Chapter 1—EXTERNAL ANATOMY

Our nervous system starts life as a groove on the surface of the embryo and rapidly closes to become a tube. To form the central nervous system, this tube kinks in several spots and proliferates to its final form. Crested offshoots from the tube form the peripheral nervous system. Several layers of protection envelop the developing brain. To support its gelatinous substance, the brain floats in water. Our brain connects to the body via a complex system of nerves and receives sustenance from the body by a complex of vessels.

In this first laboratory session you will focus on three main topics: (1) the overall structure and organization of the brain and spinal cord as revealed by their external anatomy, (2) the brain's critically important vascular supply, and (3) the brain's protective coverings. As you work through this lab, concentrate on obtaining an overview of the general structure of the nervous system and avoid worrying too much about the thousands of details that we will be largely ignoring today. We will revisit all of these structures many times throughout the remaining laboratories and will have lots of opportunity to think about them in great depth.

Before beginning these laboratories, it is important to remind you to always wear gloves when handling human nervous tissue. An extremely rare brain disease (we're literally talking one in a million) has been shown to be transmitted by brain tissue. This class of diseases is known by several names, including Prion diseases, spongiform encephalopathies, and Creutzfeldt-Jacob disease (CJD). Popular names for similar animal diseases include "mad cow disease" and scrapie. The "infectious agent" of such afflictions is very hardy, surviving formalin fixation, paraffin embedding, regular autoclaving, and other standard measures. However, transmission has only been documented by direct brain inoculation, or in some cases by ingestion. You probably won't do either. NO EATING IN THE LABORATORY, WEAR GLOVES WHEN HANDLING BRAIN TISSUE, and BE CAUTIOUS WITH THE DISSECTING EQUIPMENT.

LEARNING OBJECTIVES

- Know the main divisions of the brain and their functional relationships.
- Recognize the salient morphological features on the lateral and medial brain surfaces.

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- Identify the main vessels that serve the brain, distinguish their territories, and understand the perfusion of the brain.
- Identify the main features of the brain's coverings and their relationship to the blood vessels.
- Relate the brain specimen to radiological images.
- Relate the spinal cord to the vertebral column and its significance in lumbar puncture.

INTRODUCTION

The goal of this first chapter is to introduce you to the overall structure and organization of the brain and spinal cord, including their vascular supply and protective coverings.

Neuroanatomy is a vast and complex subject. In order to approach it successfully, you need to order your approach. The secret to a successful attack on the discipline is to intellectually divide the nervous system into the largest chunks of information first, followed by successively finer and finer grains of information. For instance, your first major "cut" should establish that the central nervous system consists of the brain and the spinal cord. Next, before you learn any details of a particular region, recognize that the brain consists of a forebrain, midbrain, and hindbrain. Follow this with the next logical subdivisions of forebrain into cortex, basal ganglia, and thalamus; and hindbrain into cerebellum, pons, and medulla. If you maintain this simple approach of acquiring your neuroanatomical sophistication in incremental steps, you'll find that it is a pleasant way to learn the material, it will make more sense to you, and the knowledge will remain with you.

As you are studying neuroanatomy, always keep in mind that the entire nervous system develops from a neural tube that bulges, bends, and kinks in various ways and places to give the brain its characteristic structure. By relating any structure in the adult nervous system to its origin in the neural tube, you will able to see the logic of its position. For instance, the three main divisions of the brain: the forebrain, midbrain, and hindbrain, arise from three primary bulges in the neural tube (see Fig. 1.1). Similarly, the ventricles are simply what is left of the hollow portion of the tube after the contortion act is completed. They are narrowed where developing nervous tissue has bulged inward, and they are

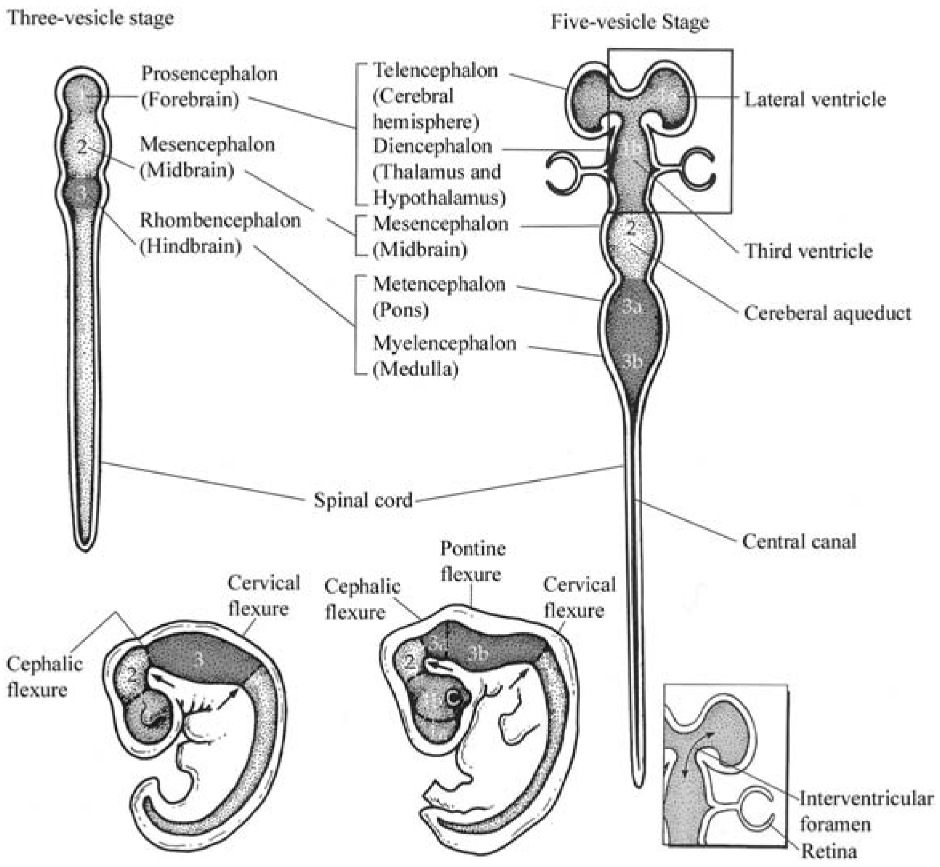

FIGURE 1.1. *Early development of the central nervous system. Early in development, after the neural tube closes, it proliferates in specific regions, which then form bulges or vesicles. While these form, the entire structure undergoes several bends or flexures. It is the vesicles, in part delineated by the flexures, that will form the cerebral hemispheres, thalamus, midbrain, and posterior fossa structures. (Modified from J. H. Martin, Neuroanatomy : Text and Atlas, second edition, © 1996, Appleton & Lange, Stamford, CT, figure 2–3, page 36.)*

bent where the neural tube has grown back on itself. The same holds true for gray matter structures. The caudate nucleus, as an example, arises as an inward bulge at the lateral base of the neural tube. Consequently it will always be found at "bottom" of the lateral ventricles.

TERMINOLOGY

A unified neuroanatomical terminology is used throughout the neurosciences. It is based on an ideal vertebrate whose nervous system is linearly organized like that of the dog shown in Figure 1.2.

Structures are oriented as being:

Rostral (toward the nose) or ***caudal*** (toward the tail)
Dorsal (toward the back) or ***ventral*** (toward the belly)
Anterior (toward the front) or ***posterior*** (toward the rear)
Superior (toward the upper side) or ***inferior*** (toward the lower side)
Medial (toward the midline) or ***lateral*** (toward side)

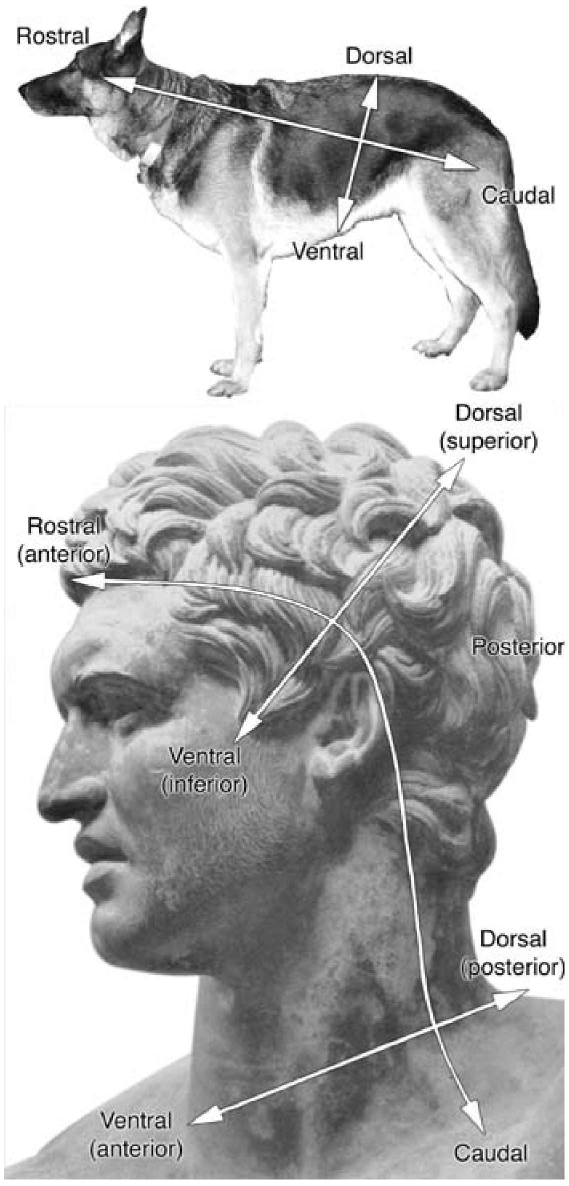

FIGURE 1.2. *Orientation of the nervous system. The terms used in the study of animal nervous systems have been adapted for the human, although we stood up several million years ago. Our modified anatomy is reflected in the terms anterior, posterior, superior, and inferior. While these terms can be used interchangeably in the spinal cord and brainstem with their animal equivalents, they differ in the forebrain. (Figure of Dionysus Soter by an unknown artist, modified from an illustration in G. Bazin, The Loom of Art, ©1962, Simon and Schuster, New York.)*

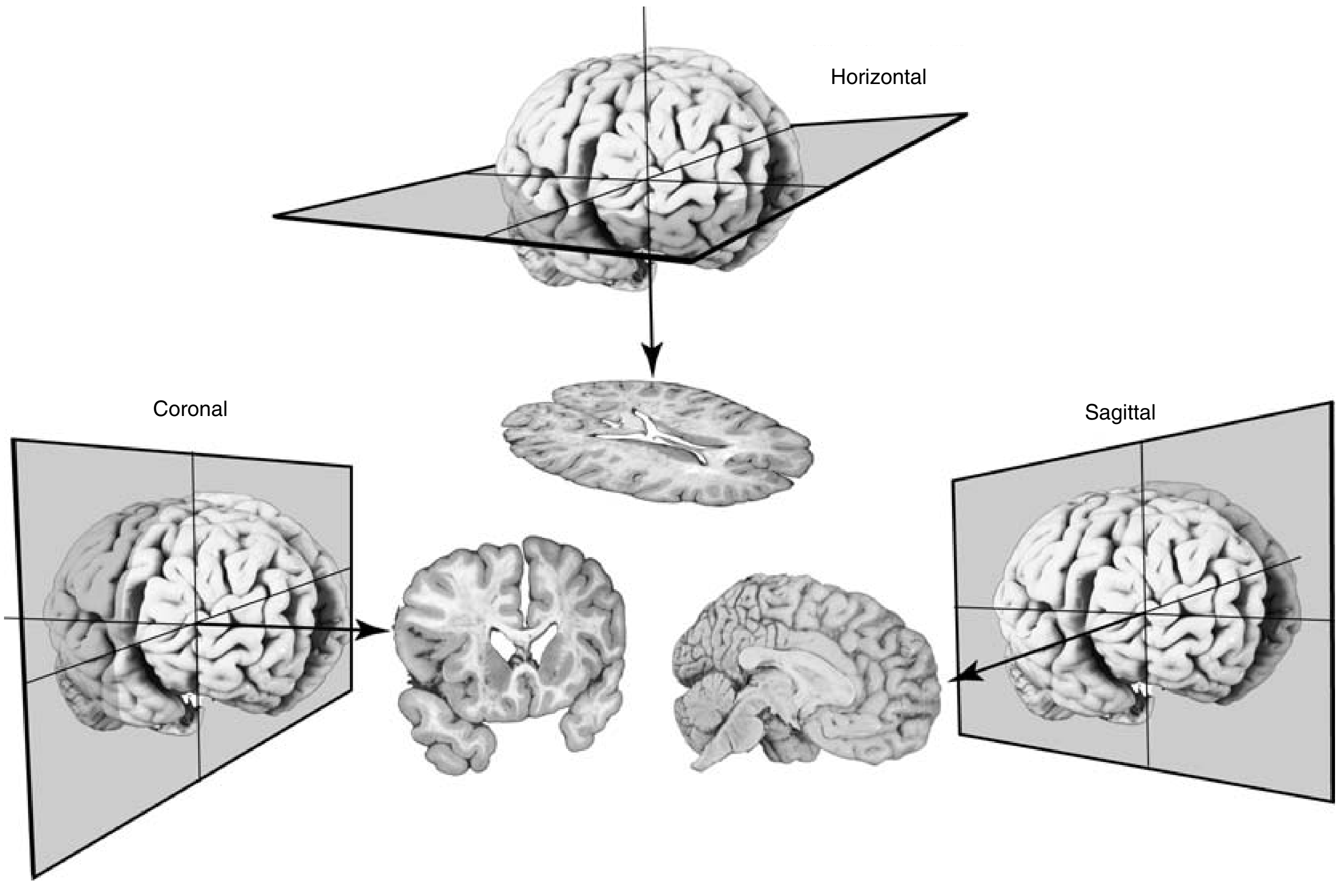

FIGURE 1.3. *Axes of the brain. The brain can be dissected in many planes, both actual specimens and in the MRI. However, the standard planes of dissection are illustrated below. Each plane of dissection has its own utility in illustrating a patient's pathology.*

These terms are applied in slightly different ways to structures in forebrain as opposed to their use in the brainstem and spinal cord. This is because we stood up. The human nervous system bends approximate 90° at the junction between the midbrain and the forebrain (Figure 1.2B). In the spinal cord, dorsal/ventral and anterior/posterior indicate the same relationships. For example, the large tracts of sensory fibers on the dorsal surface of the spinal cord are termed "dorsal columns" as well as "posterior columns." Similarly the site of concentration of motor nerve cells in the spinal cord is known as both the "ventral horn" and the "anterior horn." In the forebrain, anterior/posterior indicates the direction along the axis of the nervous system and is used in the same sense as rostral/caudal in the spinal cord. Dorsal/ventral and medial/lateral have the same meaning in the forebrain as in the spinal cord.

