FRENCH 241D | Flaubert's Brain

A Brief Survey of Human Brain Anatomy

Leonard E. White, PhD

Associate Professor
Department of Community and Family Medicine
Department of Neurobiology
Duke University School of Medicine
Duke Institute for Brain Sciences

Nell B. Cant, PhD

Professor
Department of Neurobiology
Duke University School of Medicine

with illustrations by:

S. Mark Williams, PhD
Pyramis Studios, Durham NC

Duke Institute for Brain Sciences
Duke University School of Medicine

Introduction
A Brief Survey of Human Brain Anatomy

Perspectives on Human Neuroanatomy

Neuroanatomy is a complex subject. The wealth of anatomical detail discovered and described over the past century is staggering. With the constant introduction of powerful new neuroanatomical techniques, more details are arriving at an increasing rate, and there seems to be no end in sight.

Fortunately, it is possible to acquire a rather simple (or simplified at least) anatomical framework for understanding the organization of the human brain, which is the foundation for understanding brain function and the dysfunctions that disorder human behavior. Indeed, the neuroanatomical detail required for competent research in the cognitive sciences, including the emerging field of *Neurohumanities*, forms a very limited subset of the total information available. If you choose to continue studies in cognitive neuroscience, you will be challenged to build upon this simple neuroanatomical framework a more precise and accurate understanding that will help you discuss increasingly complex aspects of brain function. But first things first.

Very soon you will encounter—perhaps for the first time—the human brain. As we explore the basic parts of the human brain, don't let the moment of excitement and wonder pass you by as you hold and closely inspect what is widely declared to be the pinnacle of vertebrate evolution! So let's get ready and organized to make the most of our learning experiences in the laboratory.

There are a few basic rules that you should follow in the laboratory when you examine human brains:

- Come to the laboratory ready to discover, with a clear 'game plan' in mind for your learning activities, so be prepared to "do" the **Challenges** in the green boxes on the pages that follow.

- Always wear gloves when handling human tissue in the laboratory; gloves will be provided.

- Laboratory coats and laboratory clothes are not required or necessary, but you may dress in laboratory attire (scrubs, old clothes) if you wish.

- Keep the brains in the pans provided for them and immerse them in water, or at least sprinkle them with water. *It is very important that the brains do not dry out!*

- Always hold the specimens above a container (*no dropped brains, please!*).

- Should any tissue break off from the specimens, leave it in the dissecting pan so that it can be disposed of properly after the laboratory session.

Treat these specimens gently! Human brains are difficult to obtain, and with proper care, these specimens will be used for years by various groups of learners in the **Duke** brain science community.

Perhaps most importantly, you should recognize the incredible generosity of the individuals who donated their bodies (and brains) to biomedical research and the education of learners, such as yourselves. As you handle the brains in the lab, consider the courageous ambition of the donors and apply yourself to your learning accordingly. This will be one means of honoring the hopes and dreams of these anonymous (to us at least) individuals who exercised their final wish to advance human knowledge through their gift to you of discovery and learning.

Introduction
A Brief Survey of Human Brain Anatomy

How to use this *Laboratory Guide*

Following this brief Introduction, you will find an illustrated narrative that will address the foundations of functional human neuroanatomy. This narrative first addresses the superficial features of the human brain, and then the internal features of the cerebral hemispheres. Application of this *Laboratory Guide* to your present and future studies of human neuroanatomy will provide the framework needed to understand cognitive neuroscience more generally, and to interpret data derived from the various means that you may employ to gain new knowledge of brain organization and function more particularly.

So how should you approach your studies with this *Laboratory Guide* in hand? Here are some tips:

1. **Read the text and study the figures in advance.** This seems obvious; however, we all know how much is asked of you on short notice. But please don't eschew the simple task of reading this *Guide* in advance of the laboratory experience. We believe that the text provides a concise exposition of human neuroanatomy and that the illustrations and photographs are clear and accurate. It is well worth your time to follow this plan.

2. **Discuss and describe the structures identified in bold font.** The neuroanatomical structures identified in **bold** are those that you should be able to describe and discuss upon completion of the laboratory session.

3. **Do the Challenges.** Throughout the narrative, you will find a set of activities in green boxes that we label "**Challenges**". These are written to provide you with active learning exercises that are designed to demonstrate or reinforce the neuroanatomy described in the corresponding section. They direct you in your interaction with brain specimens that are available in the laboratory. If you follow the first tip above before, your time in the lab can then be well focused by doing the **Challenges**. As questions and new insights arise, let the active learning described in these green boxes be the launching pad for further application and discovery.

This single learning experience in FRENCH 241D will come and go before you know it! We trust that these learning resources will serve you well now, and whenever a working knowledge of functional neuroanatomy is needed as you progress in your studies, scholarship and research.

Leonard E. White, PhD
Durham NC
September 2012
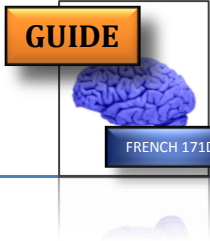
Laboratory Guide
A Brief Survey of Human Brain Anatomy

Basic subdivisions of the mammalian brain

The central nervous system is generally considered to consist of seven basic parts. From caudal (toward the tail) to rostral (toward the nose), they are the **spinal cord**, the **medulla**, the **pons**, the **cerebellum**, the **midbrain**, the **diencephalon** (including the **thalamus** and **hypothalamus**), and the **cerebral hemispheres**. The medulla, pons, and midbrain make up the **brainstem**. The cerebellum is a major structure attached to the brainstem at the level of the pons. Subdividing the nervous system in this way is somewhat artificial because the different subdivisions are highly interconnected, and most functional systems are distributed in more than one subdivision. Nevertheless, division of the nervous system into seven basic parts makes neuroanatomy easier to learn and remember. This laboratory experience is designed to help you learn how to recognize each part.

The subdivisions of the adult brain arise from three swellings that appear at the cephalic (brain) end of the neural tube at about one month of gestation (**Figure 1A**, see 'straightened neural tube' illustration). The embryonic divisions of the central nervous system give rise to adult structures as summarized in the chart to the right. This chart depicts the relationships among major parts of the developing brain. These relationships are exactly the same in the adult brain, although the relatively greater growth of the cerebral hemispheres makes this fact difficult to appreciate.

	EMBRYONIC BRAIN	ADULT BRAIN DERIVATIVES	ASSOCIATED VENTRICULAR SPACE
Prosencephalon	Telencephalon (forebrain)	Cerebral cortex	Lateral ventricles
		Basal ganglia Hippocampus Olfactory bulb Basal forebrain	
	Diencephalon	Dorsal thalamus	Third ventricle
		Hypothalamus	
	Mesencephalon	Midbrain (superior and inferior colliculi)	Cerebral aqueduct
Rhombencephalon	Metencephalon	Cerebellum	Fourth ventricle
		Pons	
	Myelencephalon	Medulla	Fourth ventricle
	Spinal cord	Spinal cord	Central canal

(Figure A21 from *Neuroscience*, 4th *Ed.*, Sinauer Assoc., Inc.; after original scheme by N.B. Cant)

The nervous system starts out as a simple tube, and the lumen of the tube remains in the adult brain as a fluid-filled space (consider for a moment the fact that the entire brain was once the walls of a simple hollow tube!). This space, known as the **ventricular system**, is filled with cerebrospinal fluid (CSF) and provides an important landmark on images of the nervous system. As the brain grows, the shape of the central space also changes, from that of a simple tube to its complex adult form. The space, although continuous, takes different names in each of the subdivisions, which are listed in the chart above.
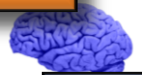
Laboratory Guide
A Brief Survey of Human Brain Anatomy

In the embryo, as the neural tube first closes, three swellings appear at its cephalic end (see **Figure 1.1A**). These will form the brain, while the rest of the neural tube gives rise to the spinal cord. The most rostral of the three, the **prosencephalon**, soon divides into two parts: the **telencephalon**, which gives rise to the cerebral hemispheres, and the diencephalon, which becomes the thalamus and hypothalamus (see **Figure 1B**). These structures together make up the adult **forebrain** (= derivatives of the prosencephalon). The spaces inside the hemispheres are known as the **lateral ventricles**, and the space inside the diencephalon is the **third ventricle**.

The **mesencephalon**, which is the middle swelling in the 4-week embryo (see **Figure 1A**), does not divide further and becomes the midbrain of the adult. The space inside the midbrain is called the **cerebral aqueduct**. The **rhombencephalon** further divides into the **metencephalon**, which becomes the pons and cerebellum, and the **myelencephalon**, which becomes the medulla (see **Figure 1B**). The derivatives of the rhombencephalon are considered the adult **hindbrain**. The part caudal to these three swellings remains long and straight and becomes the spinal cord. That in the pons and medulla is called the **fourth ventricle**. In the embryo and young children, the opening in the spinal cord is patent and is known as the **central canal**. It is very narrow and usually reduced to a "potential" space with very little CSF in the adult.

Not all of the brain structures just mentioned (terms in **bold**) are illustrated in **Figure 1**. You will see all of them shortly as we explore the major parts of the adult brain (beginning in **Figure 4**). At this point, focus on learning the relationships depicted in the chart on the previous page, and their embryological origins.

