one on the right side and the other on the left. The invisible line running down the middle of the nervous system is called the **midline**, and this gives us another way to describe anatomical references. Structures closer to the midline are **medial**; structures farther away from the midline are **lateral**. In other words, the nose is medial to the eyes, the eyes are medial to the ears, and so on. In addition, two structures that are on the same side are said to be **ipsilateral** to each other; for example, the right ear is ipsilateral to the right eye. If the structures are on opposite sides of the midline, they are said to be **contralateral** to each other; the right ear is contralateral to the left ear.

To view the internal structure of the brain, it is usually necessary to slice it up. In the language of anatomists, a slice is called a *section*; to slice is *to section*. Although one could imagine an infinite number of ways we might cut into the brain, the standard approach is to make cuts parallel to one of the three *anatomical planes of section*. The plane of the section resulting from splitting the brain into equal right and left halves is called the **midsagittal plane** (Figure 7.3a). Sections parallel to the midsagittal plane are in the **sagittal plane**.

The two other anatomical planes are perpendicular to the sagittal plane and to one another. The **horizontal plane** is parallel to the ground (Figure 7.3b). A single section in this plane could pass through both the eyes and the ears. Thus, horizontal sections split the brain into dorsal and ventral parts. The **coronal plane** is perpendicular to the ground and to the sagittal plane (Figure 7.3c). A single section in this plane could pass through both eyes or both ears but not through all four at the same time. Thus, the coronal plane splits the brain into anterior and posterior parts.



▲ FIGURE 7.3
Anatomical planes of section.

SELF-QUIZ

Take a few moments right now and be sure you understand the meaning of these terms:

anterior	dorsal	lateral	sagittal plane
rostral	ventral	ipsilateral	horizontal plane
posterior	midline	contralateral	coronal plane
caudal	medial	midsagittal plane	

The Central Nervous System

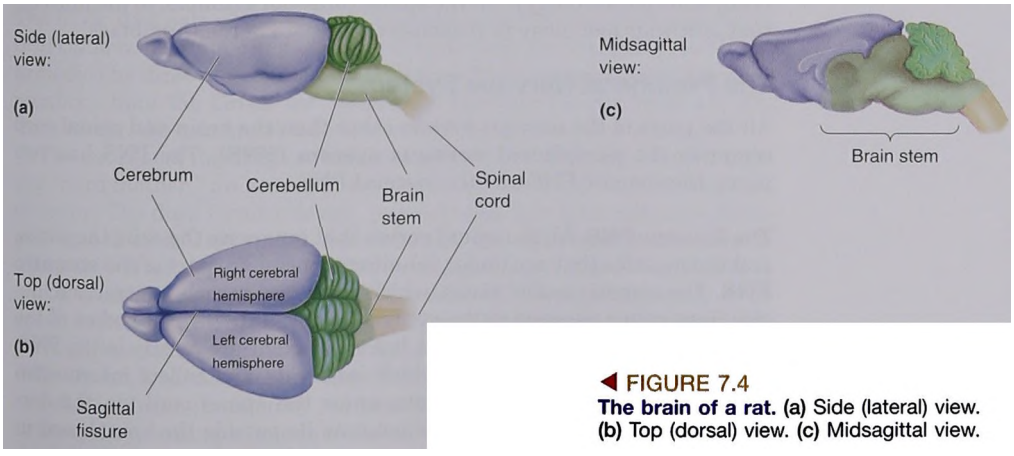
The **central nervous system (CNS)** consists of the parts of the nervous system that are encased in bone: the **brain** and the **spinal cord**. The brain lies entirely within the skull. A side view of the rat brain reveals three parts that are common to all mammals: the cerebrum, the cerebellum, and the brain stem (Figure 7.4a).

The Cerebrum. The rostral-most and largest part of the brain is the **cerebrum**. Figure 7.4b shows the rat cerebrum as it appears when viewed from above. Notice that it is clearly split down the middle into two **cerebral hemispheres**, separated by the deep *sagittal fissure*. In general, the *right* cerebral hemisphere receives sensations from, and controls movements of, the *left* side of the body. Similarly, the *left* cerebral hemisphere is concerned with sensations and movements on the *right* side of the body.