The most frequently used planes of section for the study of brain anatomy are (1) horizontal, (2) coronal, and (3) sagittal (see Fig. 1.3). These terms reflect the approach to dissection. The brain can be cut in parallel horizontal slices from top to bottom, or in anterior-to-posterior transverse sections (coronal), or in medial-to-lateral sections (sagittal). The term ***coronal*** is primarily used in reference to the cross-sectional plane of the forebrain, while ***transverse*** is used when referring to cross sections of the brainstem and spinal cord. These approaches to brain cutting are so established in tradition that they are also used in the presentation of standard brain imaging studies.

External Anatomy of the Brain and Spinal Cord

The central nervous system is composed of the spinal cord, contained within the vertebral canal, and the brain (encephalon) located within the skull. The brain itself is divided into the cerebral cortex and its basal ganglia, the thalamus and hypothalamus, the transitional midbrain, and the parts of the brain in the posterior fossa (cerebellum, pons, and medulla). These terms are often grouped together,

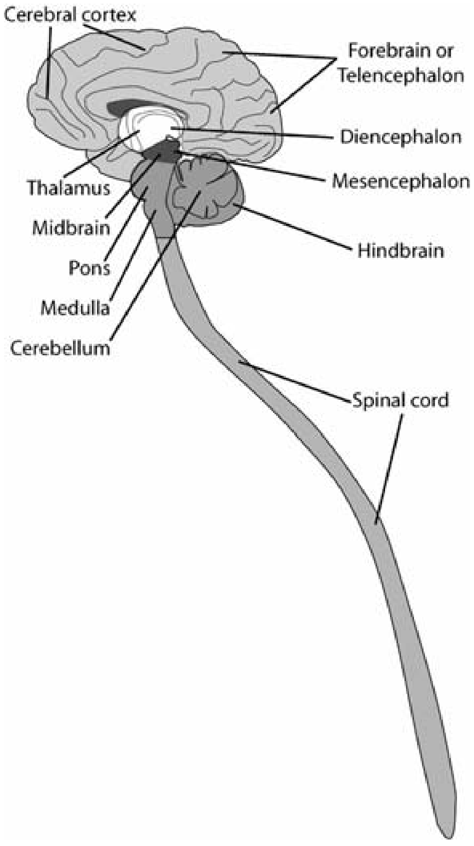

FIGURE 1.4. *Basic layout of the nervous system. Several overlapping terms describe different parts of the nervous system. The "cephalon" terms are occasionally used in clinical practice.*

either in clinical usage or in research. Starting from the midbrain, or mesencephalon, the caudal structures are termed the hindbrain, which includes the cerebellum, pons, and medulla. The diencephalon lies immediately rostral to the mesencephalon and contains the thalamus and hypothalamus. Given our anthropocentric views, the cerebral cortex and its basal ganglia are called the "final brain" or telencephalon. The forebrain (or the less common prosencephalon) groups those brain areas rostral to the mesencephalon. Of the terms used in a classification derived from embryology (the "cephalon" words), the ones most commonly used in adult neurology as adjectives to denote a rostro-caudal "level" are diencephalic and mesencephalic (see Fig. 1.4)

The spinal cord is the caudal continuation of the medulla. It is about 46 cm long and extends from the ***atlas*** (like the Greek god Atlas holding the world, as this is the bone holding the skull), to approximately L1/L2 where it ends in the conus medullaris. The cord gives off dorsal and ventral nerve roots at each segmental level. The roots pass through an intervertebral foramen and project out to the body. They also send collaterals to the sympathetic chain ganglia that lie outside the vertebral column. The nerve roots exiting below L1/L2 form the cauda equina (horse's tail).

Blood Supply

Specific brain functions are, to a great extent, localized to particular brain areas; these areas, in turn, are perfused by unique arteries. Consequently a malfunction in a given vessel often leads to a specific functional deficit. For example, a small thrombotic occlusion of the posterior cerebral artery can result in unilateral cortical blindness. In this laboratory you will focus on the vascular territories and on the overall path of the circulation.

The main blood supply to the brain comes from two paired sources, the vertebral arteries and the internal carotid arteries. The vertebral arteries ascend on the ventral surface of the medulla and fuse at the level of the pons, where they form the single basilar artery. The left and right internal carotid arteries each run directly into opposite sides of the circle of Willis. Blood supplied by the internal carotid arteries is often referred to as the ***anterior circulation,*** and that supplied by the vertebral and basilar arteries as the ***posterior circulation.*** The blood supply to the spinal cord is provided by the anterior spinal and the two posterior spinal arteries that are fed by variable radicular arteries. Blood

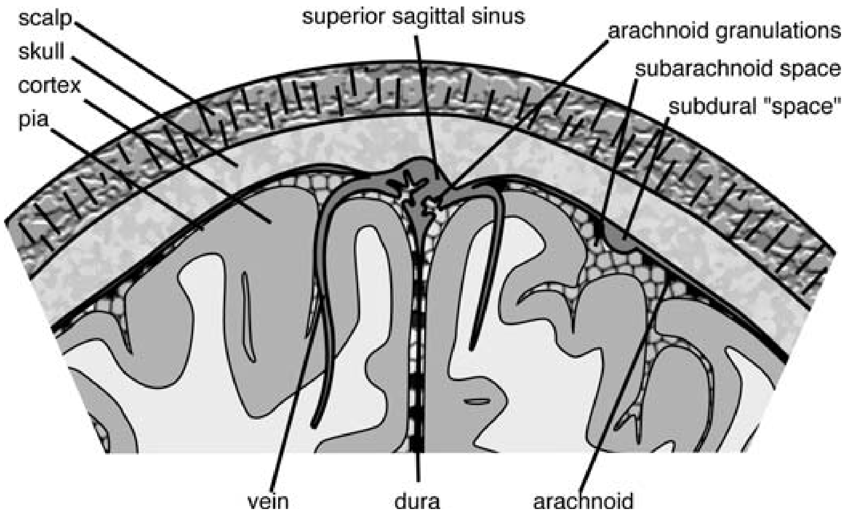

FIGURE 1.5. *Coverings of the brain. Multiple layers of tissue enclose the brain. From outside-in, the main layers are the scalp, skull, dura, arachnoid membrane, and pia mater. Except for the pia, which is really part of the brain, fluids can collect in the "spaces" between these layers in pathologic states. (Note: In this figure the dura is drawn very thick to emphasize its structure. In life it is about the thickness of a piece of thin cardboard.)*

drains from the brain into veins, then into venous sinuses, and leaves the head via the jugular veins and to a much lesser extent, via the vertebral veins. Blood leaves the spinal cord via an intricate venous system.

Brain Coverings

The brain and spinal cord are delicate organs that have a jelly-like consistency. These highly vulnerable structures are protected by the skull and vertebral column, several membrane covers, and by the cerebrospinal fluid (CSF), which provides a cushion against compressive shock. The three membranes covering the brain working from the skull inward, are the dura mater, the arachnoid mater, and the pia mater (see Fig. 1.5). The ***dura*** is a rather tough membrane that can only be torn by hand with some difficulty. It consists of two leaves: an outer periosteal layer that adheres to the inner surface of the skull, and an inner layer. The two dural layers cannot be distinguished from one another except where they depart from the conformation of the skull, and dive into the brain forming the interhemispheric falx and the tentorium overlying the cerebellum, or where they split apart to form the ***venous sinuses.*** The sinuses serve to collect blood from the veins of the brain. At the superior sagittal sinus, CSF is resorbed into the venous system.

The middle membrane, the ***arachnoid,*** has a smooth outer surface and is devoid of vasculature. Like the dura, the arachnoid covers the brain's surface without descending into the individual sulci. Thin, branching filamentous structures extend from its inner surface to the pia mater below giving the arachnoid a weblike appearance. The ***pia***, the thin innermost membrane is closely adherent to the surface of the brain and spinal cord. It follows the brain surface perfectly, covering gyri and sulci alike. Since the arachnoid bridges the sulci and fissures on the surface of the brain and spinal cord, it forms subarachnoid spaces of variable size, containing CSF. The largest spaces are called ***cisterns***.

Because of the continuity of the membranes covering the brain, in certain disease states the region between these membrane may become filled with fluids, blood, air, or tumor. Since these regions are not normally open, they are termed ***potential spaces***. Between the skull (or vertebra) and the dura is a potential space called the ***epidural*** (or extradural) space, containing only blood vessels. Under the meningeal layer of dura, between it and the arachnoid, is a potential space called the subdural space. Head trauma can cause bleeding within this space and lead to a subdural hematoma. The gap between the pia and arachnoid is called the ***subarachnoid*** space. Since these three spaces have different classes of blood vessels associated with them, characteristic types of "bleeds" result from damage to each class of vessel.

Subarachnoid space *The space between the leptomeninges and pia mater. This is a real space and is completely filled with cerebrospinal fluid. The brain essentially floats in the cerebrospinal fluid within the subarachnoid space.*

Schedule (2.5 hours)

60	External anatomy
20	Spinal cord
20	Vessels
30	Coverings
20	Case

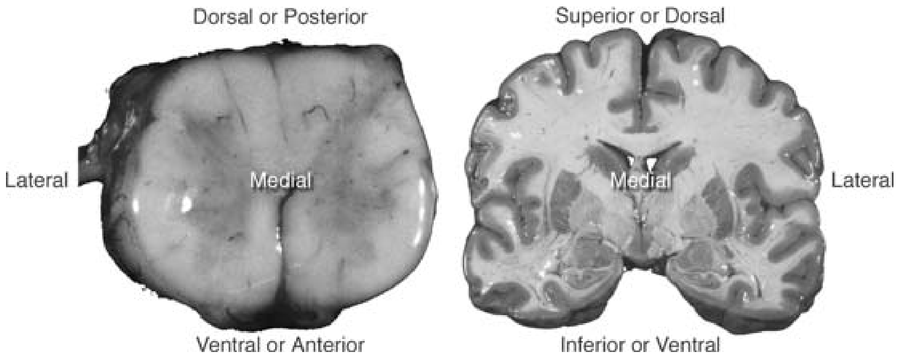

FIGURE 1.6. *Transverse section of spinal cord and coronal section of brain.*

EXTERNAL BRAIN

General Orientation of the Brain

INST Examine your whole and half brain specimens and spinal cord. Using Figure 1.2 and 1.6, review the following terms by relating them to the specimens:

- Anterior versus posterior
- Rostral versus caudal
- Ventral versus dorsal
- Lateral versus medial
- Superior versus inferior

INST Using imaginary cuts on your specimens and Figure 1.3, go through the following planes of section:

- Horizontal
- Sagittal
- Parasagittal
- Coronal and transverse

Q1.1. Where do you find transverse sections used?
A1.1. Brainstem and spinal cord.

Major Divisions

INST Using anatomic specimens, identify the four major divisions of the brain: the cerebrum, brainstem, cerebellum, and spinal cord.

Q1.2. What structures lie immediately above and below the junction between the brainstem and cerebrum?
A1.2. The midbrain is the caudal part of this junction, while the thalamus or diencephalon lies rostral to the junction.
Q1.3. What separates the cerebellum from the cerebral hemispheres?
A1.3. The transverse fissure and tentorium.