But before getting to the brain itself, it will be helpful to review several of the anatomical terms and conventions that are needed to specify position in the nervous system (next section).
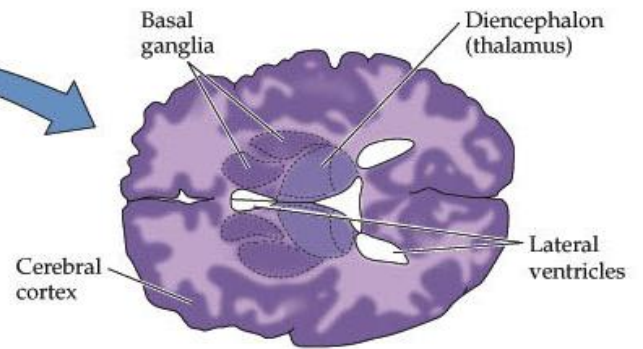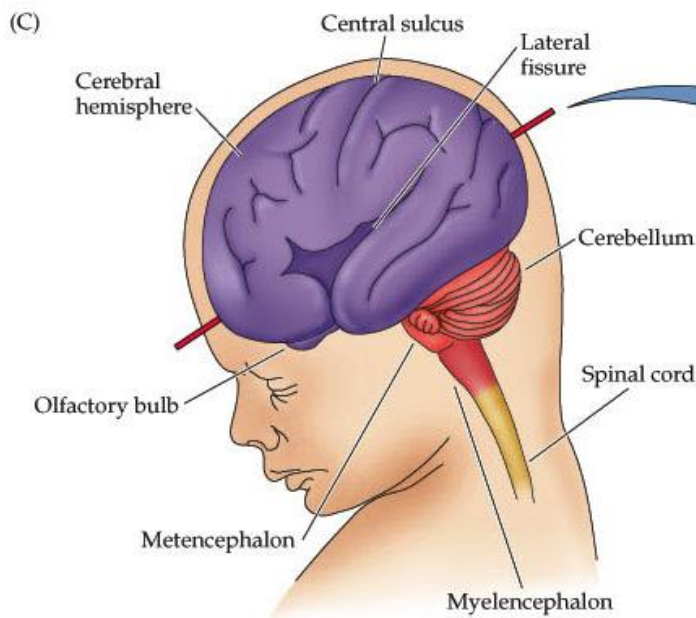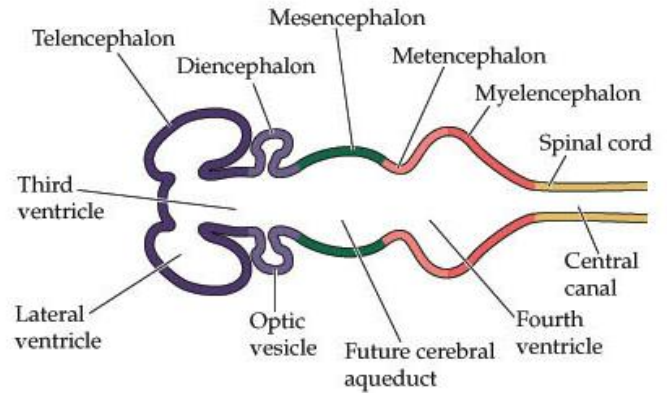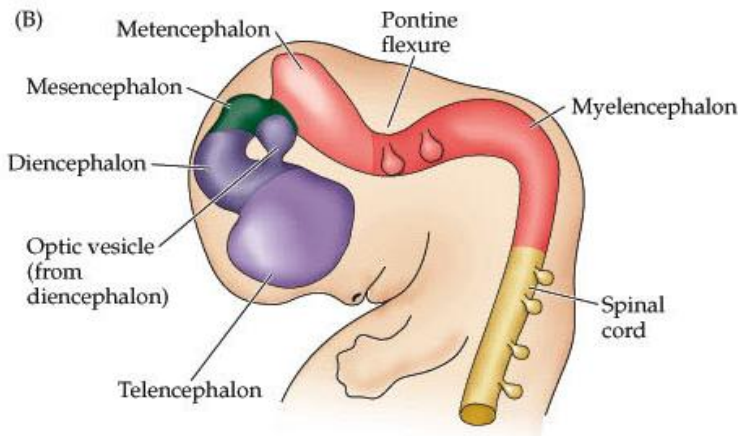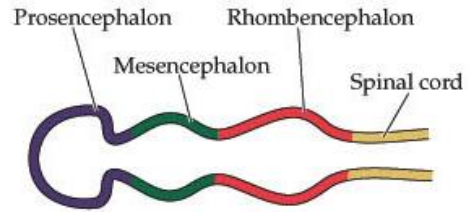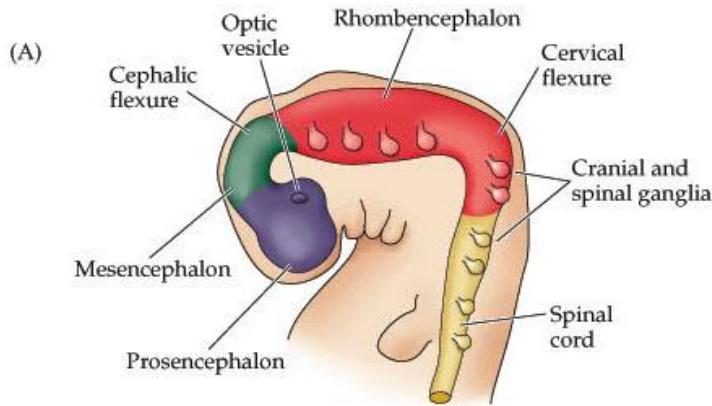
Figure 1 (next page). The developing human brain. *Left*, drawings (not to scale) of the neural tube as viewed from the side. *Right*, top two illustrations drawn as though the tube were stretched out to make it straight and the top were cut off; view is from the top. The bottom right illustration (C) shows the appearance of a section through the forebrain at the level indicating to the left (Figure 22.5 from *Neuroscience*, 4*th* Ed.).

Laboratory Guide
A Brief Survey of Human Brain Anatomy

(A)

Optic vesicle
Rhombencephalon
Cephalic flexure
Cervical flexure
Mesencephalon
Cranial and spinal ganglia
Prosencephalon
Spinal cord

Prosencephalon
Rhombencephalon
Mesencephalon
Spinal cord

(B)

Metencephalon
Pontine flexure
Mesencephalon
Myelencephalon
Diencephalon
Optic vesicle (from diencephalon)
Spinal cord
Telencephalon

Telencephalon
Mesencephalon
Diencephalon
Metencephalon
Myelencephalon
Spinal cord
Third ventricle
Lateral ventricle
Optic vesicle
Future cerebral aqueduct
Central canal
Fourth ventricle

(C)

Central sulcus
Lateral fissure
Cerebral hemisphere
Cerebellum
Spinal cord
Olfactory bulb
Metencephalon
Myelencephalon

Basal ganglia
Diencephalon (thalamus)
Cerebral cortex
Lateral ventricles

Laboratory Guide
A Brief Survey of Human Brain Anatomy

Specification of location in the nervous system

The terms used to specify location in the central nervous system are the same as those used in gross vertebrate anatomy. One complication (that can become a source of confusion if you don't understand it) arises because some terms refer to the long axis of the body, which is straight, and others refer to the long axis of the central nervous system, which has a bend in it (**Figure 2**).

Figure 2. A flexure in the long axis of the nervous system arose as humans evolved upright posture. This flexure leads to a ~120 degree angle between the long axes of the hindbrain and forebrain. The two axes intersect at the junction of the midbrain and diencephalon. This flexure has consequences for the application of standard anatomical terms used to specify location. The terms anterior and posterior and superior and inferior are used with reference to the long axis of the body, which is straight. Therefore, these terms refer to the same direction in space for both the forebrain and the hindbrain (indicated by arrows). In contrast, the terms dorsal and ventral and rostral and caudal are used with reference to the long axis of the nervous system, which bends. Thus, dorsal is toward the back for the hindbrain, but toward the top of the head for the forebrain. Ventral is toward the gut. Rostral is toward the top of the head for the hindbrain, but toward the front for the forebrain. Caudal is opposite. (Figure A1 from *Neuroscience, 4*[th] *Ed.*; after original from N.B. Cant)
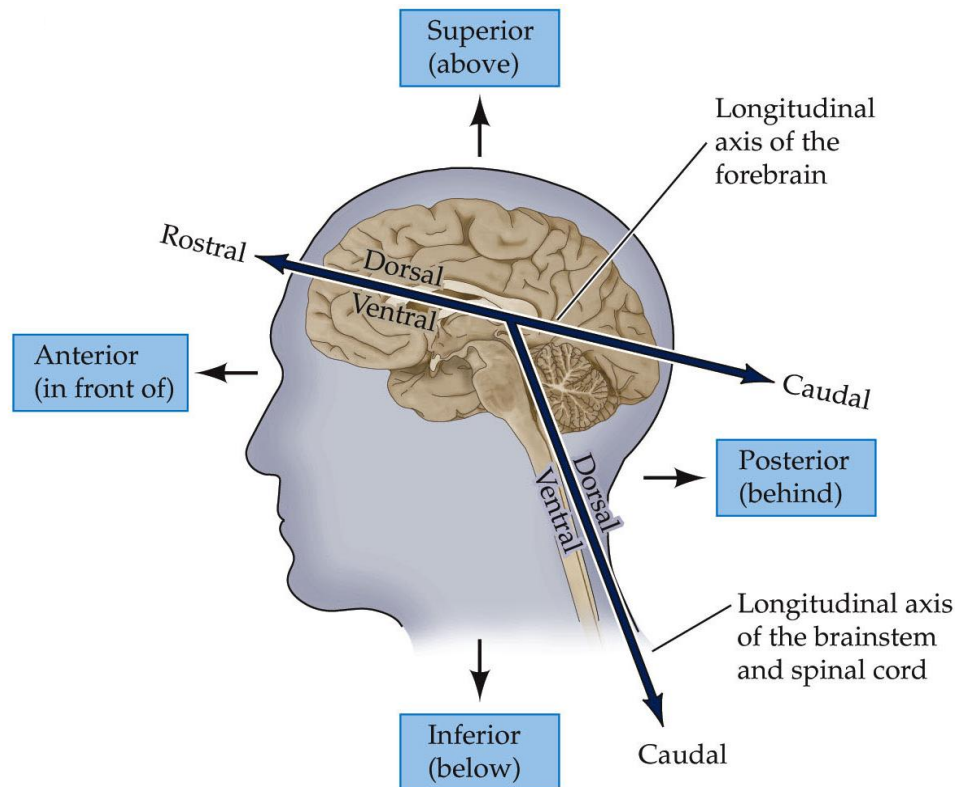
When you understand these terms and how they are used, you will see why the terminology of neuroanatomy can be confusing at first. For example, the ventral aspect of the spinal cord is also referred to as the anterior aspect in humans, since for the human spinal cord, the two words are synonymous. However, there is a nucleus (cluster of neurons) in the thalamus called the "ventral anterior nucleus". When reference is to the forebrain, the two terms specify different directions, so the compound name of this nucleus is not redundant.

Use of the terms discussed in this section allows us to specify the location of any part of the nervous system with reference to any other part. **Figure 2** is worth some study of before proceeding.

The standard planes of section

The brain is commonly cut in one of the three standard planes of section (**Figure 3**). Magnetic resonance images

Laboratory Guide
A Brief Survey of Human Brain Anatomy

(MRIs) are also usually made in these planes (or close approximations of them). It will help you to understand three-dimensional relationships in the brain if you become familiar with these planes, the application of the positional terms discussed in **Figure 2**, and the appearance of the internal structures of the brain in all three planes of section (see below).