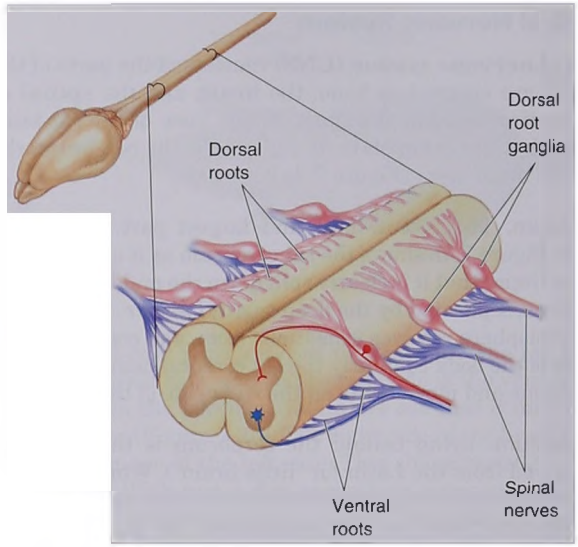
The Cerebellum. Lying behind the cerebrum is the **cerebellum** (the word is derived from the Latin for "little brain"). While the cerebellum is in fact dwarfed by the large cerebrum, it actually contains as many neurons as both cerebral hemispheres combined. The cerebellum is primarily a movement control center that has extensive connections with the cerebrum and the spinal cord. In contrast to the cerebral hemispheres, the left side of the cerebellum is concerned with movements of the left side of the body, and the right side of the cerebellum is concerned with movements of the right side.

The Brain Stem. The remaining part of the brain is the brain stem, best observed in a midsagittal view of the brain (Figure 7.4c). The **brain stem** forms the stalk from which the cerebral hemispheres and the cerebellum sprout. The brain stem is a complex nexus of fibers and cells that in part serves to relay information from the cerebrum to the spinal cord and cerebellum, and vice versa. However, the brain stem is also the site where vital functions are regulated, such as breathing, consciousness, and the control of body temperature. Indeed, while the brain stem is considered the most primitive part of the mammalian brain, it is also the most important to life. One can survive damage to the cerebrum and cerebellum, but damage to the brain stem is usually fatal.

The Spinal Cord. The spinal cord is encased in the bony vertebral column and is attached to the brain stem. The spinal cord is the major conduit of



◀ FIGURE 7.4
The brain of a rat. (a) Side (lateral) view. (b) Top (dorsal) view. (c) Midsagittal view.



▲ FIGURE 7.5
The spinal cord. The spinal cord runs inside the vertebral column. Axons enter and exit the spinal cord via the dorsal and ventral roots, respectively. These roots come together to form the spinal nerves that course through the body.

information from the skin, joints, and muscles of the body to the brain, and vice versa. A transection of the spinal cord results in anesthesia (lack of feeling) in the skin and paralysis of the muscles in parts of the body caudal to the cut. Paralysis in this case does not mean that the muscles cannot function, but they cannot be controlled by the brain.

The spinal cord communicates with the body via the **spinal nerves**, which are part of the peripheral nervous system (discussed below). Spinal nerves exit the spinal cord through notches between each vertebra of the vertebral column. Each spinal nerve attaches to the spinal cord by means of two branches, the **dorsal root** and the **ventral root** (Figure 7.5). Recall from Chapter 1 that François Magendie showed that the dorsal root contains axons bringing information *into* the spinal cord, such as those that signal the accidental entry of a thumbtack into your foot (see Figure 3.1). Charles Bell showed that the ventral root contains axons carrying information *away from* the spinal cord—for example, to the muscles that jerk your foot away in response to the pain of the thumbtack.

The Peripheral Nervous System

All the parts of the nervous system other than the brain and spinal cord comprise the **peripheral nervous system (PNS)**. The PNS has two parts: the somatic PNS and the visceral PNS.