Cerebral Hemispheres

Q1.4. The cerebral cortex is divided into four major lobes (frontal, parietal, temporal, and occipital) and the smaller insula. In order to determine their boundaries, you have to first recognize the major sulci. Use your whole brain to locate the structures below and label them on Figure 1.7. First locate the longitudinal fissure. Next identify the Sylvian fissure. Then identify the central sulcus. It's not always easy to pick out. The easiest way to locate it is on the medial surface of the half brain. Identify the prominent cingulate sulcus. The next sulcus just anterior is the central sulcus. Follow it along the lateral surface of the brain. The occipital and parietal lobes can easily be distinguished using the half brains. On the medial surface of the half brain, identify the

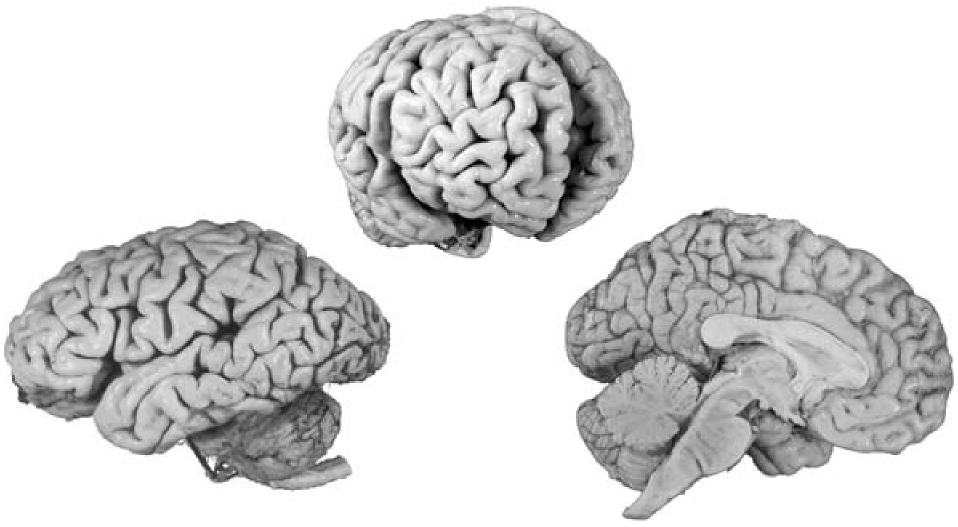

FIGURE 1.7. *External landmarks of the cerebral hemispheres. The left figure is the lateral surface, the right is the medial surface, and the middle figure is an oblique view of the brain.*

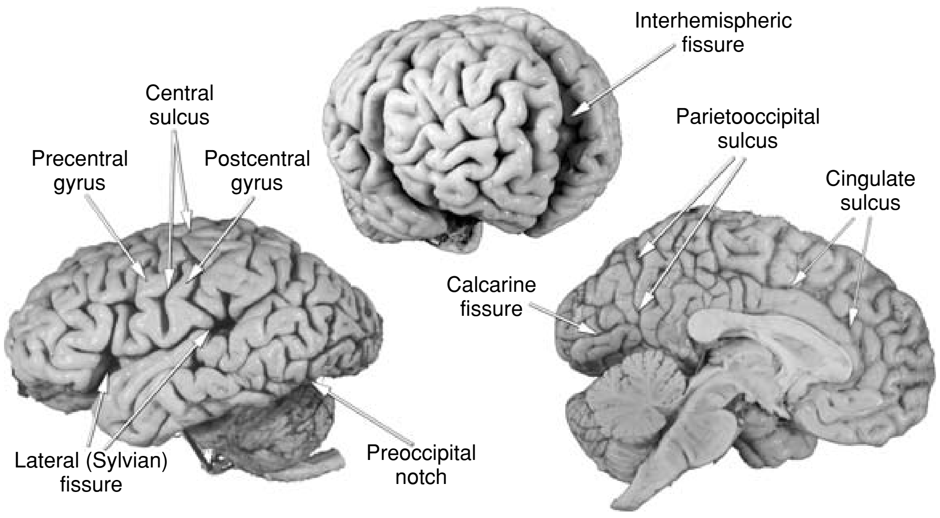

FIGURE 1.8. *External landmarks of the cerebral hemispheres. These major fissures, sulci, and gyri are common to well-formed brains.*

FIGURE 1.9. *Lateral and medial views of the brain.*

parietooccipital sulcus. Note that on the lateral surface about the same distance anterior to the occipital pole you find the preoccipital notch. Label all of these structures in Figure 1.7.

A1.4. See Figure 1.8.

Q1.5. Identify the frontal and occipital poles, which are the anterior and posterior tips of the brain. Using the landmarks above, identify on the brain and in Figure 1.9 (shade and label):

- Frontal lobe (FL)
- Temporal lobe (TL)
- Parietal lobe (PL)
- Occipital lobe (OL)
- “Limbic” lobe (LL) (cingulate gyrus)

A1.5. *See Figure 1.10.*

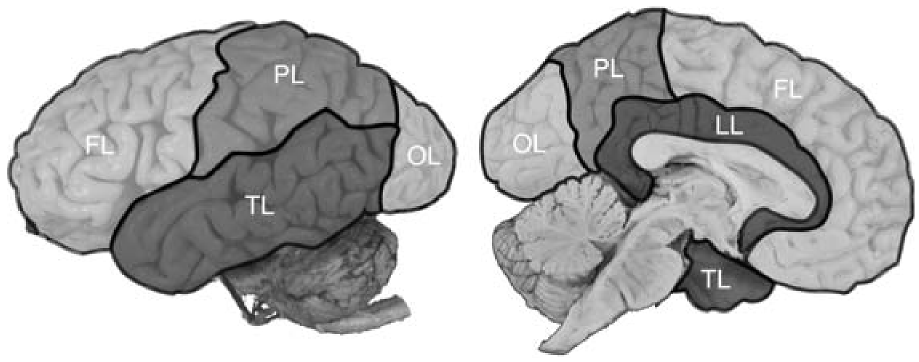

FIGURE 1.10. *Major lobes of the brain.*

INST Finally, gently spread apart the banks of the Sylvian fissure and find the insular cortex buried underneath. Compare what you can see with the dissection in Figure 1.11 of the fully exposed insular cortex.

Q1.6. One of the most striking features of the brain is that many of its morphologically distinct parts have specific functions localized to them. Locate the prominent gyri listed in Table 1.1 and assign a general function in the table.

A1.6. See Table 1.2.

INST After you have identified these gyri, compare how consistent they are. Compare the appearance and location of each of these gyri between hemispheres in the same brain and between your brain specimens. How much do they vary?

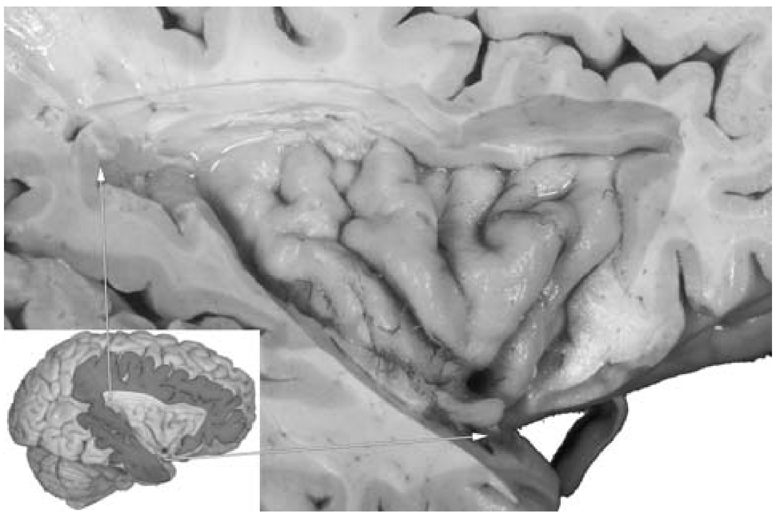

FIGURE 1.11. *Dissection of the insular cortex. Shaded regions in the inset show the portions of the frontal, parietal, and temporal cortices that have been cut away to expose the insular cortex. Much of this cortex remains hidden from view, even when the Sylvian fissure is gently opened up. To see the entire insula requires extensive dissection of the surrounding cortices.*

TABLE 1.1. Gyral Function Worksheet

Gyrus	Function
Precentral	____________
Postcentral	____________
Superior temporal	____________
Calcarine (look at medial face of half brain)	____________
Cingulate	____________

Q1.7. Look at the medial or sagittal aspect of the half brain. Using an atlas for assistance, identify these additional prominent features on the brain and in Figure 1.12:

- Corpus callosum
- Diencephalon/thalamus
- Third ventricle
- Lateral ventricle
- Midbrain
- Pons
- Medulla
- Cerebellum
- Cingulate gyrus
- Cingulate sulcus
- Parietooccipital sulcus
- Calcarine fissure

A1.7. See Figure 1.13.

Q1.8. The corpus callosum is the massive white matter tract joining the two hemispheres. To get an excellent perspective on the corpus callosum, examine the dissection in Figure 1.14. From just the photograph, what do you think the fibers interconnect?

A1.8. The fibers connect the two hemispheres so that they can communicate with each other. When the corpus callosum is surgically transected for certain types of severe epileptic conditions, it results in each cerebral hemisphere functioning more or less autonomously. These are the famous "split brain" cases. When the same information is presented separately to each hemisphere, a visual image for instance, the interpretation varies depending upon whether the left or the right hemisphere is processing the information.

Base of the Brain

Q1.9. Locate these prominent features on the base of the whole and half brains and label them in Figure 1.15:

- Olfactory bulb and Olfactory tract
- Optic nerve and chiasm
- Mammillary bodies
- Internal carotid artery

TABLE 1.2. Function of Select Gyri

Gyrus	Function
Precentral	Primary motor area
Postcentral	Primary somatosensory area
Superior temporal	Hearing
Calcarine cortex (look at medial face of half brain)	Vision
Cingulate	Emotion and motivation

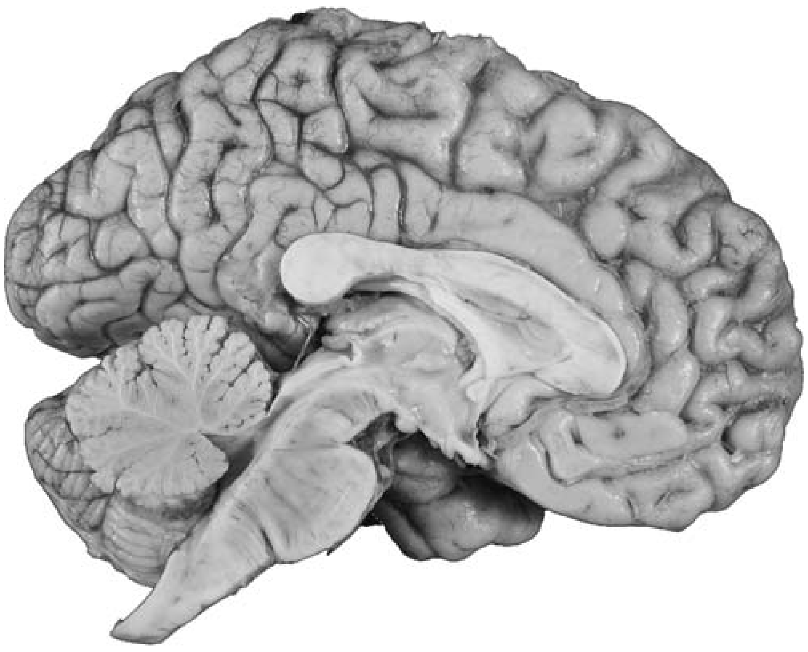

FIGURE 1.12. *Sagittal section of brain.*

- Pituitary (unlikely to remain after the autopsy)
- Cranial nerve III

A1.9. See Figure 1.16.