Figure 3. Standard planes of section. The **horizontal** or **axial** plane (think, horizon) shows structures as they would appear from above or below. The **frontal** or **coronal** plane (think, tiara-style crown) shows structures as they would appear from the front or back. The **sagittal** plane shows structures they would appear from the side (think, Sagittarius—the archer's plane). (*left*, Figure A1 from *Neuroscience, 4*^th *Ed.*; *right*, courtesy Pyramis Studios, Durham NC)

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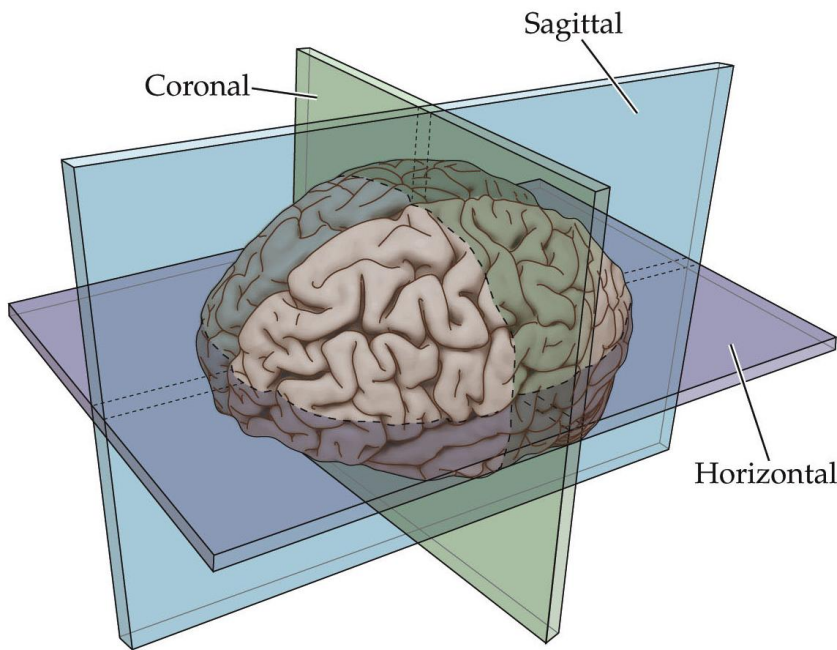
Horizonal (Axial)
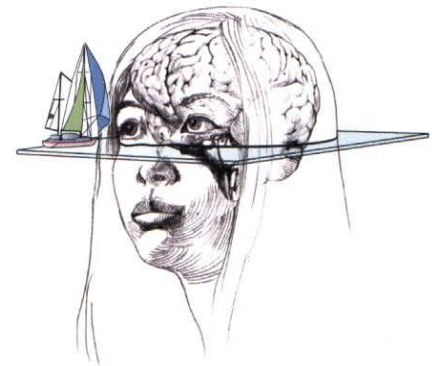
Coronal (Frontal)

Sagittal

Coronal —
Sagittal
Horizontal

Other pairs of terms that are important to know are:

Lateral—toward the side and away from the midline
Medial—toward the midline and away from the side

Ipsilateral—on the same side (as another structure)
Contralateral—on the opposite side

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Laboratory Guide
A Brief Survey of Human Brain Anatomy

Because of the flexure at the junction of the midbrain and diencephalon, coronal sections are the closest to cross-sections of the forebrain, whereas horizontal sections are the closest to cross-sections of the brainstem. (Cross-sections—also called transverse sections—are sections cut perpendicular to the long axis of the CNS.) The first thing you should do when confronted with a new section of the brain is to figure out the plane of section.

Surface views of the human brain

When you view the lateral aspect of a human brain specimen (**Figures 4–6**), three structures are usually visible: the **cerebral hemisphere**, the **cerebellum**, and part of the **brainstem** (although the brainstem is not visible in the specimen photographed in lateral view for **Figure 6**). The spinal cord has usually been severed (but we'll consider the spinal cord later), and the rest of the subdivisions are hidden from lateral view by the hemispheres. The diencephalon and the rest of the brainstem are visible on the medial surface of a brain that has been cut in the midsagittal plane (**Figure 7**). Parts of all of the subdivisions are also visible from the ventral surface of the whole brain (**Figure 8**). Over the next several pages, you will find illustrations and photographs of these brain surfaces, and sufficient detail in the text to appreciate the overall organization of the parts of the brain that are visible from each perspective.

Lateral aspect of the brain. The **cerebral hemispheres** are relatively large in humans. They are entirely covered by a 2–3-mm thick layer of cells and cellular processes called the **cerebral cortex**. The surface of each hemisphere is highly infolded; the ridges thus formed are known as **gyri** (singular: gyrus) and the valleys are called **sulci** (singular: sulcus) or **fissures** (if they are especially deep). The appearance of the sulci and gyri varies somewhat from brain to brain. (As you might guess, each one has its own name, but it is necessary to become familiar with only a few of them.) The hemispheres are conventionally divided into lobes named for the bones of the skull that overlie them, namely the **frontal**, **parietal**, **occipital** and **temporal lobes** (see **Figure 4**) [**Challenge 1**].
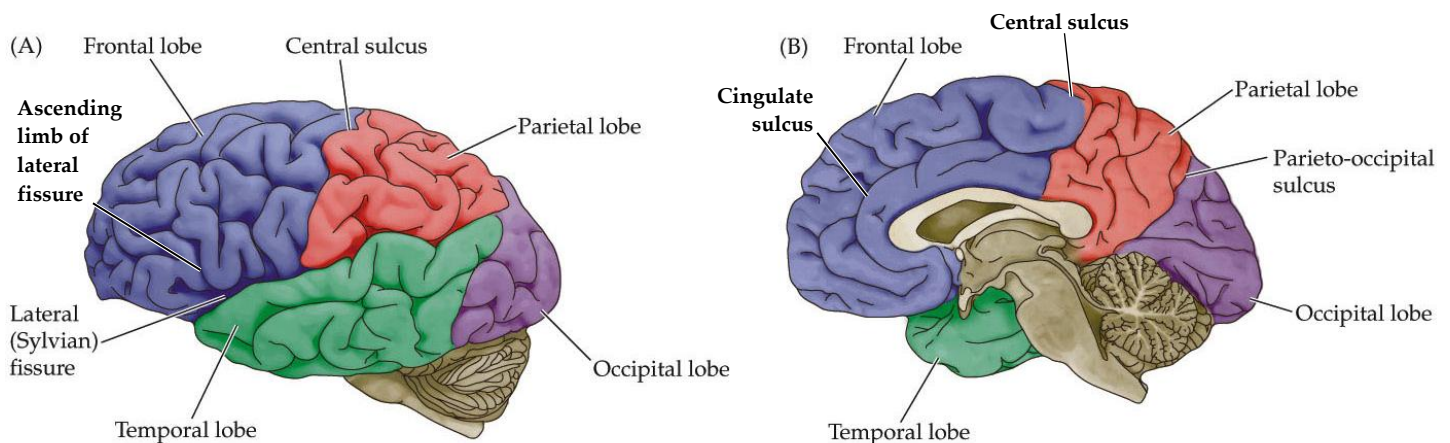

Figure 4. Lateral and midsagittal views of the human brain, emphasizing the division of the cerebral cortex into four lobes (identified with color). (Figure A3 from *Neuroscience, 4th Ed.*)

Laboratory Guide
A Brief Survey of Human Brain Anatomy

Challenge 1—lobes of the cerebral hemispheres

Get your hands on a whole- or half-brain specimen, refer to Figure 4 ***and the text and figures that follow, and identify the four lobes of the cerebral hemisphere.*** Do your best to apply the conventional criteria for dividing the lobes (see text below for details), and take special note of the location and configuration of three deep sulci/fissures:

- the **central sulcus**,
- the **lateral fissure**, and
- the **parieto-occipital sulcus**. [Which specimen will you need for this sulcus: whole or half?]

In addition, you will also need to imagine the anterior boundary of the occipital lobe from the lateral view of the hemisphere, so you will need to sight the **pre-occipital notch**. As you inspect several specimens in the lab, please notice differences among specimens—and even between hempishres of the same brain. What do you think these 'macroanatomical' difference mean? Do they imply 'microanatomical' differences as well? Let's discuss. And *vive la difference!*

The frontal lobe is the most anterior of the four and is separated from the parietal lobe by the **central sulcus**, which is one of the most important landmarks in the cerebral cortex (see Figure 4, boundary between blue and red colored regions; see also pink box below) [**Challenge 2**]. An important gyrus in the frontal lobe is the **precentral gyrus**. (The prefix 'pre,' when used to refer to anatomical position, refers to something that is in front of something else or that is anterior.) The cortex of the precentral gyrus is the somatic 'motor cortex,' which contains neurons whose axons project to the motor nuclei in the brainstem and spinal cord that innervate the skeletal muscles of the body.

Fine, skilled movements are dependent on the integrity of the motor cortex (and, of course, the axons extending from it). The axons that arise from neurons in the motor cortex and extend to the spinal cord are known as the **corticospinal tract**. Those axons that extend from the motor cortex to nuclei in the brainstem are known as the **corticobulbar tract**. (The brainstem is sometimes referred to as 'bulbar' because it has a shape resembling a bulb.) While you can't see the individual fibers that make up the tracts, you can see the structures through which they pass as they course between the cortex and their targets in the brainstem and spinal cord.

Laboratory Guide
A Brief Survey of Human Brain Anatomy

Challenge 2—considering the central sulcus

The central sulcus is one of the most important landmarks in the human brain because it rather precisely divides the somatic sensory cortex of the parietal lobe from the somatic motor cortex of the frontal lobe. Furthermore, an appreciation of the structure of the central sulcus—actually, the structure of the gyri that define the central sulcus—will help you understand how the opposite side of the body is represented in the somatic sensory and motor areas that reside in these gyral formations.

So how should one recognize the central sulcus? Surprisingly, the most reliable way to find the central sulcus is not by inspecting the lateral surface of the brain, where this is one of the longest and deepest sulci of the human cerebral cortex (**Figure 4**). Rather, the best way to find the central sulcus is to start on the medial surface of the hemisphere; so get your hands on a brain sectioned through the sagittal plane. First, locate the gyral structure that sits just dorsal to the **corpus callosum** (which is the massive bundle of white matter that interconnects the two hemispheres); this gyrus is called the **cingulate gyrus**. The sulcus formed by the dorsal bank of the cingulate gyrus is named, appropriately enough, the **cingulate sulcus**. Now follow the course of this sulcus posteriorly. Just past the middle of the hemisphere, there is a sharp, dorsal curve in this sulcus called the "marginal branch" (or ramus) of the cingulate sulcus where the cingulate sulcus turns toward the dorsal surface of the hemisphere.

Now, keep your eye (or a probe) on this marginal branch and identify the very first sulcus that terminates in the gyral formation just anterior to the marginal branch. Even without examining the lateral surface of the cerebral cortex, you can be sure that this first sulcus anterior to the marginal branch of the cingulate sulcus is the central sulcus. But to be certain, follow the course of the sulcus that you just identified as the central sulcus and you should see that it courses along the lateral surface in a gentle anterior progression as you trace it from the dorsal midline toward its inferior margin. Along the way, note the lazy "S"-shaped bend it takes near the middle of the cerebral hemisphere. That is also a cerebral "hot-spot" for that is where the somatic sensory and motor representations of the contralateral arm and hand are localized.