The Somatic PNS. All the spinal nerves that innervate the skin, the joints, and the muscles that are under voluntary control are part of the **somatic PNS**. The somatic motor axons, which command muscle contraction, derive from motor neurons in the ventral spinal cord. The cell bodies of the motor neurons lie within the CNS, but their axons are mostly in the PNS.

The somatic sensory axons, which innervate and collect information from the skin, muscles, and joints, enter the spinal cord via the dorsal roots. The cell bodies of these neurons lie outside the spinal cord in

clusters called **dorsal root ganglia**. There is a dorsal root ganglion for each spinal nerve (see Figure 7.5).

The Visceral PNS. The **visceral PNS**, also called the involuntary, vegetative, or **autonomic nervous system (ANS)**, consists of the neurons that innervate the internal organs, blood vessels, and glands. Visceral sensory axons bring information about visceral function to the CNS, such as the pressure and oxygen content of the blood in the arteries. Visceral motor fibers command the contraction and relaxation of muscles that form the walls of the intestines and the blood vessels (called *smooth muscles*), the rate of cardiac muscle contraction, and the secretory function of various glands. For example, the visceral PNS controls blood pressure by regulating the heart rate and the diameter of the blood vessels.

We will return to the structure and function of the ANS in Chapter 15. For now, remember that when one speaks of an emotional reaction that is beyond voluntary control—like "butterflies in the stomach" or blushing—it usually is mediated by the visceral PNS (the ANS).

Afferent and Efferent Axons. Our discussion of the PNS is a good place to introduce two terms that are used to describe axons in the nervous system. Derived from the Latin, **afferent** ("carry to") and **efferent** ("carry from") indicate whether the axons are transporting information *toward* or *away from* a particular point. Consider the axons in the PNS relative to a point of reference in the CNS. The somatic or visceral sensory axons bringing information *into* the CNS are afferents. The axons that emerge *from* the CNS to innervate the muscles and glands are efferents.

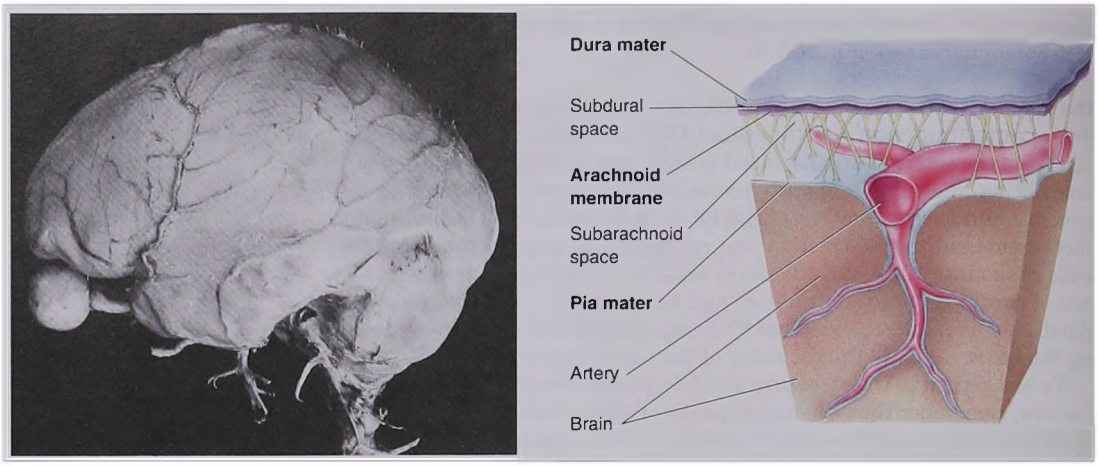
The Cranial Nerves

In addition to the nerves that arise from the spinal cord and innervate the body, there are 12 pairs of **cranial nerves** that arise from the brain stem and innervate (mostly) the head. Each cranial nerve has a name and a number associated with it (originally numbered by Galen, about 1800 years ago, from anterior to posterior). Some of the cranial nerves are part of the CNS, others are part of the somatic PNS, and still others are part of the visceral PNS. Many cranial nerves contain a complex mixture of axons that perform different functions. The cranial nerves and their various functions are summarized in the chapter appendix.