Brainstem

Q1.10. On both the intact brain and sagittal section, locate these brainstem structures and label them in Figure 1.17:

- Basilar artery
- Midbrain
- Pons
- Cerebellum
- Medulla
- Inferior olive

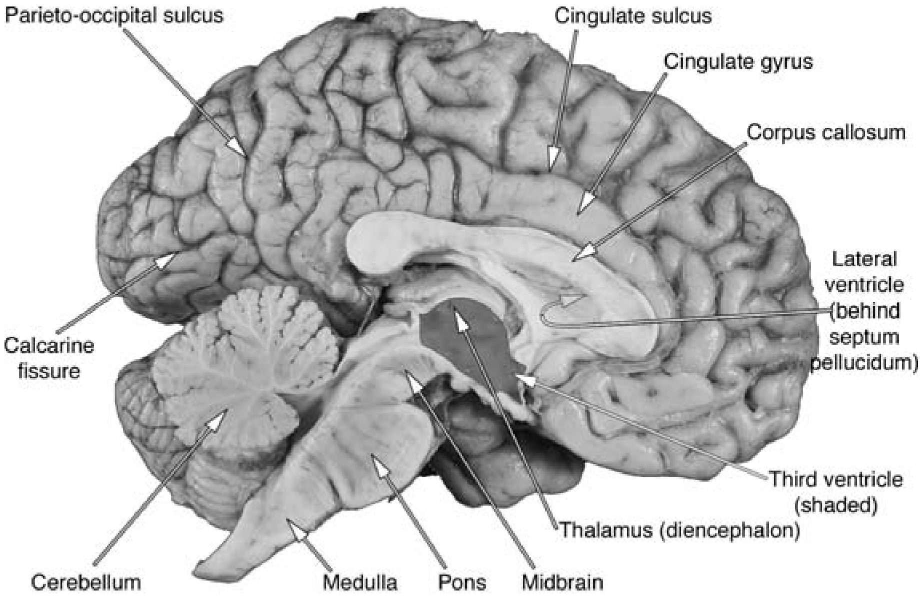

FIGURE 1.13. *Landmarks on the medial brain surface.*

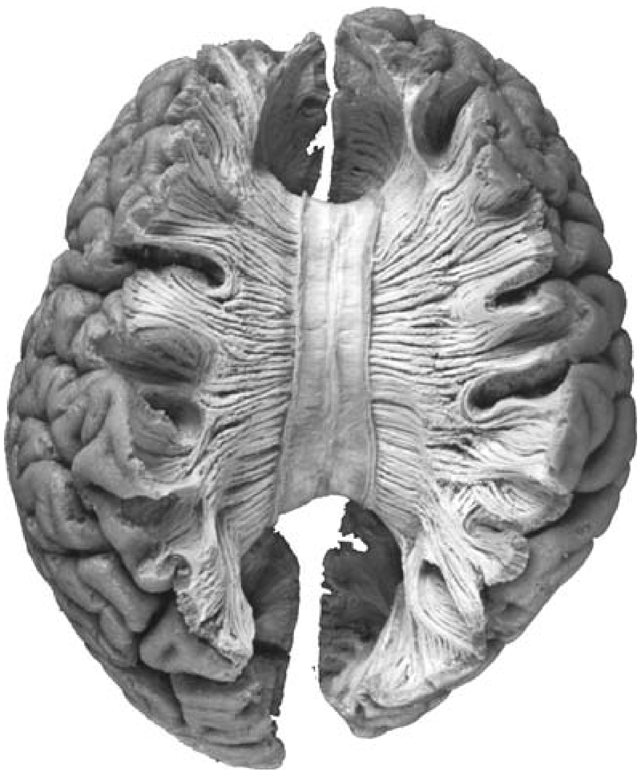

FIGURE 1.14. *Dissection of white matter bundles in the corpus callosum. Special processing of brain will partially separate white matter fibers along major bundles. Gentle dissection and removal of adjacent brain will then reveal major pathways, such as this view of corpus callosum fibers. (Modified from Gluhbegovic and Williams, The Human Brain, a Photographic Guide. © 1980, Harper & Row, figure 5–21, page 141.)*

- Pyramids
- Pyramidal decussation
- Cranial nerve V
- Cerebral aqueduct
- Fourth Ventricle

A1.10. See Figure 1.18.

SPINAL CORD

In this portion of the laboratory you'll examine the external structure of the spinal cord, note its relationship to the spinal column, and examine the implications of the cord being shorter than the spinal column.

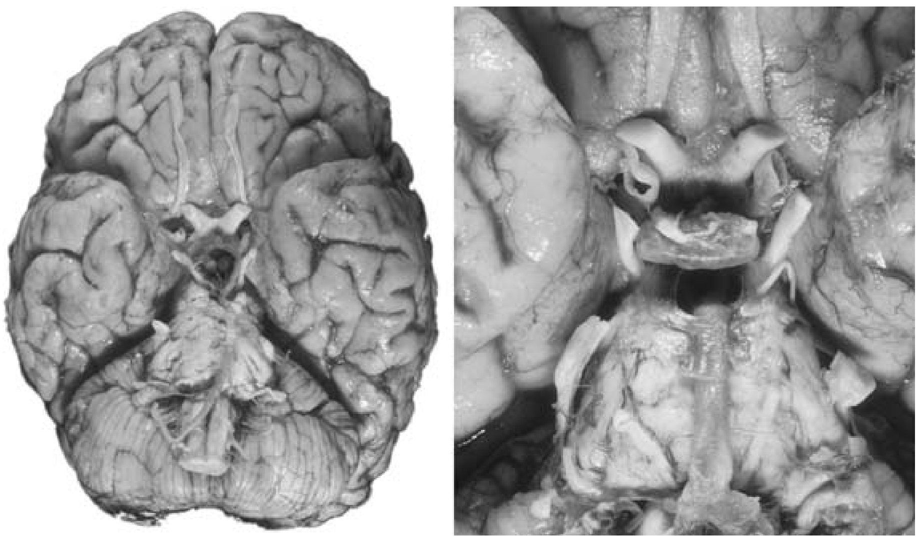

FIGURE 1.15. *Base of brain. In the left specimen, the pituitary was removed at autopsy.*

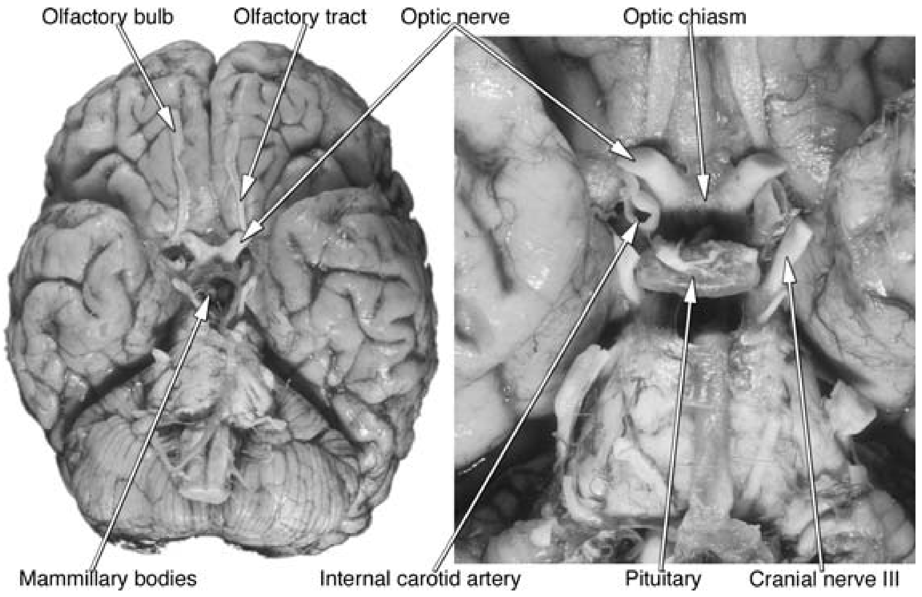

FIGURE 1.16. *Some important structures on the inferior brain surface.*

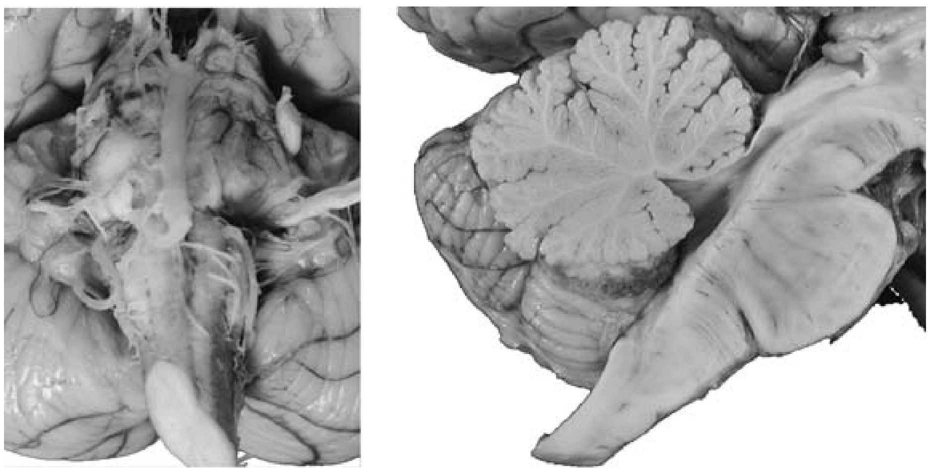

FIGURE 1.17. *Inferior (left) and sagittal (right) views of the brainstem and cerebellum (or hindbrain).*

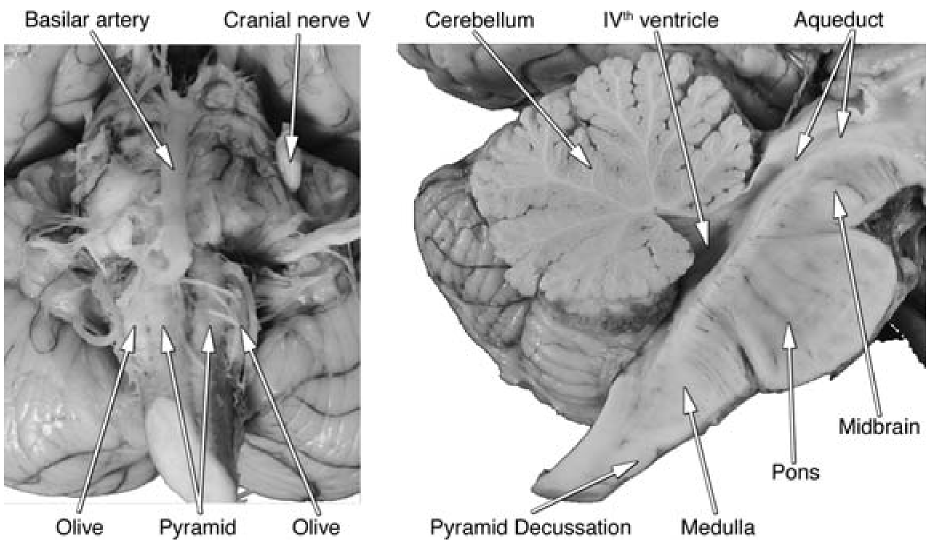

FIGURE 1.18. *Major landmarks on the inferior and medial surfaces of the posterior fossa.*

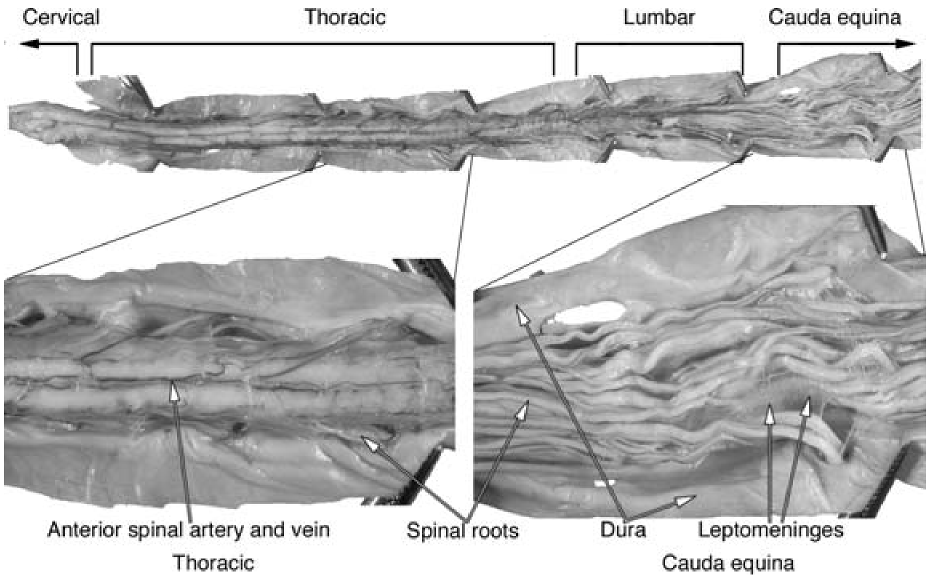

FIGURE 1.19. *Major divisions of the spinal cord. The spinal cord extends from below the decussation of the pyramidal tracts in the medulla to its base or conus medullaris. Extending from the cord at each level are ventral and dorsal spinal roots, which travel caudally to their exits in the longer vertebral column. The rostral and caudal ends of the cord have cervical and lumbar "enlargements" that contain greater amounts of gray matter to control the upper and lower limbs. Below about vertebral level L1–L2 the spinal cord ends, yet its roots continue caudally to their lumbar and sacral exits. This lowest region of the spinal canal contains a plethora of spinal roots resembling a horse's tail or cauda equina. Below the lumbar section of cord lies the short sacral segment, which is not labeled below.*

First determine the rostral and caudal ends of the spinal cord and the general location of each level (cervical, thoracic, lumbar, and sacral). (Many of the cord specimens extend rostrally only to the upper thoracic level.)

Q1.11. Identify the caudal end by means of the ***cauda equina.*** See Figure 1.19. Where is it found in the spinal column and what does this represent?

A1.11. It is found in the lumbar cistern and represents the collection of dorsal and ventral roots extending caudally toward their respective points of exit.

Q1.12. Orient the spinal cord with respect to the vertebral column of your skeleton. Do they match? Where does the cord end?

A1.12. The spinal cord is shorter than the vertebral column. It ends at approximately L1.

INST The cerebrospinal fluid (CSF) bathing the cord is sampled by means of a lumbar puncture. A needle is inserted between L4 and L5. Match your cord to the spinal column so that you can visualize the structures that the needle encounters.

INST Now examine the spinal cord in a bit more detail. Using scissors, carefully cut one side of the dura along the entire length of the cord. DO NOT REMOVE IT, but gently move it to the side so you can visualize the cord. You may want to partially cut up the other side of the dura so you can see both the dorsal and ventral aspects of the cord.

Q1.13. First reorient yourself. How can you tell the rostral from caudal end? How can you identify ventral (anterior) from dorsal (posterior)?