One additional note: that gyral structure bounded by the marginal branch of the cingulate sulcus on the dorsal midline of the hemisphere is also important; this structure, named the **paracentral lobule**, contains the somatic sensory and motor representations of the contralateral foot.

So where's the contralateral face represented, you might ask (another major body part for muscle activity and somatic sensation)? Here's another surprise: the contralateral face is localized to the inferior segment of the central sulcus below that lazy "S" shape (not where you might expect it if the body where mapped continuously). As you take all of this in, remember: in each of these regions of the central sulcus, somatic sensation is represented on the posterior or parietal side of the central sulcus and motor control is localized to the anterior or frontal side of the sulcus.

Laboratory Guide
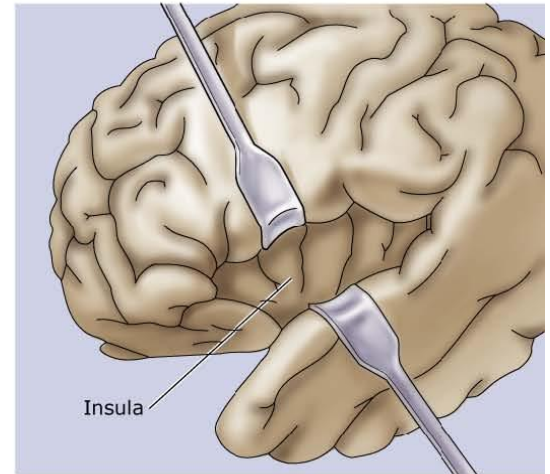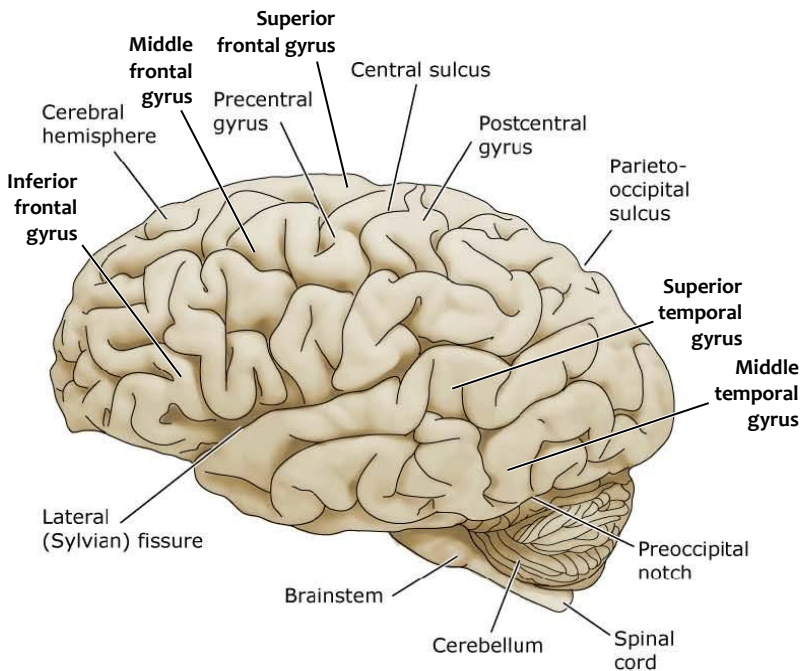## A Brief Survey of Human Brain Anatomy

Figure 5. (left) The lateral surface of the human brain. (right) Location of the insular cortex. Portions of the frontal, parietal and temporal lobes have been gently retracted apart, exposing the underlying **insula** that becomes covered by the expanding cortical mantle in brain development. (Figure A10 from *Neuroscience, 4th Ed.*)

Now, view the lateral surface of either hemisphere.   On the inferior-lateral aspect of the hemisphere, you should readily appreciate a deep, fairly straight fissure that separates the frontal and parietal lobes from the temporal lobe; this space is called the **lateral fissure** or Sylvian fissure, named after the important Renaissance neuroanatomist, *Franciscus Sylvius*.

François de le Boë ("Franciscus Sylvius")
Dutch Physician / Anatomist, 1614-1672

Rotate the brain so that you are now looking down from above.   The hemispheres are separated by an even deeper fissure called the **longitudinal fissure** (or superior sagittal fissure).   The gyral formations anterior to the precentral gyrus on the dorsal-lateral aspect of the frontal lobe between the lateral fissure and the longitudinal fissure can be recognized as three parallel, longitudinal gyri.   Adjacent to the longitudinal fissure is the **superior frontal gyrus**, which is typically the most obvious of the three.   This gyrus continues on the medial surface of the hemisphere in the depths of the longitudinal fissure; we will see it again when we examine the midsagittal section through the brain.   Just inferior to the superior frontal gyrus is the **middle frontal gyrus**, with the **superior frontal sulcus** separating the two.   Note that these two gyral formations are fairly straight and parallel to the longitudinal fissure in the parasagittal plane.   At their posterior end, they sometimes merge with the precentral gyrus, which forms, of course, the anterior bank of the central sulcus and contains the motor cortex (as described above). However, there is often an interrupted (i.e., a superficially discontinuous) sulcus that separates them from the precentral gyrus; this sulcus is named the **precentral sulcus**.

Laboratory Guide
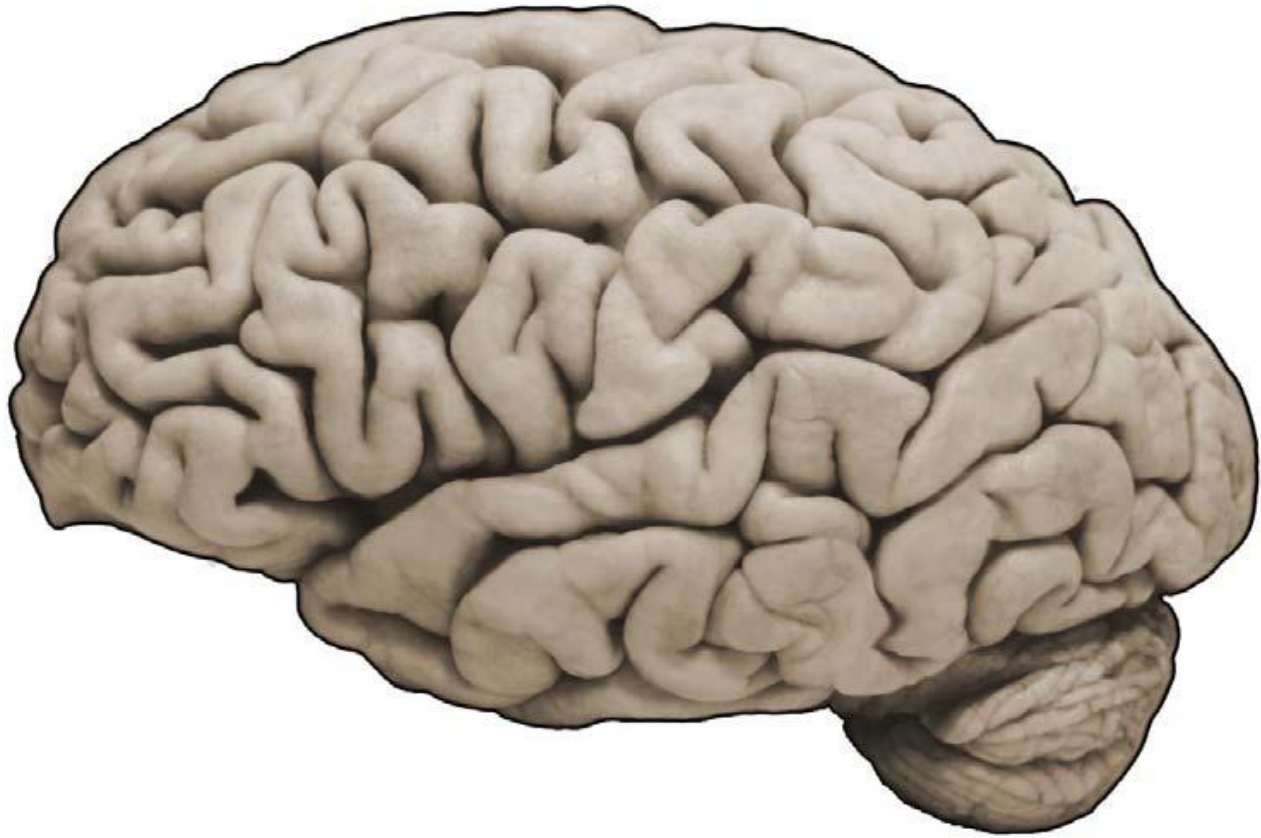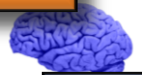## A Brief Survey of Human Brain Anatomy

Figure 6. Lateral surface of the human brain. This figure is not labeled so that you may refer to it for review; see **Figure 4 & 5** for an illustrated and labeled view of the same hemisphere. (Image from *Sylvius4*)

Just inferior to the middle frontal gyrus, across the **inferior frontal sulcus**, is a much more complex gyral formation. For our purposes, we won't be concerned with the names of these subcomponents or their differential functional contributions to cognition and behavior. Suffice it to say that the **inferior frontal gyrus** contains a critical functional division of the motor cortex that participates in the production of speech.   This division has a special name, **Broca's Area**, given in honor of the famous French neurologist, Paul Broca, who first recognized the significance of this gyral formation for human speech in the mid-19th century.   Interestingly, the left hemisphere is dominant in most individuals (especially males) for this function, such that damage to the left inferior frontal gyrus is much more likely to produce an impairment of language production, called *Broca's aphasia* (aphasia means "without speech"), than a comparable lesion involving the right inferior frontal gyrus.

Laboratory Guide
A Brief Survey of Human Brain Anatomy

Next, let's cross the lateral fissure.   The gyral structure that forms the inferior bank of the lateral fissure is the **superior temporal gyrus**.   Note that this gyrus is arranged parallel to the lateral fissure and extends from the anterior pole of the temporal lobe to the parietal lobe (specifically, the angular gyrus of the inferior parietal lobule).   The elongation of this structure in nearly the horizontal plane establishes a framework for considering the remaining temporal gyral formations of the lateral surface.   Including the superior temporal gyrus, it should be possible to recognize three elongated gyral structures that lie parallel to the lateral fissure: the **superior**, **middle** and **inferior temporal gyri**.   The superior and middle temporal gyri are separated by the **superior temporal sulcus** and the middle and inferior gyri are separated by the **inferior temporal sulcus**, although the latter sulcus is often discontinuous and sometimes difficult to recognize.

Notice how the lateral aspects of the frontal and temporal lobes bear some resemblance (at least conceptually): they both comprise three, parallel longitudinal gyri that extend from the anterior pole of each lobe back toward the parietal lobe.   To consolidate this means for conceptualizing these gyral formations, consider **Challenge 3**.