The Meninges

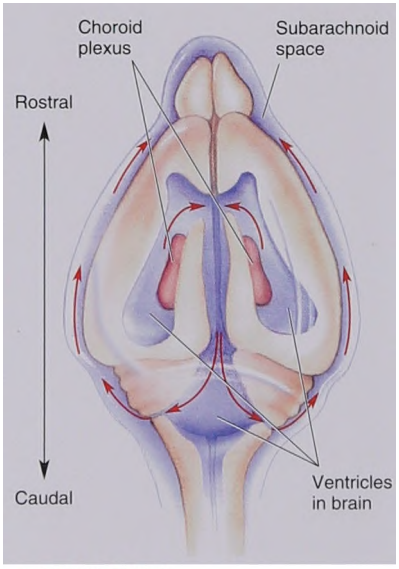
The CNS, that part of the nervous system encased in the skull and vertebral column, does not come in direct contact with the overlying bone. It is protected by three membranes collectively called the **meninges** (singular: meninx), from the Greek for "covering." The three membranes are the dura mater, the arachnoid membrane, and the pia mater (Figure 7.6).

The outermost covering is the **dura mater**, from the Latin words meaning "hard mother," an accurate description of the dura's leatherlike consistency. The dura forms a tough, inelastic bag that surrounds the brain and spinal cord. Just under the dura lies the **arachnoid membrane** (from the Greek for "spider"). This meningeal layer has an appearance and a consistency resembling a spider web. While there normally is no space between the dura and the arachnoid, if the blood vessels passing through the dura are ruptured, blood can collect here and form what is called a *subdural hematoma*. The buildup of fluid in this subdural space can disrupt brain function by compressing parts of the CNS. The disorder is treated by drilling a hole in the skull and draining the blood.



▲ FIGURE 7.6
The meninges. (a) The skull has been removed to show the tough outer meningeal membrane, the dura mater. (Source: Gluhbegoric and Williams, 1980.) (b) Illustrated in cross section, the three meningeal layers protecting the brain and spinal cord are the dura mater, the arachnoid membrane, and the pia mater.

The **pia mater**, the "gentle mother," is a thin membrane that adheres closely to the surface of the brain. Along the pia run many blood vessels that ultimately dive into the substance of the underlying brain. The pia is separated from the arachnoid by a fluid-filled space. This *subarachnoid space* is filled with salty clear liquid called **cerebrospinal fluid (CSF)**. Thus, in a sense, the brain floats inside the head in this thin layer of CSF.



▲ FIGURE 7.7
The ventricular system in a rat brain. CSF is produced in the ventricles of the paired cerebral hemispheres and flows through a series of central ventricles at the core of the brain stem. CSF escapes into the subarachnoid space via small apertures near the base of the cerebellum. In the subarachnoid space, CSF is absorbed into the blood.

The Ventricular System

In Chapter 1, we noted that the brain is hollow. The fluid-filled caverns and canals inside the brain constitute the **ventricular system**. The fluid that runs in this system is CSF, the same as the fluid in the subarachnoid space. CSF is produced by a special tissue, called the *choroid plexus*, in the ventricles of the cerebral hemispheres. CSF flows from the paired ventricles of the cerebrum to a series of connected, central cavities at the core of the brain stem (Figure 7.7). CSF exits the ventricular system and enters the subarachnoid space by way of small openings, or apertures, located near where the cerebellum attaches to the brain stem. In the subarachnoid space, CSF is absorbed by the blood vessels at special structures called *arachnoid villi*. If the normal flow of CSF is disrupted, brain damage can result (Box 7.1).

We will return to fill in some details about the ventricular system in a moment. As we will see, understanding the organization of the ventricular system holds the key to understanding how the mammalian brain is organized.

New Views of the Brain

For centuries, anatomists have investigated the internal structure of the brain by removing it from the skull, sectioning it in various planes, staining the sections, and examining the stained sections. Much has been learned by this approach, but there are some limitations. Among these are the challenges of seeing how parts deep in the brain fit together in

BOX 7.1 OF SPECIAL INTEREST

Water on the Brain

If the flow of CSF from the choroid plexus through the ventricular system to the subarachnoid space is impaired, the fluid will back up and cause a swelling of the ventricles. This condition is called *hydrocephalus*, a term originally meaning "water head."