A1.13. Fortunately, the cord is different along each axis. The caudal end has the cauda equina (horse tail) to distinguish it from the rostral end. The ventral surface has a single central vessel while the dorsal surface has several, irregular, and lateral vessels.

Q1.14. Note the length of the nerve roots and the angle that they come off of the cord. How does this vary along the length of the cord and what is the explanation for the variation?

A1.14. In early embryonic life the cord is the same length as the vertebral canal. As it develops, its growth falls behind that of the spinal column. As the cord segments become increasingly displaced

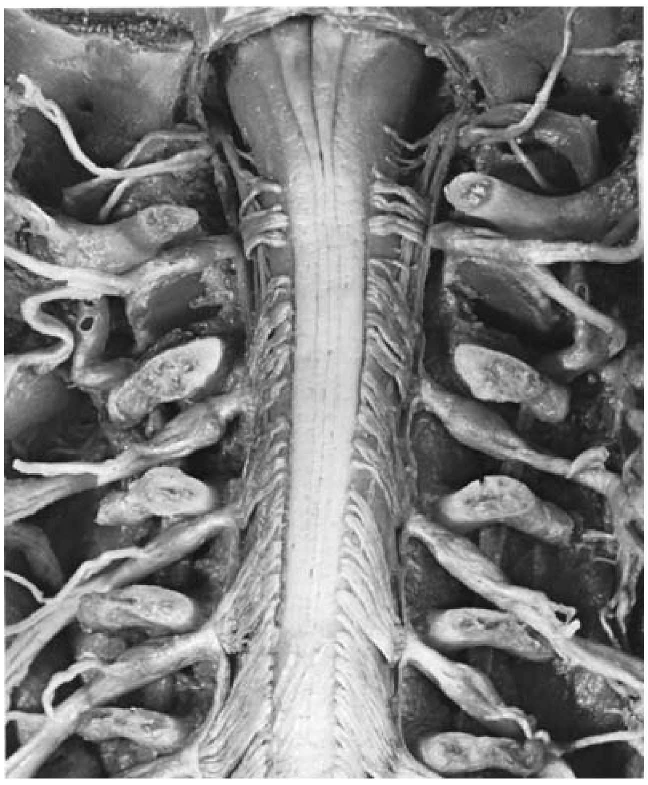

FIGURE 1.20. *Posterior in situ dissection of the spinal cord. The spinous processes and lamina have been removed from the posterior surface to reveal the enclosed spinal cord and its proximal roots with their ganglia. (Modified from Gluhbegovic and Williams, The Human Brain, a Photographic Guide. © 1980, Harper & Row, figure 1–3, page 7.)*

rostrally with respect to the vertebrae, the angle of the roots gradually shifts from a horizontal to a more oblique orientation. The roots also become longer since they have farther to travel to reach their exit foramina.

Q1.15. Examine your specimen and compare it to Figure 1.20. Identify the anterior and posterior aspects of your cord specimen. What features make this possible?

A1.15. The easiest way to distinguish front from back in the cord is to look at its vessels. The anterior has a single median artery and vein, while the posterior has a complex pattern of vessels. The anterior spinal artery lies in the groove of the deep median fissure.

Q1.16. Is the anterior vessel you see an artery or a vein?

A1.16. It is a vein. The artery is a thick-walled muscular structure, which usually contains little blood post-mortem, while the vein is a thin-walled tube filled with blood. It is usually the blood that makes the vein visible. With close inspection, you can see both.

Q1.17. Identify the anterior and posterior roots as well as the cervical and lumbar enlargements. What is the significance of these enlargements?

A1.17. The lumbar and cervical enlargements result from the large number of anterior horn α-motor neurons that are present at these levels to control the muscles of the lower and upper extremities respectively.

Q1.18. Examine a dorsal root ganglion (DRG). Where should you look for them? What type of neurons are contained within it and what is the direction of flow of information? Locate them in Figure 1.20.

A1.18. The ***dorsal root ganglia*** *are located outside the dura, just after the anterior and posterior roots penetrate this thick tissue. These ganglia contain primary sensory neurons conveying information about touch, pressure, vibration, joint position, pain, and temperature. Information flows from the body surface and muscles, to the DRG neurons, and thence into the spinal cord. In Figure 1.20, the ganglia are located between each pair of cut vertebral arches.*

INST Finally, examine the upper cut end of the cord and observe the relationship of gray matter (predominantly cell bodies) to white matter (predominantly myelinated axons). Note the butterfly or H-shape of the gray matter that surrounds the central canal (see Fig. 1.6). The ends, or horns, of the gray matter are called the posterior (or dorsal) horns (these receive sensory inputs) and the anterior

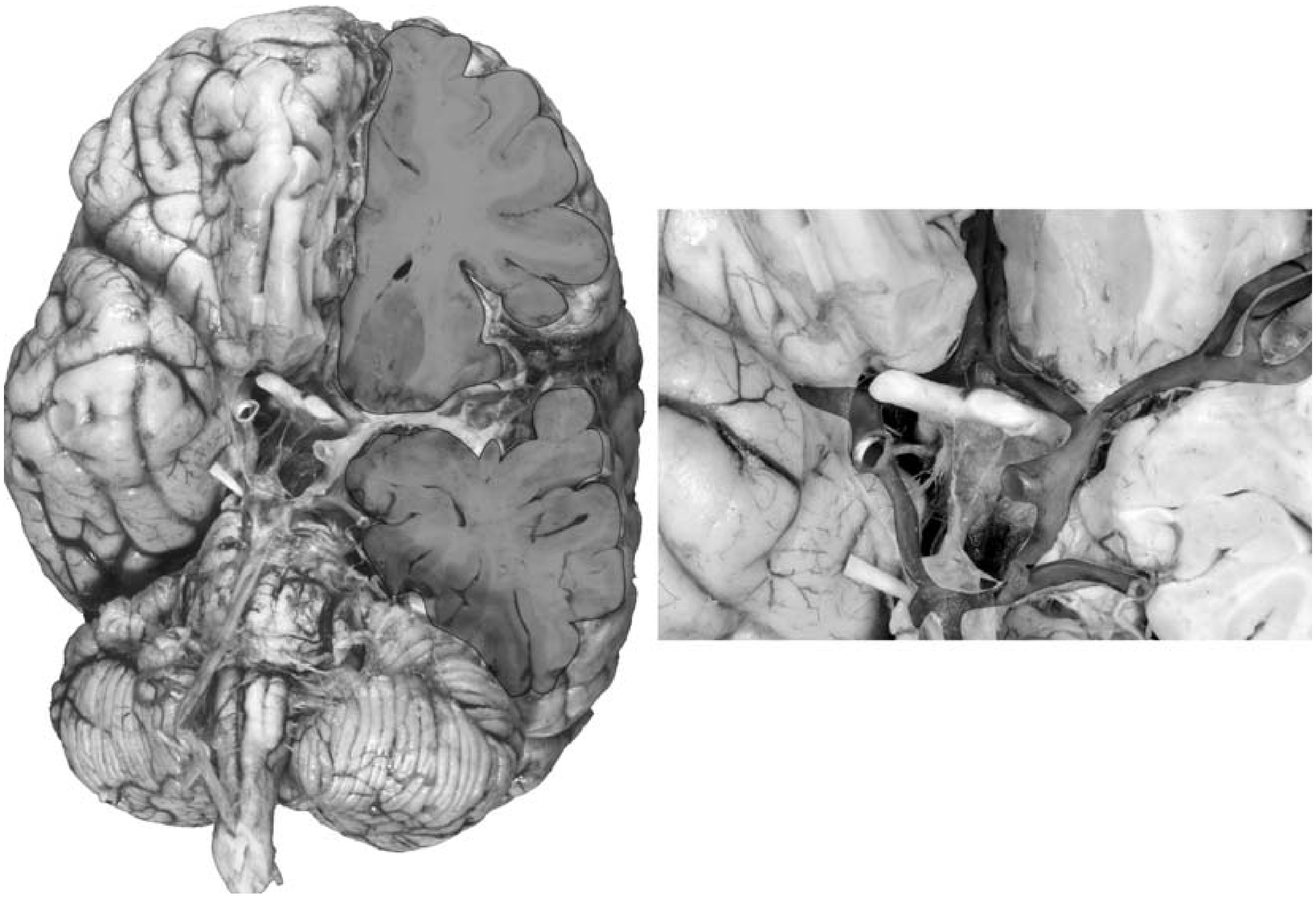

FIGURE 1.21. *Cerebral artery dissection. The inferior surface of the left frontal and temporal lobes has been dissected away to reveal the recessed main cerebral arteries. The dissected surface has been shaded on the left, and the vessels have been darkened in the close-up on the right.*

horns. The anterior horns are the sites of the cell bodies of motor neurons that directly innervate muscles, and form the final common efferent pathway. You'll investigate this relationship some more in the next chapter.

VESSELS

Q1.19. Using the diagrams in the brain atlas, identify the following key structures on the whole brain and in Figure 1.21:
- Internal carotid artery
- Circle of Willis
- Anterior cerebral artery
- Middle cerebral artery
- Posterior cerebral artery
- Vertebral artery
- Basilar artery.

A1.19. See Figure 1.22.

Q1.20. Figure 1.23 is a dissection of the cerebral circulation, showing the circle of Willis in the center. On the figure label the anterior cerebral, middle cerebral, posterior cerebral, internal carotid, basilar, and superior cerebellar arteries.

A1.20. See Figure 1.24.

Q1.21. What is the role of the Circle of Willis?

A1.21. The ***circle of Willis*** *interconnects the major cerebral arteries. If a major vessel becomes occluded either within or proximal to the circle, the communicating arteries permit anastomotic flow,*

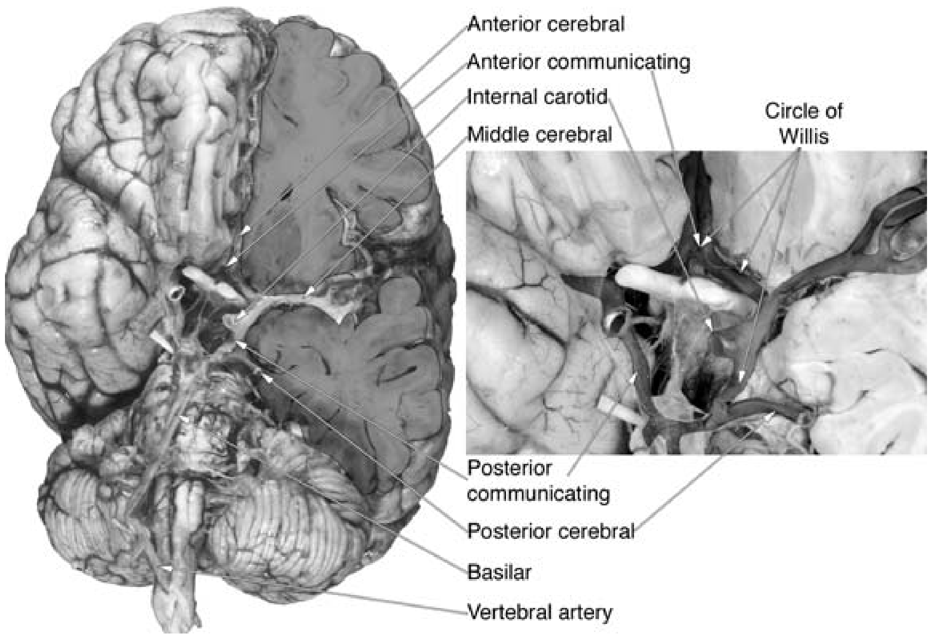

FIGURE 1.22. *Major arteries of the brain.*

which will maintain perfusion of brain areas. However, don't feel you can now eat cheeseburgers with impunity; by the time you reach adulthood, the anastomotic potential of the circle is greatly diminished. It is useless in acute occlusions and has only a small role in adults, even when the occlusions develop slowly.

It's important to note that there is a great deal of variation in the circle, including large posterior communicating arteries and completely absent vessels. Examine your specimen for abnormalities.

Q1.22. The anterior cerebral artery feeds the sagittal and medial portions of cortex, the posterior cerebral artery distributes to the occipital lobes and inferior temporal lobes, and the middle cerebral artery supplies the lateral cerebrum. On your brain specimens, indicate the territories of these main cerebral arteries. Shade their approximate territories on Figure 1.25.

A1.22. See Figure 1.26.

INST Examine the angiograms in Figure 1.27, obtained from postmortem injection of contrast agent into the spinal arteries. Panel *A* shows a mid-sagittal view of the anterior spinal artery at the level of C3. Panel *B* is a microangiogram of a cross section at L2 showing both the anterior and posterior

FIGURE 1.23. *Dissection of the main arteries in the cerebral circulation. Rostral is up.*

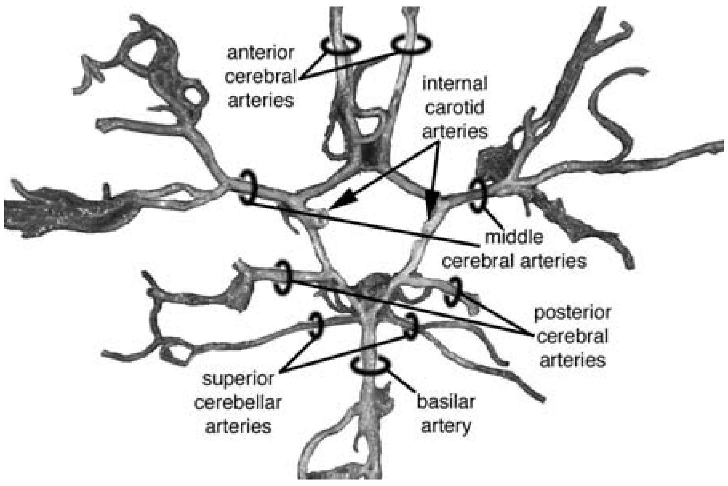

FIGURE 1.24. *Major arteries in a circle of Willis dissection.*

spinal arteries. It is important to correlate the various types of imaging to the actual neuroanatomy learned from your specimens.