Once you are familiar with these gyral features in one specimen, spend some time examining as many autopsy specimens as are available nearby in the laboratory.   Once again, look for differences and common structural themes among brains and between hemispheres.   In particular, carefully examine the pattern and length of the lateral fissure and consider the following questions.

- Are the two lateral fissures in the two hemispheres of the same brain roughly the same?   If not, how are they different?

- Does the left lateral fissure tend to run mainly in the horizontal plane and extend further posteriorly, compared to the right lateral fissure?

- Is there an ascending branch (ramus) of the posterior lateral fissure in the right hemisphere, but not the left hemisphere?

These questions have been asked and addressed in studies of hemispheric asymmetries and gender differences related to language lateralization in the human brain.   The superior aspect of the temporal lobe contains the cortical divisions whose functions pertain to audition and the reception of language.   The posterior aspect of the superior temporal gyrus has a special functional name, **Wernicke's Area**, named in recognition of the seminal contributions of the 19th century German physician, Carl Wernicke, who described a disturbance of understanding speech, called *Wernicke's aphasia*.   You may find differences in the structure of the superior temporal gyrus in the two hemispheres reflected in the pattern and length of the lateral fissure; such differences may, in turn, be related to the language dominance of the left hemisphere.   Hemispheric differences in this cortical region may even relate to musical abilities and other special talents that pertain to audition and semantic encoding.

- Other regions of the temporal lobe serve visual processing, emotional processing, memory, and the integration of sensory experience, and we will consider these functions later in the course.

Laboratory Guide
A Brief Survey of Human Brain Anatomy

Since you already worked through recognition of the central sulcus, you should now be able to view the lateral surface of any hemisphere and know to look for the central sulcus lazily coursing from the longitudinal fissure over the dorsal-lateral surface of the cerebrum in a lateral-ventral and slightly anterior direction (hopefully, the directional terms applied to the forebrain are also becoming second-nature to you).   Much of the cortex that you observe posterior to the central sulcus is part of the parietal lobe.   The prominent gyral structure that forms the posterior bank of the central sulcus is the **postcentral gyrus**, which is parallel to the precentral gyrus of course. This gyrus is concerned with somatic sensation and is a major focus of studies of touch and body position sensations.   Immediately posterior to the postcentral gyrus is the **postcentral sulcus**, which separates the postcentral gyrus from two major gyral formations of the parietal lobe: the **superior** and **inferior parietal lobules**. The boundary between these two lobules is often difficult to appreciate; it is recognized as a meandering and often discontinuous sulcus called the **intraparietal sulcus** that tends to run in a parasagittal plane.   We will return to the superior parietal lobule when we explore the medial surface of the hemisphere.

The gyral formations just inferior to the intraparietal sulcus include the **supramarginal gyrus** and the **angular gyrus**, two principal components of the inferior parietal lobule.   The inferior margin of the parietal lobe is formed mostly by the prominent lateral fissure.   However, the posterior limit of the lateral fissure does not define the entire inferior boundary of the parietal lobe.   The supramarginal gyrus usually forms a "horseshoe" shape around the posterior limit of the lateral fissure, with the angular gyrus just posterior to the supramarginal gyrus.

Likewise, it is often difficult to discern the boundaries where the posterior parietal and temporal lobes meet the anterior occipital lobe on the lateral surface of the cerebrum, and it may make no functional sense to attempt to do so.   Nevertheless, we can define an imaginary lateral boundary between the parietal and occipital lobes in this complex and variable region.   Emerging from the depths of the longitudinal fissure along the medial bank of the cerebral hemisphere (about one-fourth of the length of the fissure from its posterior limit) is the **parieto-occipital sulcus**.   We will see this sulcus more plainly when we explore the medial face of the hemisphere.

For now, refer to **Figure 4** and appreciate the parieto-occipital sulcus as the medial boundary between the parietal and occipital lobes.   View the lateral surface of the hemisphere again and carefully inspect its inferior margin. Just above the cerebellum, there is often a small groove or notch in the gyral structure that can be appreciated 3-4 cm anterior from the caudal pole of the hemisphere.   This groove is called the "pre-occipital notch" (see **Figure 5**).   Now, draw an imaginary line between the parieto-occipital sulcus dorsally and the pre-occipital notch ventrally; this line will serve as the lateral boundary between the parietal and occipital lobes.   Simply put, all gyral structures posterior to this line are occipital and have some role to play in elaborating visual perception. Fortunately for you, the complexity and inter-individual variation of these gyri defies easy application of standard nomenclature; for this reason, we will refer to these gyral structures as **lateral occipital gyri** and leave the business of naming these gyri for the cortical cartographers.

Lastly, there is a region of cortex called the **insula**, which is not visible from the lateral surface of the hemisphere because it is hidden beneath the frontal, temporal, and parietal lobes.   The components of these lobes that cover the insular cortex are often called 'opercular' components ('opercular' means a lid or cover).   It can be seen if portions of these two lobes are removed or gently retracted (as is illustrated in **Figure 5**).   In spite of its name, the insular cortex does not form an island; it is a part of the continuous sheet of cortex and is deeply buried only because of the relatively greater growth of the cortex around it.   Neurons in the insular cortex are concerned with visceral, autonomic, and taste functions and are thought to contribute in complex ways to integrative brain functions that impact cognition and affect, and the expression of thought and emotion in the visceral motor activities of the body.
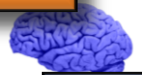
Laboratory Guide
A Brief Survey of Human Brain Anatomy

Challenge 3—fingers on the brain

You may soon be quite comfortable naming and identifying each of the major gyri and sulci that define the basic organizational plan of the human cerebral cortex.   To help get you further along toward this goal, ***hold a half- or whole-brain specimen in your non-preferred hand*** (or simply lay the specimen on a tray in front of you).   With your *preferred* hand, get ready to lay your fingers across the surface of the cerebral hemisphere so that your fingers overlie particular gyri, as directed below, and the spaces between your fingers overlie the corresponding sulci.   Got it?   OK.   Here's where to start:

- **Find the central sulcus**.   Now, ***lay your index finger and your middle finger on top of the pre- and post-central gyri*** so that the closed space between your fingers represents the central sulcus.

- **Demonstrate the dorsal-lateral prefrontal cortex**.   Next, ***lay three fingers across the dorsal-lateral surface of the frontal lobe, with one finger over each of the prominent parallel gyri that form the anterior two-thirds of the lobe.***   This will picture for you how the sometimes complex gyral formations of the dorsal-lateral prefrontal cortex may be simplified into three, longitudinal and parallel gyri: the **superior frontal gyrus** (index or ring finger goes there, depending on hemisphere and hand), the **middle frontal gyrus** (middle finger goes there), and the **inferior frontal gyrus** (covered by the ring or index finger).   As you are doing so, you may wish to refer to **Figure 5**.   Also, note how the closed spaces between your fingers should—with some imagination—define the **superior frontal sulcus** and the **inferior frontal sulcus** (which may appear interrupted from the surface in some hemispheres).   If you are doing this as suggested, your finger tips should just be touching the precentral gyrus.   Are they?

- **Demonstrate the lateral temporal cortex**.   Now, ***repeat this finger placement over the principal gyri of the lateral temporal lobe.***   Again, in the temporal lobe, there are three, longitudinal gyri that your fingers should make plain: the **superior temporal gyrus** (index or ring finger goes there), the **middle temporal gyrus** (middle finger goes there), and the **inferior temporal gyrus** (covered by the ring or index finger).   Again, note how the closed spaces between your fingers define the **superior temporal sulcus** and the **inferior temporal sulcus**.

- **Demonstrate the lateral parietal cortex**.   Lastly, turn your attention to the complex gyral formations of the parietal lobe just posterior to the postcentral gyrus.   Actually, they can be simplified into two gyral formations: the **superior parietal lobule** and the **inferior parietal lobule**.   These two major gyral formations are divided by a deep sulcus that runs more-or-less in the longitudinal axis of the forebrain, called the **intraparietal sulcus**.   This sulcus may not look very impressive from the surface, but once you explore cross-sections you will discover that this indeed is a deep and prominent sulcus of the parietal lobe.   So one last time, ***place your index and middle fingers over the dorsal-lateral parietal lobe with the space between your fingers overlying the intraparietal sulcus***.   Your top (dorsal) finger should be over the superior parietal lobule and your bottom (ventral) finger over the inferior parietal lobule.

Duke Institute for Brain Sciences
Duke University School of Medicine

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Laboratory Guide
A Brief Survey of Human Brain Anatomy

Medial aspect of the brain.   When the brain is cut in the midsagittal plane, all of its subdivisions are visible on the cut surface (**Figure 7**).   Just as in the embryo, the subdivisions are arranged as though they were stacked on top of one another, with the hemispheres bulging out laterally at the top and the cerebellum bulging out dorsally about half-way up the stack.   The cerebral hemisphere, because of its relatively great size, is still the most prominent part of the brain in this view.

Beginning from the superior margin of the hemisphere, the most anterior and dorsal gyral formation is simply the medial continuation of the superior frontal gyrus.   A long, almost horizontal sulcus, the **cingulate sulcus**, extends across the medial surface of the frontal and parietal lobes just below the superior frontal gyrus.   The prominent gyrus below it, the **cingulate gyrus**, along with the cortex adjacent to it, wraps around the **corpus callosum** and lateral ventricle into the temporal lobe; this extended rim (L., limbus) of cortex is sometimes called the 'limbic lobe'.   These cortical areas—and the subcortical areas connected to them, together with additional telencephalic structures in the temporal lobe and ventral frontal lobe—are often referred to as the 'limbic system'.   However, this so-called system (so-called primarily for historical reasons) is not unimodal, as the term 'system' implies.   Rather, the limbic 'system' is involved in the regulation of visceral motor activity, emotional experience and expression, olfaction, and memory, to name some of its better understood functions.

> Many authors now advocate dismissal of the term **"limbic system"** as an outmoded and misleading concept, and rather emphasize the diverse functions associated with components of an expansive constellation of structures in the ventral-medial forebrain.

The caudal portion of the superior frontal gyrus forms the **paracentral lobule**, as it joins the medial continuation of the pre- and post-central gyri.   Just as on the lateral surface of the hemisphere, on the medial face of the hemisphere the frontal lobe extends from the central sulcus forward.   At the inferior margin of the frontal lobe is the medial aspect of an inferior gyrus called the **gyrus rectus** (see 'ventral view' below), and a small cortical division, called the **subcallosal area**, just below the genu ("knee") of the corpus callosum.