Occasionally, babies are born with hydrocephalus. However, because the skull is soft and not completely formed, the head will expand in response to the increased intracranial fluid, sparing the brain from damage. Often this condition goes unnoticed until the size of the head reaches enormous proportions.

In adults, hydrocephalus is a much more serious situation because the skull cannot expand, and intracranial pressure increases as a result. The soft brain tissue is then compressed, impairing function and leading to death if left untreated. Typically, this "obstructive" hydrocephalus is also accompanied by severe headache, caused by the distention of nerve endings in the meninges. Treatment consists of inserting a tube into the swollen ventricle and draining off the excess fluid (Figure A).

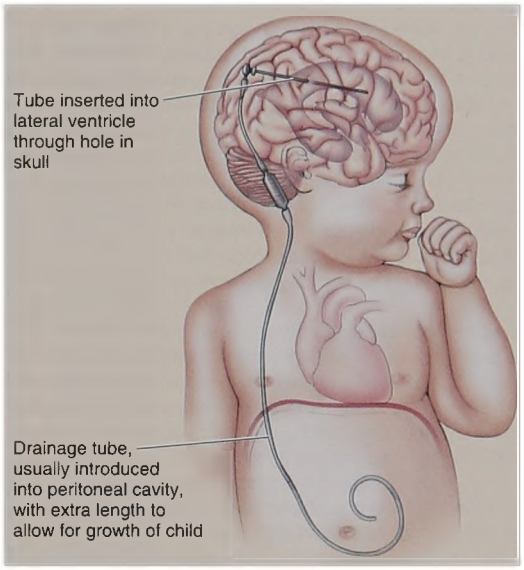
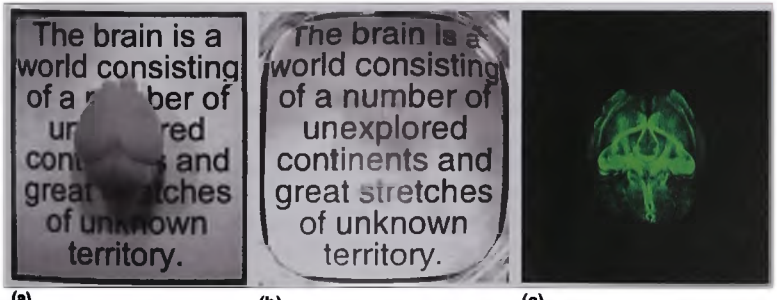


Figure A

three dimensions. A breakthrough occurred in 2013 when researchers at Stanford University introduced a new method, called CLARITY, which allows visualization of deep structures without sectioning the brain. The trick is to soak the brain in a solution that replaces light-absorbing lipids with a water-soluble gel that turns the brain transparent. If such a "clarified" brain contains neurons that are labeled with fluorescent molecules, such as green fluorescent protein (GFP; see Chapter 2), then appropriate illumination will reveal the location of these cells deep inside the brain (Figure 7.8).



◀ FIGURE 7.8
A method to turn the brain transparent and visualize fluorescent neurons deep in the brain. (a) A mouse brain viewed from above. (b) The same brain rendered transparent by replacing lipids with a water-soluble gel. (c) The transparent brain illuminated to evoke fluorescence from neurons that express green fluorescent protein. (Source: Courtesy of Dr. Kwanghun Chung, Massachusetts Institute of Technology. Adapted from Chung and Deisseroth. 2013, Figure 2.)

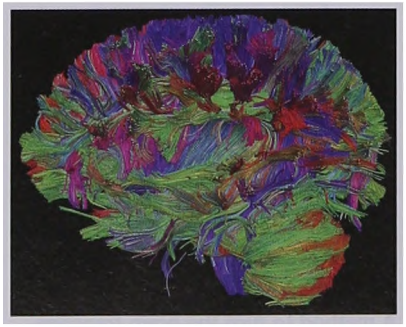
Of course, a clarified brain is still a dead brain. This, to say the least, limits the usefulness of such anatomical methods for diagnosing neurological disorders in living individuals. Thus, it is no exaggeration to say that neuroanatomy was revolutionized by the introduction of several methods that enable one to produce images of the living brain. Here we briefly introduce them.