Q1.23. Disruption of which spinal artery is more likely to result in lower motor symptoms? Damage the dorsal columns?

A1.23. Anterior. Posterior.

Before moving on, the scanning electron micrograph in Figure 1.28 is to remind you that you've been studying the major vessels only. All nervous tissue is richly invested with vasculature. All neurons are within a few cell diameters of a vessel. The image was made by injection of the vessels with plastic, followed by digesting away of the remaining tissue. Note the amazing complexity of the capillary bed. Changes in blood dynamics at capillary level correlate with local changes in brain activity. This is the basis for functional brain imaging techniques in which local changes in brain activity can be correlated to specific functional tasks.

INST The blood exits the brain via the sinus system. The superficial veins and the CSF empty into the superior sagittal sinus and the deep veins empty into the straight sinus. Examine your specimens including the sheep brain, to see where these sinuses run. Then look at Figure 1.29, which cartoons the organization of the sinuses in the cranium.

FIGURE 1.25. *Vascular territory worksheet.*

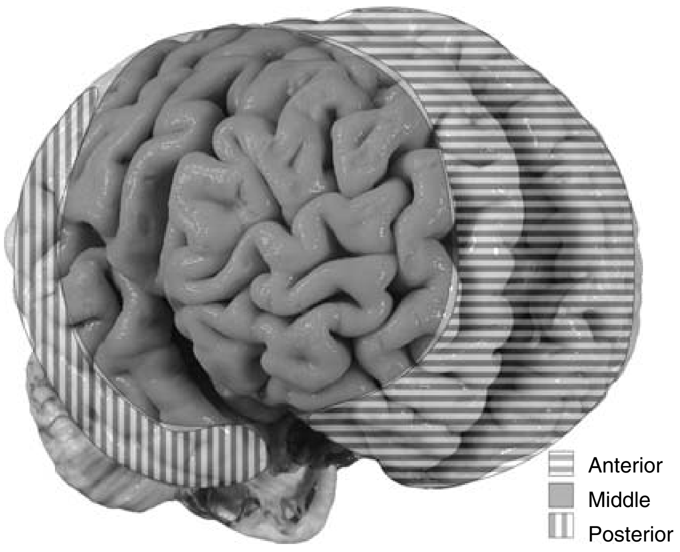

FIGURE 1.26. *Approximate vascular territories of the three main cerebral arteries.*

Q1.24. Look at Figure 1.30, which is an MRI venogram. Using Figure 1.29, identify the numbered structures 1–5. Add arrows to indicate the direction of flow.

1.24.1. ______________________

1.24.2. ______________________

1.24.3. ______________________

1.24.4. ______________________

1.24.5. ______________________

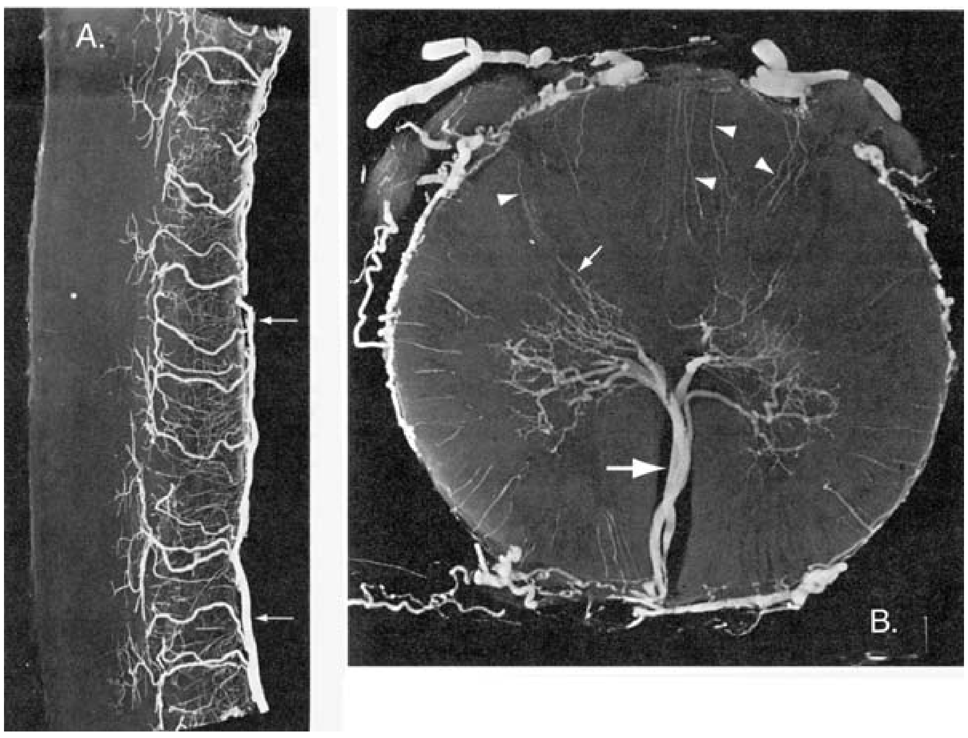

FIGURE 1.27. *Spinal arteries after contrast injection into anterior spinal artery. The injection was done postmortem, and then X-rayed after fixation and dissection. (Modified from Nolte, The Human Brain, 4th ed., © 1999, Mosby, St. Louis, figure 10-28, page 249.)*

FIGURE 1.28. *Scanning electron micrograph of the capillary network in the temporal lobe of a chincilla. (Modified from Harrison et al., 2002. Cerebral Cortex, 12:225–233.)*

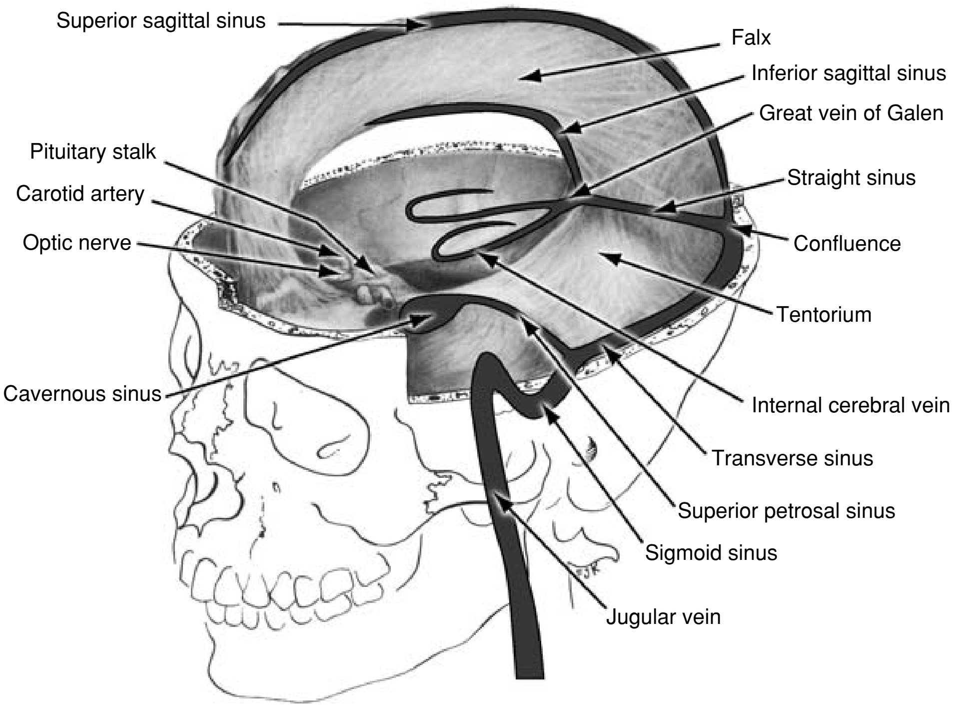

FIGURE 1.29. *Dural folds and sinuses. (Adapted from The Human Brain and Spinal Cord: Functional Neuroanatomy and Dissection Guide by Lennart Heimer, © 1983, Springer-Verlag, New York, figure 24, page 39.)*

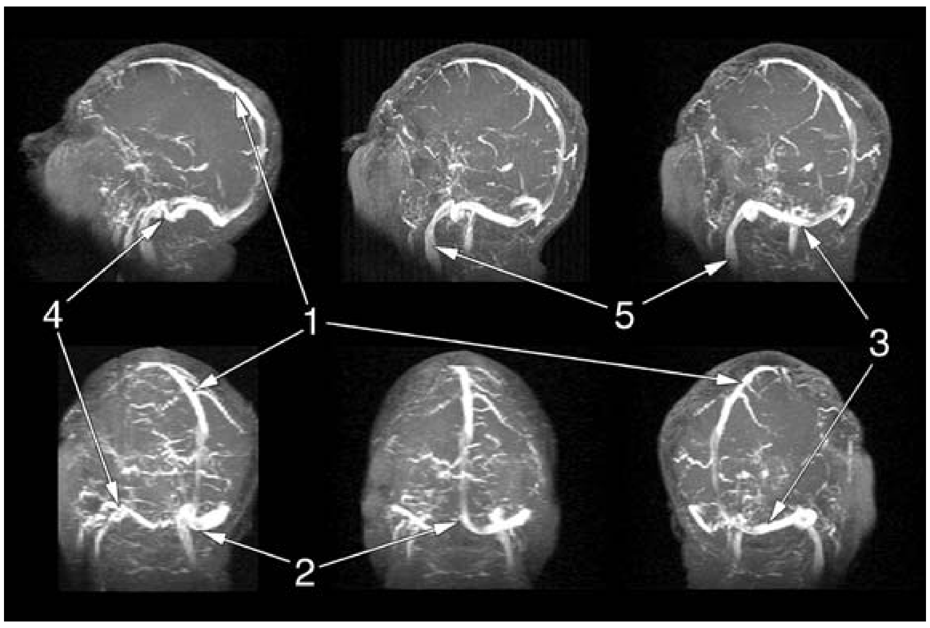

FIGURE 1.30. *MRI venogram at select rotations. These scans label protons in one position and then identify those that have moved after a short time interval.*

A1.24. *1.24.1. Superior sagittal sinus*
1.24.2. Confluence of the sinuses
1.24.3. Transverse sinus
1.24.4. Sigmoid sinus
1.24.5. Jugular vein

THE BRAIN'S COVERINGS

Q1.25. Working from the outside in, the brain is covered by the scalp, the skull, the dura mater, and the meninges. These tissues can be distinguished in patients using an MRI scan (magnetic resonance image). Compare the images in Figure 1.31 of a routine MRI scan and a coronal section from the Visible Human Project. Identify the major coverings on the MRI image.

A1.25. From outside-in on the MRI: The bright material is the scalp, which can be seen as a continuation of the cheeks. Deep to the scalp is a fuzzy irregular layer of masseter muscle and beneath this is the bone (black on MRI). Beneath the bone is a line of dura, well-seen where it descends in the

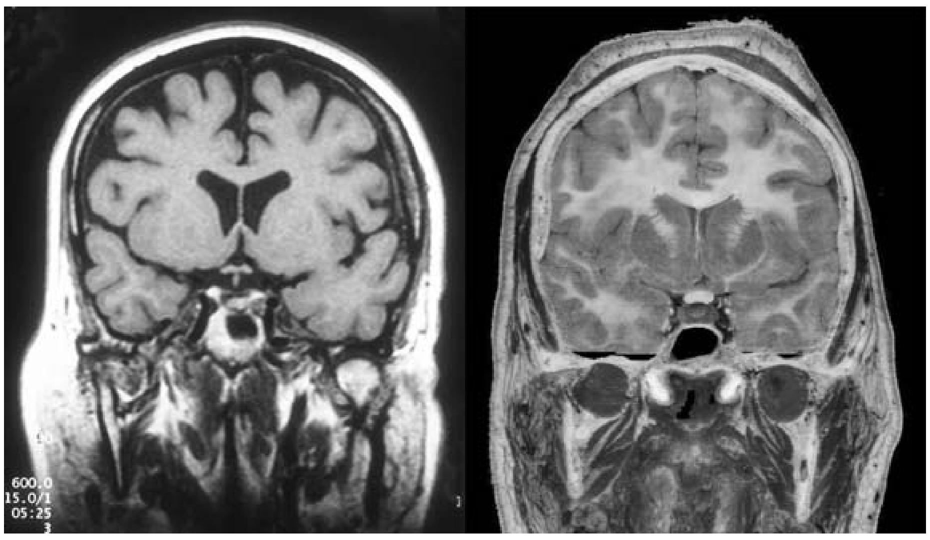

FIGURE 1.31. *Comparison of T1-weighted MRI and coronal section through anatomic specimen. The MRI scan was from an elderly patient with a long history of dementia, while the anatomic specimen was from the middle-aged woman in the Visible Human Project. (Right panel adapted from an image created by the Head Browser developed by the University of Michigan, Visible Human Project, National Library of Medicine.)*