Locate again the medial terminus of the central sulcus in the paracentral lobule.   That sulcus marks the anterior boundary of the parietal lobe, at least its dorsal portion; the rest of the anterior boundary follows the posterior limit of the cingulate gyrus.   Now, about half-way between the central sulcus and the posterior pole of the hemisphere, note the presence of a prominent sulcus running in nearly the coronal plane (actually, it is usually angled posteriorly from its inferior to superior ends) (see **Figure 4**).   This sulcus is the **parieto-occipital sulcus** and it divides the parietal and occipital lobes.   The entire gyral formation visible in this view of the parietal lobe is called the **precuneus gyrus** (its name will make sense as you read on).   Now, view the brain from its dorsal surface.   Can you now appreciate where the parieto-occipital sulcus intersects the longitudinal fissure?

In the dorsal view, there is often a rather prominent furrow where this sulcus widens at the dorsal midline (which you were already directed to recognize).   Keep the location of that intersection in mind; cortex posterior to this location is part of the occipital lobe (as our exploration of the medial parietal surface should make clear) and the gyral formation between this intersection and the central sulcus is, of course, the parietal lobe.   By convention, much of the parietal lobe visible to you in this dorsal view, excluding the postcentral gyrus, is called the superior parietal lobule, which is a continuation of the precuneus gyrus onto the dorsal-lateral surface of the hemisphere.

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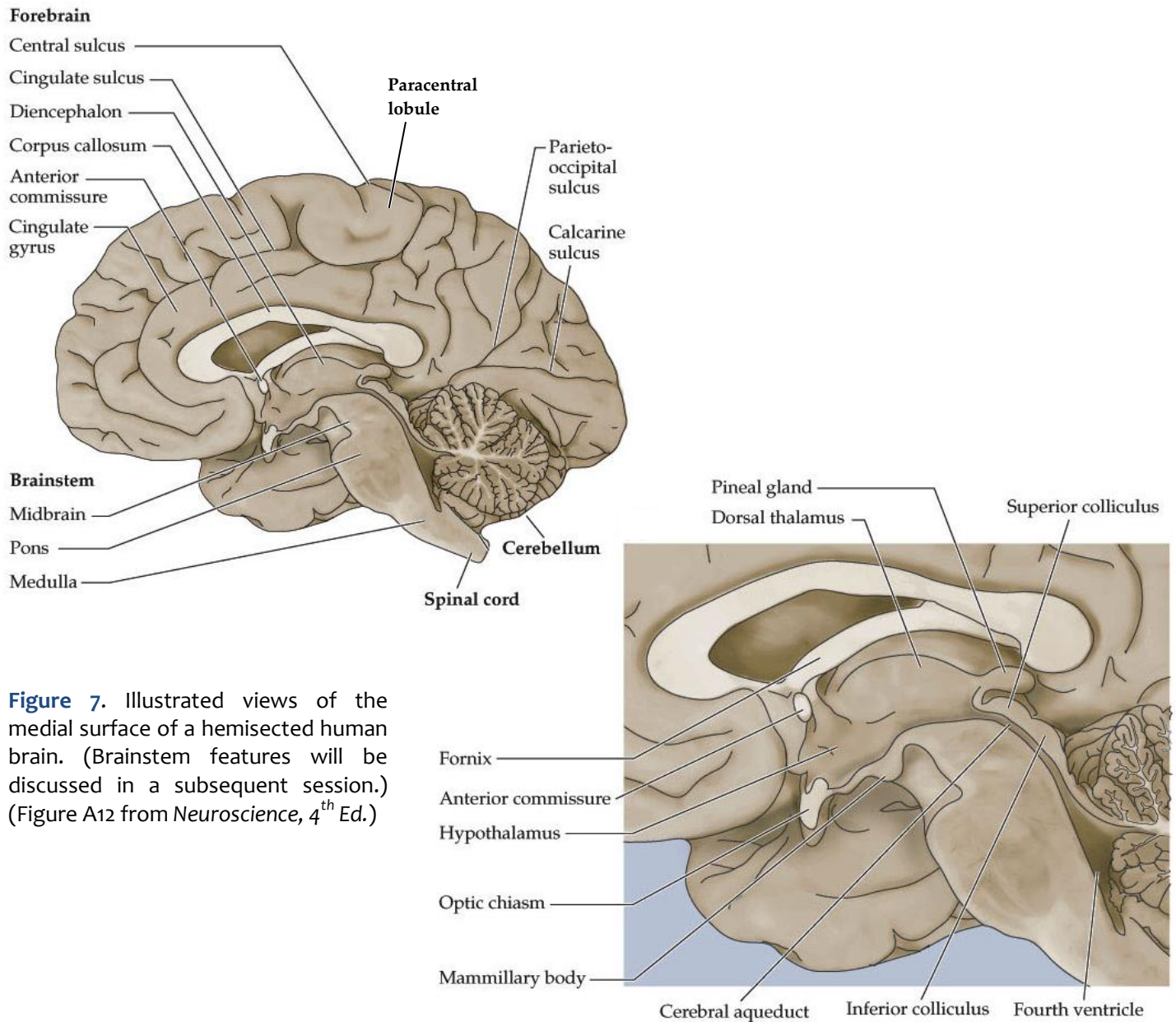## A Brief Survey of Human Brain Anatomy

Forebrain
Central sulcus
Cingulate sulcus
Diencephalon
Corpus callosum
Anterior commissure
Cingulate gyrus

Paracentral lobule

Parieto-occipital sulcus
Calcarine sulcus

Brainstem
Midbrain
Pons
Medulla

Cerebellum
Spinal cord

Pineal gland
Dorsal thalamus
Superior colliculus

Fornix
Anterior commissure
Hypothalamus
Optic chiasm
Mammillary body
Cerebral aqueduct   Inferior colliculus   Fourth ventricle

Figure 7. Illustrated views of the medial surface of a hemisected human brain. (Brainstem features will be discussed in a subsequent session.) (Figure A12 from *Neuroscience, 4th Ed.*)

So much for a brief consideration of the dorsal view of the brain; let's return to the medial (midsagittal) surface of the hemisphere.

Note the prominent sulcus that runs across the surface of the medial occipital lobe and intersects the parieto-occipital sulcus at nearly a right angle; this is the **calcarine sulcus**. The inferior bank of the calcarine sulcus is the **lingual gyrus**, and the superior bank is formed by a wedge-shaped gyral formation between the parieto-occipital and calcarine sulci called the **cuneus** (cuneus means "wedge"). Now that you know the name of

Laboratory Guide
A Brief Survey of Human Brain Anatomy

the gyral structure that forms the posterior bank of the parieto-occipital sulcus, you can appreciate why the anterior bank of this sulcus in the parietal lobe is formed by the precuneus gyrus. [Generally speaking, the prefix "pre" in neuroanatomy signifies toward the front (toward rostral).]

And now, a simple statement about function: the occipital lobe serves vision.   The cortex in the banks of the calcarine sulcus is the first division of the occipital lobe to receive information derived from the retinas (relayed via the thalamus).   Damage to this part of the occipital lobe can result in blindness for some portion of the visual field.   Surrounding occipital regions—and posterior parts of the parietal and temporal lobe—process increasingly more complex aspects of vision (e.g., the location, color, form and motion of objects, and recognition of their identity).   Localized injury or disease affecting one of these "higher-order" visual areas can result in remarkably specific impairments of visual function, such as the inability to appreciate motion or recognize a familiar face (more on such visual functions in later class sessions).

Three prominent fiber bundles (i.e., bundles of axons extending from one part of the brain to another) associated with the cerebral hemispheres can be seen from this view (see **Figure 7**). These are:

1. the **corpus callosum**, a huge structure that contains many millions of axons and connects the cortices of the two hemispheres, except for cortex in the anterior temporal and ventral (orbital) frontal lobes;

2. the **anterior commissure**, a much smaller bundle of axons that connects cortex in the anterior temporal and ventral frontal lobes, in addition to other ventral telencephalic structures (it is located at the most rostral end of the part of the neural tube that did not evaginate as the hemispheres); and

3. the **fornix**, a large fiber bundle that connects the hippocampus (a part of the temporal lobe that you haven't seen yet) with the hypothalamus.

In the view shown in **Figure 8**, the axons in the corpus callosum and anterior commissure are running perpendicular to the plane of the page, and the visible fibers of the fornix are running within the plane of the page.

If it were possible to unfold the cerebral cortex from one hemisphere (which can be done in digital representations of the cerebral hemisphere), the surface area of the resulting, flattened cerebral cortex would be roughly approximated by the crust of a 13-inch pizza (thin crust, *New York* style, of course, given the thinness of the cortex).

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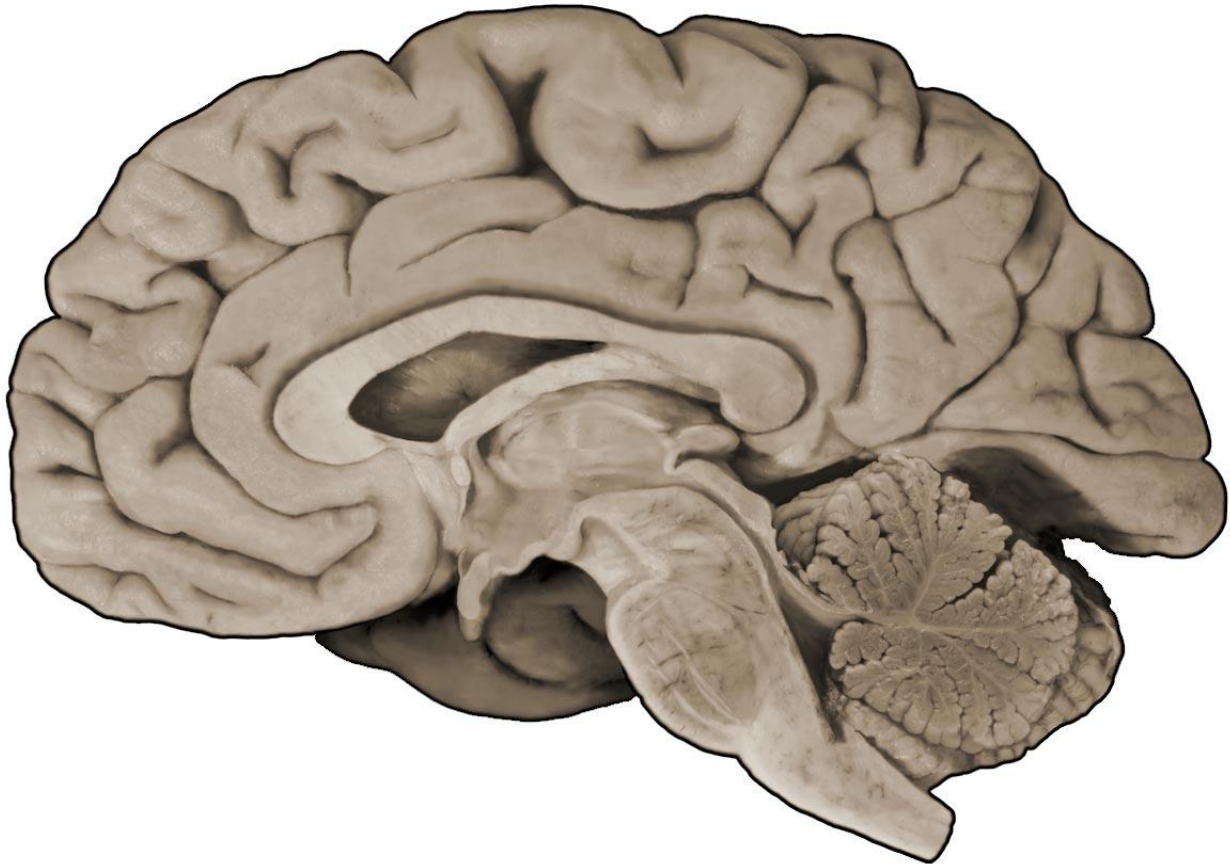## A Brief Survey of Human Brain Anatomy