Imaging the Structure of the Living Brain. Some types of electromagnetic radiation, like X-rays, penetrate the body and are absorbed by various radiopaque tissues. Thus, using X-ray-sensitive film, one can make two-dimensional images of the shadows formed by the radiopaque structures within the body. This technique works well for the bones of the skull, but not for the brain. The brain is a complex three-dimensional volume of slight and varying radiopacity, so little information can be gleaned from a single two-dimensional X-ray image.

An ingenious solution, called *computed tomography (CT),* was developed by Godfrey Hounsfields and Allan Cormack, who shared the Nobel Prize in 1979. The goal of CT is to generate an image of a slice of brain. (The word *tomography* is derived from the Greek for "cut.") To accomplish this, an X-ray source is rotated around the head within the plane of the desired cross section. On the other side of the head, in the trajectory of the X-ray beam, are sensitive electronic sensors of X-irradiation. The information about relative radiopacity obtained with different viewing angles is fed to a computer that executes a mathematical algorithm on the data. The end result is a digital reconstruction of the position and amount of radiopaque material within the plane of the slice. CT scans noninvasively revealed, for the first time, the gross organization of gray and white matter, and the position of the ventricles, in the living brain.

While still used widely, CT is gradually being replaced by a newer imaging method, called *magnetic resonance imaging (MRI).* The advantages of MRI are that it yields a much more detailed map of the brain than CT, it does not require X-irradiation, and images of brain slices can be made in any plane desired. MRI uses information about how hydrogen atoms in the brain respond to perturbations of a strong magnetic field (Box 7.2). The electromagnetic signals emitted by the atoms are detected by an array of sensors around the head and fed to a powerful computer that constructs a map of the brain. The information from an MRI scan can be used to build a strikingly detailed image of the whole brain.

Another application of MRI, called *diffusion tensor imaging* (DTI), enables visualization of large bundles of axons in the brain. By comparing the position of the hydrogen atoms in water molecules at discrete time intervals, the diffusion of water in the brain can be measured. Water diffuses much more readily alongside axon membranes than across them, and this difference can be used to detect axon bundles that connect different regions of the brain (Figure 7.9).



▲ FIGURE 7.9
Diffusion tensor imaging of the human brain. Displayed is a computer reconstruction of axon bundles in a living human brain viewed from the side. Anterior is to the left. The bundles are pseudocolored based on the direction of water diffusion. (Source: Courtesy of Dr. Satrajit Ghosh, Massachusetts Institute of Technology.)

Functional Brain Imaging. CT and MRI are extremely valuable for detecting structural changes in the living brain, such as brain swelling after a head injury and brain tumors. Nonetheless, much of what goes on in the brain—healthy or diseased—is chemical and electrical in nature and not observable by simple inspection of the brain's anatomy. Amazingly, however, even these secrets are beginning to yield to the newest imaging techniques.

BOX 7.2 BRAIN FOOD

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) is a general technique that can be used for determining the amount of certain atoms at different locations in the body. It has become an important tool in neuroscience because it can be used noninvasively to obtain a detailed picture of the nervous system, particularly the brain.

In the most common form of MRI, the hydrogen atoms are quantified—for instance, those located in water or fat in the brain. An important fact of physics is that when a hydrogen atom is put in a magnetic field, its nucleus (which consists of a single proton) can exist in either of two states: a high-energy state or a low-energy state. Because hydrogen atoms are abundant in the brain, there are many protons in each state.

The key to MRI is making the protons jump from one state to the other. Energy is added to the protons by passing an electromagnetic wave (i.e., a radio signal) through the head while it is positioned between the poles of a large magnet. When the radio signal is set at just the right frequency, the protons in the low-energy state will absorb energy from the signal and hop to the high-energy state. The frequency at which the protons absorb energy is called the *resonant frequency* (hence the name magnetic resonance). When the radio signal is turned off, some of the protons fall back down to the low-energy state, thereby emitting a radio signal of their own at a particular frequency. This signal can be picked up by a radio receiver. The stronger the signal, the more hydrogen atoms between the poles of the magnet.