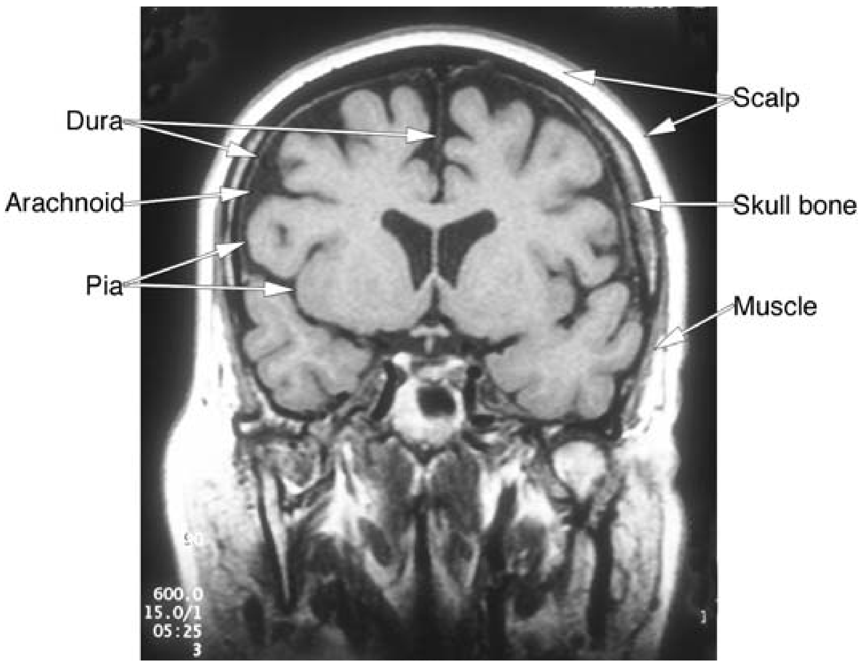

FIGURE 1.32. *Coverings of the brain on MRI scan.*

midline as the falx. Beneath the dura is the gray matter and the black CSF. The dura cannot easily be distinguished from its closely adherent arachnoid in nonpathologic states. In this case, some separation may be seen on the left side of the image. The pia is really just the surface of the brain; it is not a distinct layer on MRI scans or on a gross brain specimen. See Figure 1.32.

Q1.26. In order to get a true sense for how the brain sits in its coverings, examine Figure 1.33. Try to identify the dura and arachnoid membrane. Where might they be separated?

A1.26. See Figure 1.34. Only around surface vessels do the dura and arachnoid normally separate from each other. However, this potential space can become a real space in pathologic states, producing a subdural hemorrhage. In contrast, the delicate arachnoid remains slightly separated from the underlying cortex, producing a space that bathes the brain in cerebrospinal fluid.

Skull

Q1.27. Examine a skull, and a skull-brain model. Identify the following landmarks on the skull and label them in Figure 1.35: foramen magnum, temporal bone, acoustic meatus, cribriform plate, optic canal and superior orbital fissure.

A1.27. See Figure 1.36.

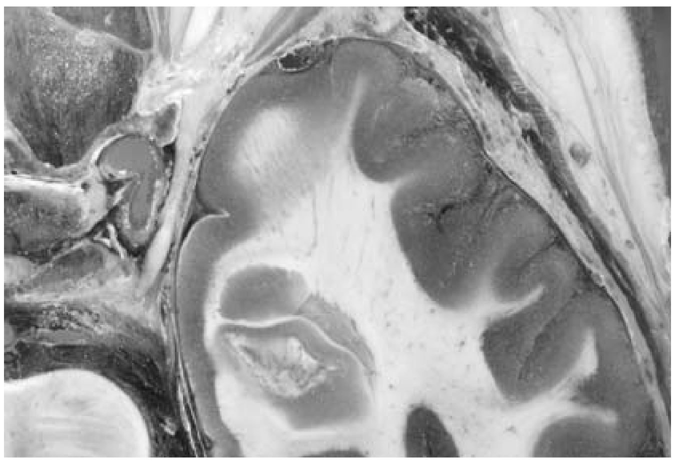

FIGURE 1.33. *Close-up, in situ, horizontal view of the brain in the skull. The head in this individual was specially prepared to accurately preserve its anatomic relationships. It was then serially sliced and photographed. (Image courtesy of Peter Ratiu and Berend Hillen, Visible Human Project, National Library of Medicine.)*

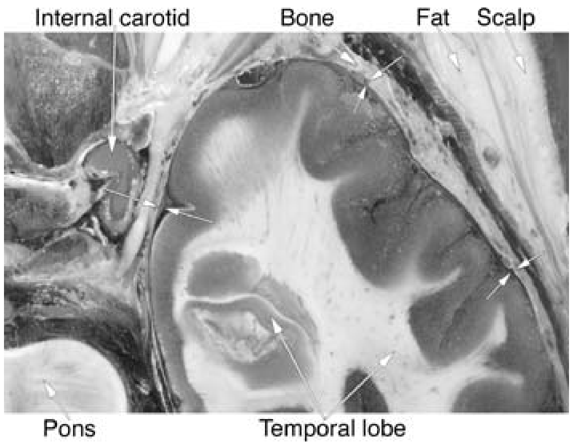

FIGURE 1.34. *Membranes on brain surface. Unlabeled white arrows point the dura on the exterior and arachnoid next to the brain surface at the point where surface vessels run.*

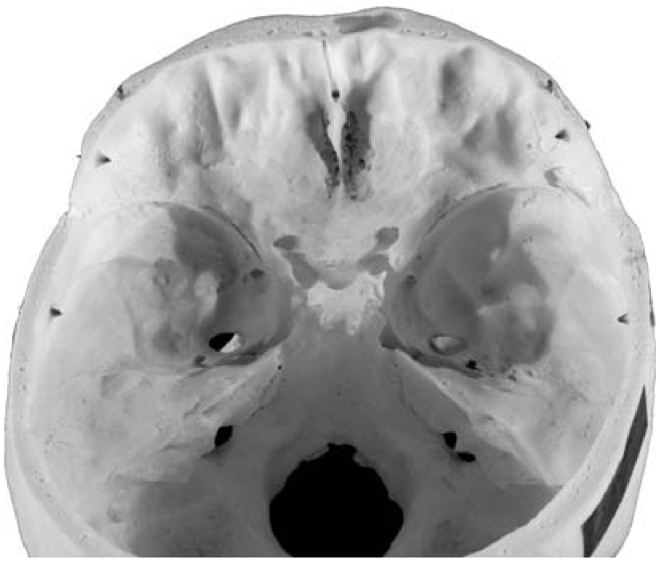

FIGURE 1.35. *Human skull base, view from posterior-superior.*

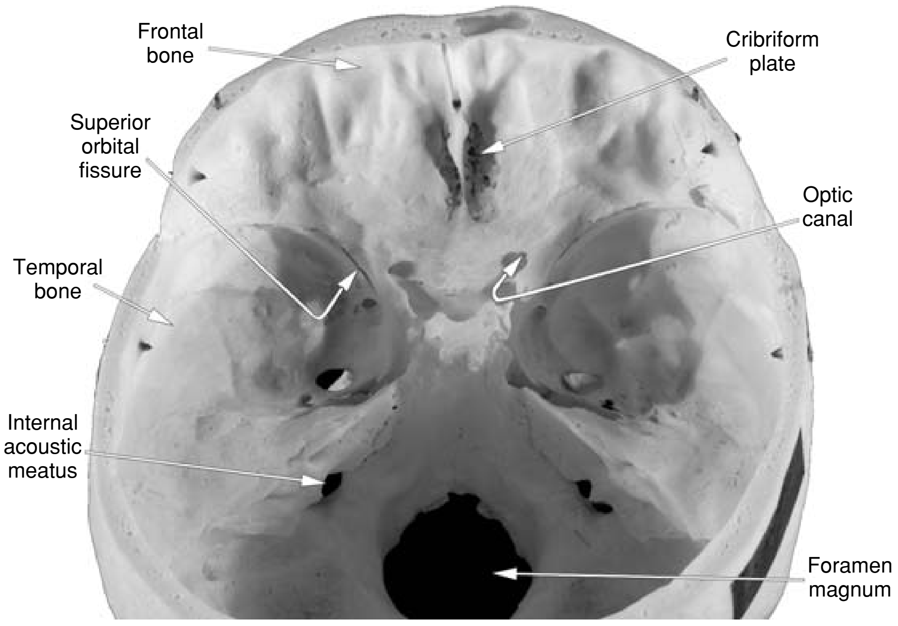

FIGURE 1.36. *Several important structures on the interior skull base.*

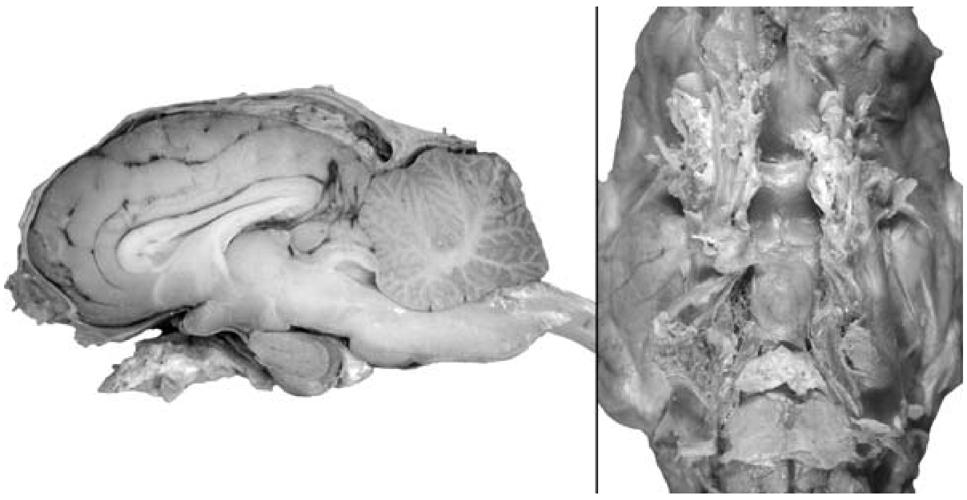

FIGURE 1.37. *Sheep's brain with the dura attached, medial and inferior view.*

Q1.28. Orient the brain with respect to the skull. Where does the cerebellum sit? Locate the positions occupied by the four lobes of the brain. Where is the skull smooth? Where is it sharp? When the brain strikes a massive hard object as with a serious fall, the brain glides over the surface of the skull. Which surfaces are most likely to damage the brain?

*A1.28. The skull is smoothest over the superior convexity and roughest over the eyes (orbitofrontal area) and in the anterior temporal fossa. Head injuries, especially those when the brain and skull are moving together as in a motor vehicle accident, typically produce the greatest injury over the roughest areas of the skull. A fall to the back of the head frequently produces a contusion on the inferior frontal surface of the brain (**“contrecoup" injury**).*

Soft Tissue Coverings

Q1.29. Examine the sheep brain (see Fig. 1.37). Identify cranial nerves I and V. How do they differ from those of humans? Is cranial nerve V extradural or intradural? Dissect one of the sheep brains along the sagittal plain, leaving the dura intact. Compare it with an intact sheep brain. Identify the pituitary gland and the pineal gland. What is their relationship to the dura? Any differences with the human sagittal section?

A1.29. The olfactory nerve in a sheep is huge compared to the diminutive version in humans. Because the brain has the entire dura intact, you can now see the relationship of the trigeminal ganglion to the brain. It is the paired ragged area off the midline in the right image of Figure 1.37. In the human specimens this ganglion usually remains in the skull, beneath the dura. Remember, the dorsal root ganglia (or its equivalent, the trigeminal or gasserian ganglion) are outside the dural sheath. The pituitary looks huge relative to that in the human (see the base of brain picture in Figure 1.15); most of this is an illusion, since it is the sheep's brain that is so much smaller than ours. Good thing, since we don't want sheep to eat us. The pituitary lies in its own little dural cavity. The dura inserts around the pineal gland, which, like the pituitary, is relatively large in a sheep.

INST Make a small incision coronally into the top of the dura and identify the superior sagittal sinus. Dissect off the entire dura from sheep’s brain being careful to preserve its overall structure. See Figure 1.38. Try to tear it with your hands. You now know why it is called “dura.” Note that the brain comes off the dura with great ease, and also has its own, separate vasculature.

Q1.30. Compare the dissected sheep’s dura in Figure 1.38 to the human illustration in Figure 1.39. Identify the falx and tentorium. Note the bridging veins extending from cortex to the superior sagittal sinus. Identify the arachnoid granulations on the human and sheep brains. Why are they important?

A1.30. The CSF passes from the subarachnoid space into the sinus via these granulations, which pierce the otherwise impenetrable dura mater.

FIGURE 1.38. *Dura (*right, *inferior view) dissected from a sheep's brain (*left, *superior view).*

Q1.31. Figure 1.40 shows a cross section of the dissected dura from a human brain. What brain structures are apposed to the numbered sites? Name numbers 2 and 3.