Figure 8. Medial surface of the hemisected human brain. This figure is not labeled so that you may refer to it for review; see Figure 6 for illustrated and labeled views of the same hemisphere. (Image from *Sylvius4*)

The other subdivisions of the brain, all of which can be seen in **Figure 8**, are as follows:

1. The **diencephalon** consists of four parts arrayed from dorsal to ventral.   A. The epithalamus is a small strip of tissue to which is attached the **pineal gland**.   B. The **thalamus**, the largest part, relays most of the information going into the cortex from other parts of the brain and spinal cord. The thalamus consists of many further subdivisions, some of which you will learn about in later sessions.   C. The **subthalamus**, a small area concerned with control of motor and cognitive functions, cannot be seen from this view since it does not extend all the way to the midline.   D. The **hypothalamus**, a small but crucial part of the brain, is devoted to the control of homeostasis and a rich variety of physiological activities that are essential for survival and reproduction.   It is bounded rostrally by the optic chiasm, and its caudal extremity is made up of swellings known as the mammillary bodies.   On some brain specimens, the pituitary gland or part of its stalk (the infundibulum) may still be attached to the ventral surface of the hypothalamus.

Laboratory Guide
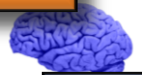## A Brief Survey of Human Brain Anatomy

2. The **midbrain** lies just caudal to the thalamus. Prominent landmarks that can be seen on the dorsal surface of the midbrain are the **superior** and **inferior colliculi**. They are concerned with oculomotor function and postural adjustments (superior colliculi) and audition (inferior colliculi). The other prominent external feature of the midbrain, the cerebral peduncles, cannot be seen very well from this view as they do not quite reach the midline. We will return to them in a later section.

3. The **pons** is next as we proceed caudally. It would be difficult to miss the pons because of the massive enlargement on its ventral surface. (Pons means 'bridge'; the enlargement is made up of cells with transversely oriented axons that cross the midline and could be said to form a bridge across the base of the brainstem.) A further feature that identifies the pons is its attachment to the cerebellum which lies dorsal to it. The cerebellum plays a crucial role in the control of movement.

4. Finally, the most caudal subdivision of the brainstem is the **medulla** (also known as the medulla oblongata). From the medial view shown in **Figure 8**, it looks relatively featureless. We will explore its external landmarks further on the ventral view of the brain and in subsequent laboratory sessions.

All components of the ventricular system, except perhaps for the lateral ventricles, can be seen on a typical medial surface of the brain cut in the midsagittal plane. In **Figure 8**, the **lateral ventricle** is visible in this hemisphere because the septum pellucidum has been dissected away; this is a very thin layer of tissue that forms the medial wall separating the two lateral ventricles. The **third ventricle** forms a narrow space in the midline region of the diencephalon, between the one that you see and the one that has been cut away. The communication of the third ventricle with the lateral ventricle is through a small hole, the **interventricular foramen** (or foramen of Monroe), at the anterior end of the third ventricle. The third ventricle is continuous caudally with the **cerebral aqueduct** which runs through the midbrain. At its caudal end, it joins the **fourth ventricle**, a large space in the dorsal pons and medulla. The fourth ventricle narrows caudally to join the **central canal**. We will take a closer look at the ventricles when we inspect cross-sections through the forebrain. [**Challenge 4**]

Challenge 4—midsagittal surface

Get your hands on a half-brain cut in the midsagittal plane and identify the structures labeled in **Figure 7***.* As you are doing so, you may wish to label the photograph of a midsagittal hemisphere in **Figure 8**. So much of the CNS is visible on the cut midsagittal surface, it is well worth studying such specimens (and photographs) to see how many brain structures you can recognize and describe.

Laboratory Guide
A Brief Survey of Human Brain Anatomy

Ventral aspect of the brain. **Figures 9** & **10** provide another look at the surface of the whole brain. Most of the subdivisions of the brain can be seen when it is viewed from its ventral aspect. The inferior surfaces of the frontal and temporal lobes of the cerebral hemispheres are prominent in this view. Running along the inferior surface of the frontal lobe near the midline are the olfactory tracts, which arise in little swellings at their anterior ends, the **olfactory bulbs**. The olfactory bulbs receive the axons of sensory cells in the olfactory mucosa (these axons are the first cranial nerve), and neurons in the bulbs give rise to fibers in the olfactory tracts (therefore, the tracts are part of the forebrain). Just superior to the bulbs, of course, is the ventral aspect of the frontal lobe, often referred to as the "orbital cortex" since this is the portion of the frontal lobe the overlies the orbits. The olfactory bulbs and tracts lie in the olfactory sulci (one in each hemisphere). This sulcus divides the **gyrus rectus** at the medial margin of the ventral frontal lobe from the more complex gyral structures that occupy much of the remaining ventral aspect; we will refer to these gyri simply as **orbital gyri**. Most of the ventral aspect of the frontal lobe is visible in **Figures 9** & **10**, except for that posterior portion hidden by the underlying anterior temporal lobes.

On the ventral surface of the temporal lobe, the inferior temporal gyrus occupies most of the visible surface of the lobe (with brainstem and cerebellum intact). However, it is possible to appreciate additional gyral structures on the medial side of the ventral temporal lobe. The medial boundary of the inferior temporal gyrus is formed by two sulci, the rhinal sulcus more anteriorly and the collateral sulcus more posteriorly. Just on the medial side of these sulci are gyral structures that are associated with the *hippocampal formation* (a primitive cortical structure that we will see when we explore a dissect the brain); first, is the **parahippocampal gyrus** and then a medial protuberance of this gyrus called the **uncus**. Just posterior to the parahippocampal gyrus is another prominent structure called the **occipito-temporal gyrus** (also called—especially by functional brain imagers—the **fusiform gyrus**), but this gyrus is mostly hidden from view in **Figures 9** & **10** by the cerebellum.

A small part of the diencephalon is visible in this view of the brain. The part that you see is the hypothalamus, bounded rostrally by the **optic chiasm** (formed by the crossing of some of the axons in cranial nerve II) and caudally by the mammillary bodies, which are considered part of the hypothalamus. The midbrain is mostly hidden from view by the temporal lobes; however, the prominent paired **cerebral peduncles** are visible (these structures define a space between them called the interpeduncular fossa).

The pons is obvious in this view, as are the **middle cerebellar peduncles**, which attach the pons to the cerebellum. Cranial nerve V (the trigeminal nerve), the largest of the cranial nerves, arises at the level of the pons. Caudal to the pons is the medulla. The columnar swellings on its ventral surface on either side of the midline are known as the **medullary pyramids**. They contain axons that arise in the precentral (the motor cortex) and the postcentral gyri (the somatic sensory cortex) and terminate in the spinal cord (i.e., the corticospinal tract) and medulla (a portion of the corticobulbar tract). Lateral to the pyramids are the **inferior olives**. Caudal to the medulla, a portion of the cervical spinal cord is seen. Cranial nerves VI-XII arise from the medulla or at the junction of the pons and medulla. [**Challenge 5**].

Duke Institute for Brain Sciences
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Laboratory Guide
A Brief Survey of Human Brain Anatomy

Figure 9. Illustrated views of the ventral surface of the human brain shown in Figure 10. (Figure A11 from *Neuroscience, 4th Ed.*)
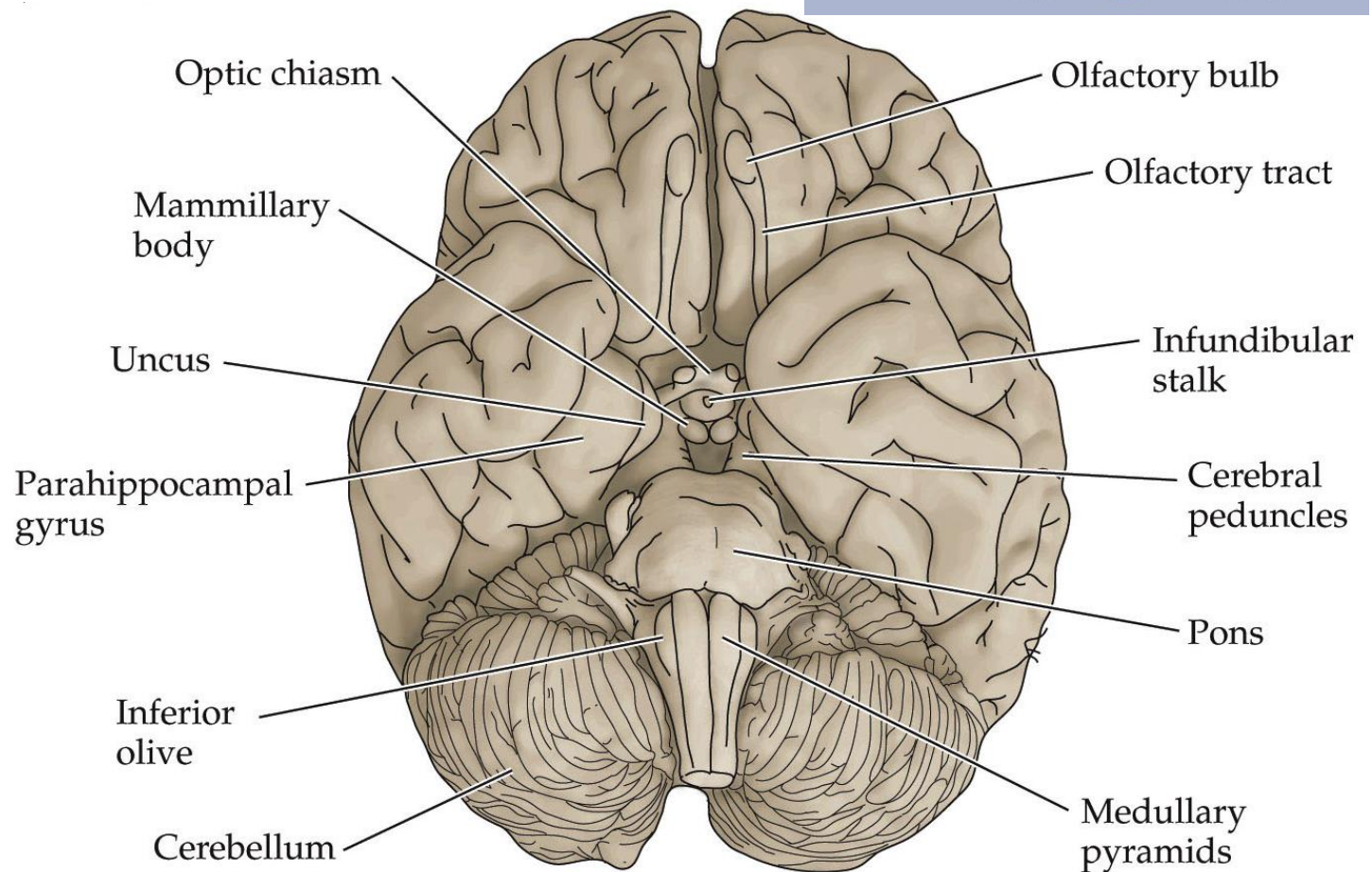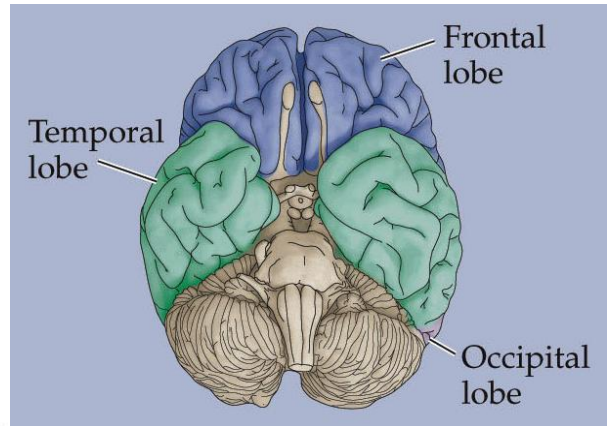
Challenge 5—ventral surface