If we used the procedure discussed earlier, we would simply get a measurement of the total amount of hydrogen in the head. However, it is possible to measure hydrogen amounts at a fine spatial scale by taking advantage of the fact that the frequency at which protons emit energy is proportional to the size of the magnetic field. In the MRI machines used in hospitals, the magnetic fields vary from one side of the magnet to the other. This gives a spatial code to the radio waves emitted by the protons: High-frequency signals come from hydrogen atoms near the strong side of the magnet, and low-frequency signals come from the weak side of the magnet.

The last step in the MRI process is to orient the gradient of the magnet at many different angles relative to the head and measure the amount of hydrogen. It takes about 15 minutes to make all the measurements for a typical brain scan. A sophisticated computer program is then used to make a single image from the measurements, resulting in a picture of the distribution of hydrogen atoms in the head.

Figure A is an MRI image of a lateral view of the brain in a living human. In Figure B, another MRI image, a slice has been made in the brain. Notice how clearly you can see the white and gray matter. This differentiation makes it possible to see the effects of demyelinating diseases on white matter in the brain. MRI images also reveal lesions in the brain because tumors and inflammation generally increase the amount of extracellular water.

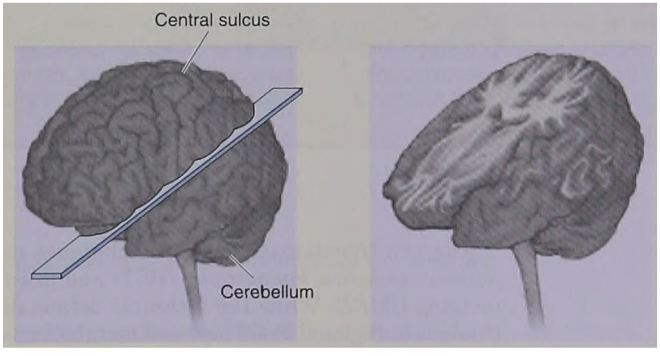


Figure A Figure B

BOX 7.3 BRAIN FOOD

PET and fMRI

Until recently, "mind reading" has been beyond the reach of science. However, with the introduction of *positron emission tomography (PET)* and *functional magnetic resonance imaging (fMRI)*, it is now possible to observe and measure changes in brain activity associated with the planning and execution of specific tasks.

PET imaging was developed in the 1970s by two groups of physicists, one at Washington University led by M. M. Ter-Pogossian and M. E. Phelps, and a second at UCLA led by Z. H. Cho. The basic procedure is very simple. A radioactive solution containing atoms that emit positrons (positively charged electrons) is introduced into the bloodstream. Positrons, emitted wherever the blood goes, interact with electrons to produce photons of electromagnetic radiation. The locations of the positron-emitting atoms are found by detectors that pick up the photons.

One powerful application of PET is the measurement of metabolic activity in the brain. In a technique developed by Louis Sokoloff and his colleagues at the National Institute of Mental Health, a positron-emitting isotope of fluorine or oxygen is attached to 2-deoxyglucose (2-DG). This radioactive 2-DG is injected into the bloodstream and travels to the brain. Metabolically active neurons, which normally use glucose, also take up the 2-DG. The 2-DG is phosphorylated by enzymes inside the neuron, and this modification prevents the 2-DG from leaving. Thus, the amount of radioactive 2-DG accumulated in a neuron and the number of positron emissions indicate the level of neuronal metabolic activity.

In a typical PET application, a person's head is placed in an apparatus surrounded by detectors (Figure A). Using computer algorithms, the photons (resulting from positron emissions) reaching each of the detectors are recorded. With this information, levels of activity for populations of neurons at various sites in the brain can be calculated. Compiling these measurements produces an image of the brain activity pattern. The researcher monitors brain activity while the subject performs a task, such as moving a finger or reading aloud. Different tasks "light up" different brain areas. In order to obtain a picture of the activity induced by a particular behavioral or thought task, a subtraction technique is used. Even in the absence of any sensory stimulation, the PET image will contain a great deal of brain activity. To create an image of the brain activity resulting from a specific task, such as a person looking at a picture, this background activity is subtracted out (Figure B).