1.31.1 ____________ 1.31.3 ____________

1.31.2 ____________

A1.31 *1.31.1. Cerebral hemispheres*
1.31.2. Medial surface of the hemispheres; falx
1.31.3. Cerebellum below and occipital lobe above; tentorium

INST Using your specimens and Figure 1.5 of the brain coverings, note the relationship between the meninges and the blood vessels. Determine where the main arteries, venous sinuses, and veins are located.

Q1.32. Examine the arachnoid mater on the brain specimens. While the arachnoid is relatively closely apposed to the brain, it doesn't descend into the sulci or the deep spaces surrounding the brain. This results in the formation of cisterns in the cranial vault that are occupied by the CSF. Look at the sagittal MRI in Figure 1.41. In this image the cerebral spinal fluid appears black (along with bone, but for different reasons).

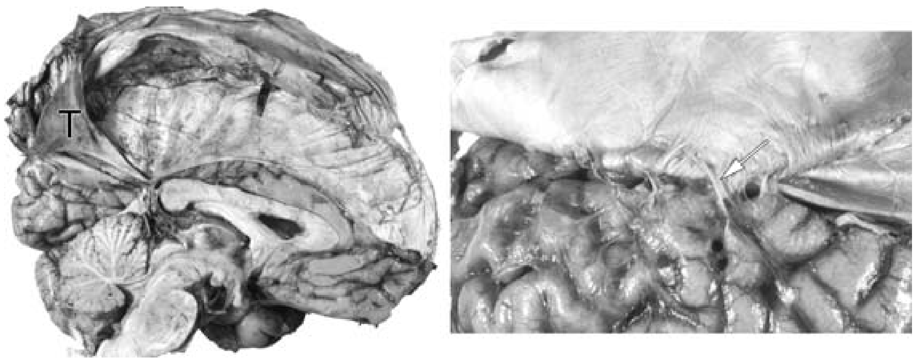

FIGURE 1.39. *Dura attached to brain. The left figure shows its insertion onto brain ("T"—tentorium). The right photograph is a close-up of the dura reflected off the cortical surface, illustrating the bridging veins (*arrow*).*

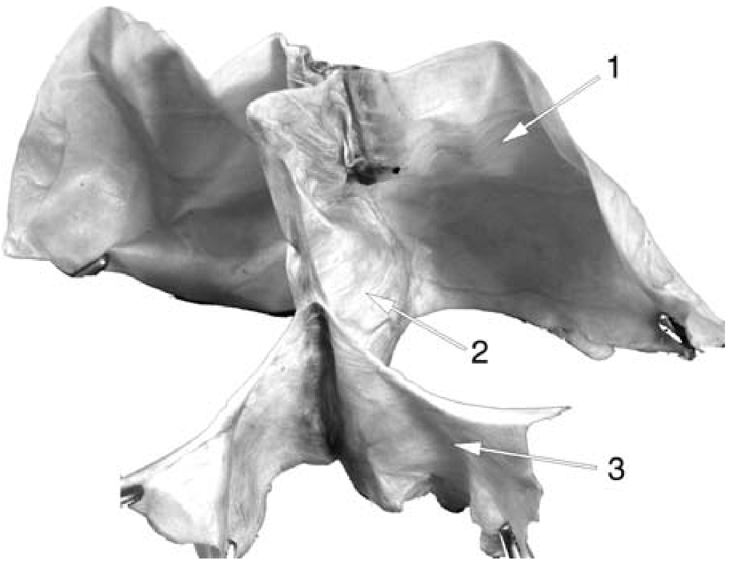

FIGURE 1.40. *Cross-section of human dura, dissected off brain.*

You can see several cisterns outside the brain and ventricular reservoirs within the brain. Identify on Figure 1.41:

- Cisterna magna
- Prepontine cistern
- Interpeduncular cistern
- Quadrigeminal cistern

Should a spinal tap not be possible, which cistern would be the best to choose if you needed to sample the CSF?

A1.32. See Figure 1.42. The cisterna magna is the easiest and largest of the cisterns, and is typically the one sampled when fluid cannot be gotten from the back.

CLINICAL CASE: HEMORRHAGE

The patient was a 73-year-old man who had an acute onset of a new, severe headache, nausea, and vomiting. A head CT was performed.

FIGURE 1.41. *Normal sagittal T1 MRI. The CSF is black on T1 images, since water is free to move about and release its proton-labels distant from where they were applied. Bone is also black, but only because it contains little water. The image shows both cisterns and the ventricular system as either black or gray.*

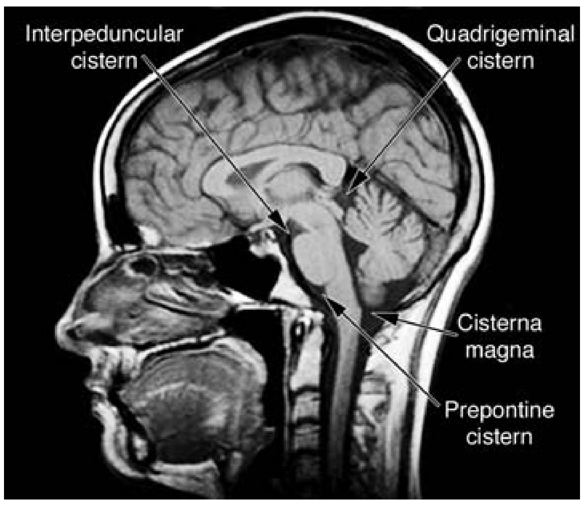

FIGURE 1.42. *Major cisterns in a sagittal T1 MRI.*

Q1.33. Examine the CT scans on the patient in Figure 1.43, and compare it with the normal CT in Figure 1.44. On a CT scan, bone is very opaque to X-rays and hence is white, blood is less opaque, brain even less, and CSF is the most transparent to this radiation. What do you see? Where is the lesion? How can you tell? Is it inside or outside the brain?

A1.33. The "lesion" is a diffuse density around most of the brain surface, which is not present in the normal control. This is blood on a CT scan. You can tell this is subarachnoid hemorrhage, since it dives into the depths of the sulci and spreads over much of the brain surface, without "obeying" the boundaries of the dura. The hemorrhage is not present in the ventricular system, hence the blood did not originate in or near the ventricles (a relatively common presentation in middle age and in prematurity). This indicates the most likely source is a vessel between the leptomeninges and the brain.

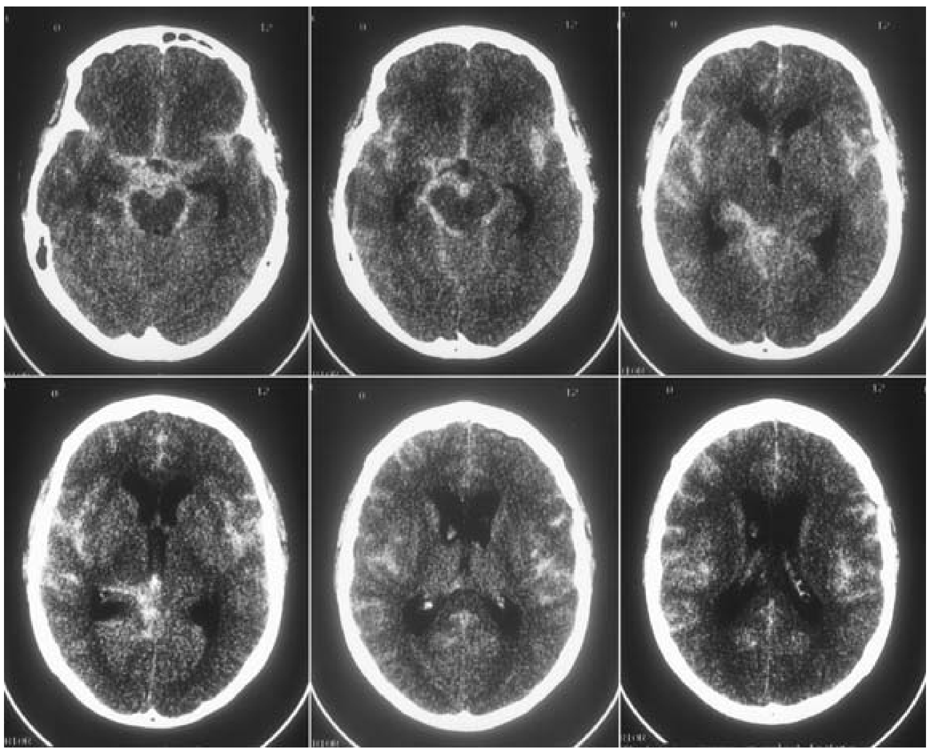

FIGURE 1.43. *Head CT scan from patient.*

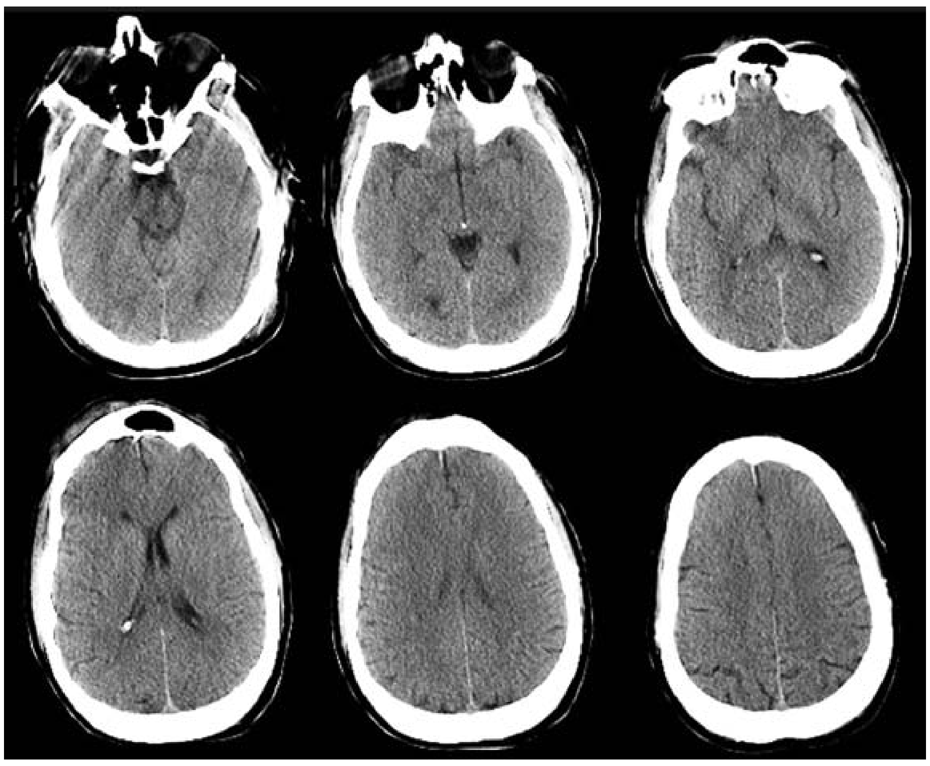

FIGURE 1.44. *Normal head CT scan.*

Q1.34. The patient was found to have an arteriovenous malformation in the cerebellum that had ruptured. Although this malformation was surgically removed, the patient continued to do poorly, and eventually expired. Examine the image of his brain in Figure 1.45. How can you tell in which space the blood resides? How could blood from the cerebellum reach the frontal poles?

A1.34. The blood is subarachnoid; it lies underneath the glistening surface of the meninges. Unlike subdural blood, this hemorrhage has access to the pain receptors in the meninges, and produces a severe headache. Since the subarachnoid space is a continuous space of cerebrospinal fluid, once the blood reaches the ventricular system, it can spread along the pathways of this fluid. Blood generally does not track back into the brain, since the flow is from the choroid plexus outward.

In any patient with a sudden onset of a severe new headache, you are obligated to look for blood, either by a head scan or by a spinal tap. Ruptured aneurysms and vascular malformations are the most common suspects, especially in younger patients.

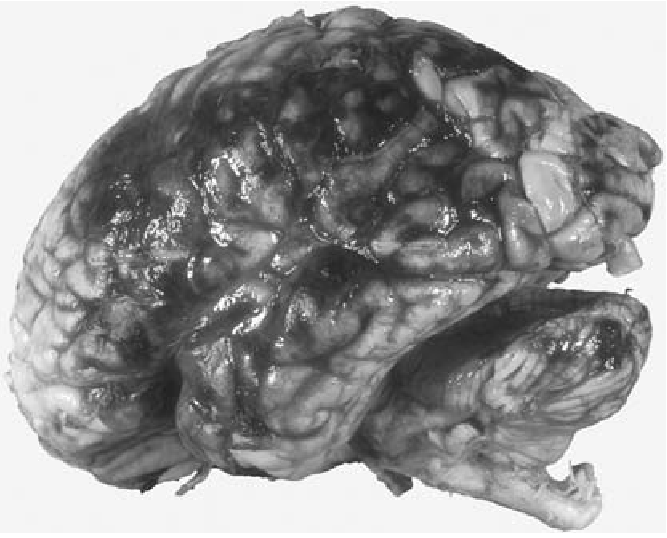

FIGURE 1.45. *Gross brain specimen, showing extensive subarachnoid hemorrhage.*