Although PET imaging has proven to be a valuable technique, it has significant limitations. Because the spatial resolution is only 5–10 mm^3, the images show the activity of many thousands of cells. Also, a single PET brain scan may take one to several minutes to obtain. This, along with concerns about radiation exposure, limits the number of scans that can be obtained from one person in a reasonable time period. Thus, the work of S. Ogawa at Bell Labs, showing that MRI techniques could be used to measure local changes in blood oxygen levels that result from brain activity, was an important advance.

The fMRI method takes advantage of the fact that oxyhemoglobin (the oxygenated from of hemoglobin in the blood) has a magnetic resonance different from that of deoxyhemoglobin (hemoglobin that has donated its oxygen). More active regions of the brain receive more blood, and this blood donates more of its oxygen. Functional MRI detects the locations of increased neural activity by measuring the ratio of oxyhemoglobin to deoxyhemoglobin. It has emerged as the method of choice for functional brain imaging because the scans can be made rapidly (50 msec), they have good spatial resolution (3 mm^3), and they are completely noninvasive.

The two "functional imaging" techniques now in widespread use are *positron emission tomography (PET)* and *functional magnetic resonance imaging (fMRI)*. While the technical details differ, both methods detect changes in regional blood flow and metabolism within the brain (Box 7.3). The basic principle is simple. Neurons that are active demand more glucose and oxygen. The brain vasculature responds to neural activity by directing more blood to the active regions. Thus, by detecting changes in blood flow, PET and fMRI reveal the regions of brain that are most active under different circumstances.

The advent of imaging techniques has offered neuroscientists the extraordinary opportunity of peering into the living, thinking brain. As you can imagine, however, even the most sophisticated brain images are useless unless you know what you are looking at. Next, let's take a closer look at how the brain is organized.

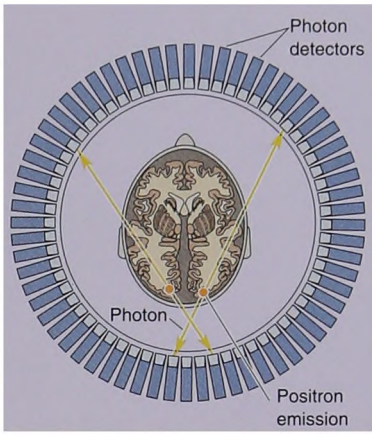


Figure A
The PET procedure. (Source: Posner and Raichle, 1994, p. 61.)

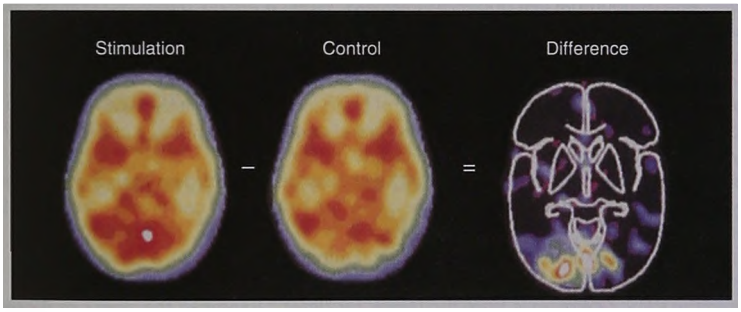


Figure B
A PET image. (Source: Posner and Raichle, 1994, p. 65.)

SELF-QUIZ

Take a few moments right now and be sure you understand the meaning of these terms:

central nervous system (CNS)
brain
spinal cord
cerebrum
cerebral hemispheres
cerebellum
brain stem
spinal nerve
dorsal root
ventral root
peripheral nervous system (PNS)
somatic PNS
dorsal root ganglia
visceral PNS
autonomic nervous system (ANS)
afferent
efferent
cranial nerve
meninges
dura mater
arachnoid membrane
pia mater
cerebrospinal fluid (CSF)
ventricular system