***Get your hands on a whole-brain and identify all of the structures labeled in* Figure 9.** As you are doing so, you may wish to label the photograph of the ventral surface of the brain shown in **Figure 10**.

Laboratory Guide
A Brief Survey of Human Brain Anatomy
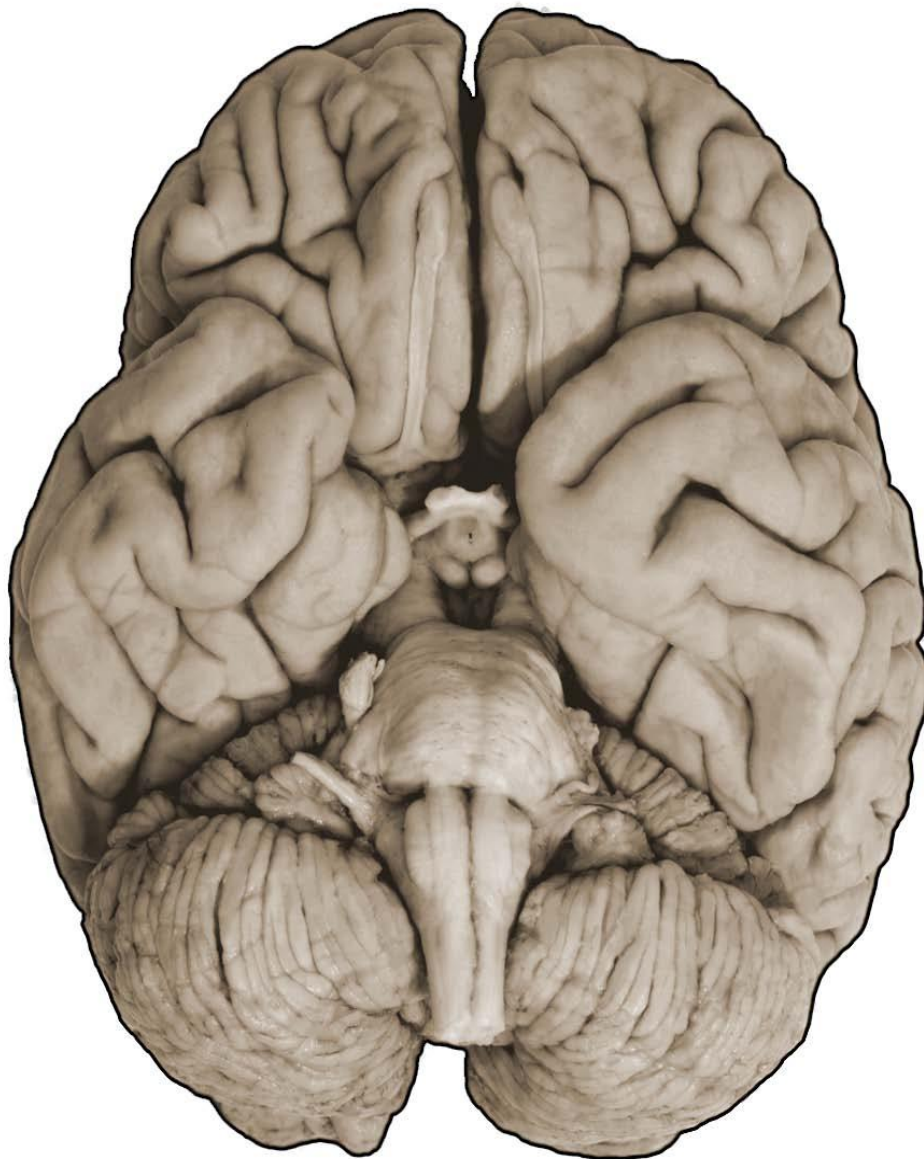
Figure 10. The ventral surface of the brain. (Image from *Sylvius4*)

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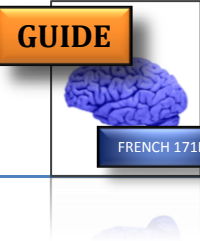
Laboratory Guide
A Brief Survey of Human Brain Anatomy

Some terminology and general principles for learning deep brain anatomy

Before beginning to study the internal anatomy of the brain, it will be helpful to familiarize yourself with some common conventions that are used to describe the deep structures of the central nervous system. The next few pages contain definitions and illustrations of some commonly used neuroanatomical terminology. They may be useful for reference as you study this material.

The simplest classification of central nervous tissue is into **white matter** and **gray matter** (**Figure 11**). The gray matter (so-named because it looks grayish in fresh specimens, as you have already seen) is made up of neuronal cell bodies, their dendrites, and the terminal arborizations of both local axons and those from distant sources. The dendrites and the axons that form synapses with them are sometimes referred to as "neuropil." The white matter is made up of the axons that connect separated areas of gray matter. The myelin that ensheathes many of these axons gives the white matter its glistening white appearance. (Note that an individual neuron can contribute to both gray and white matter.) Axons projecting from one part of the brain to another usually group together in bundles. Likewise, neurons that serve similar functions often form clusters.
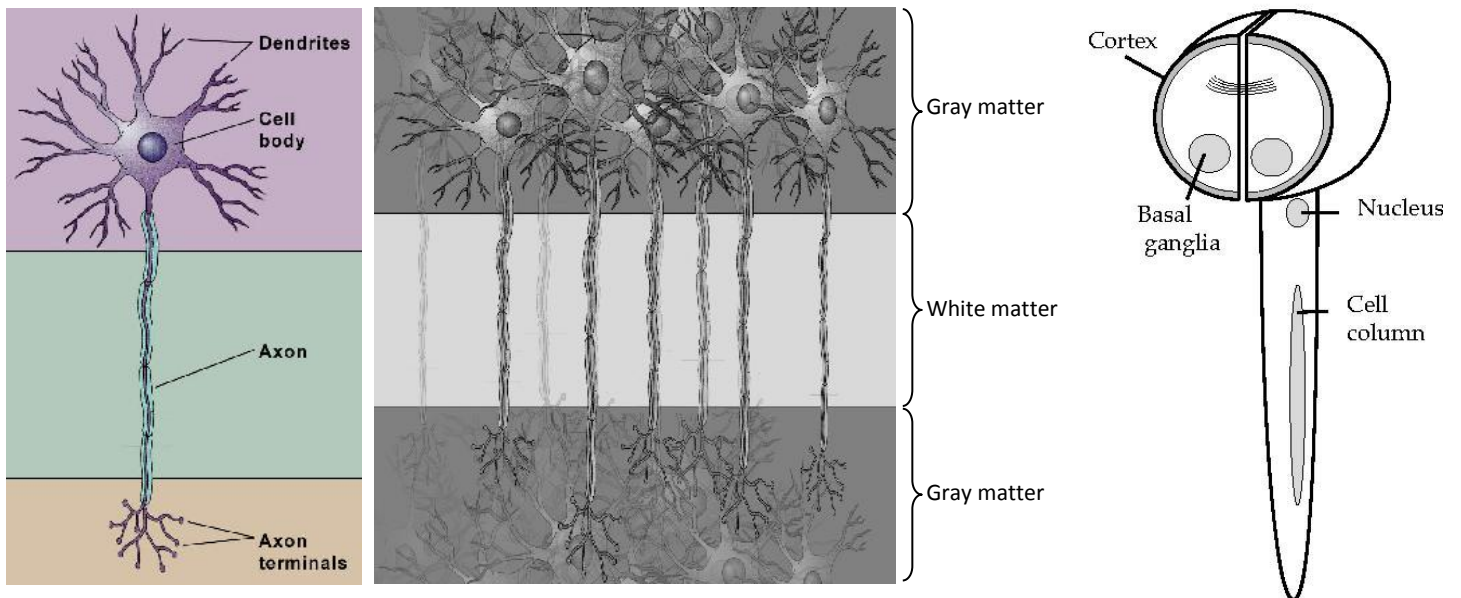

Figure 11. Gray and white matter in the central nervous system. *Left,* Drawings depicting the composition of both types of neural tissue (Illustration courtesy of Pyramis Studios, Durham NC). *Right,* Drawing of the organization of gray and white matter in the brain and spinal cord; cortex, basal ganglia, nucleus and cell column are all examples of gray matter in the central nervous system. (Illustration by N.B. Cant)

Laboratory Guide
A Brief Survey of Human Brain Anatomy

Common terms used to refer to white matter bundles and gray matter clusters:

Terms used to refer to gray matter

Column
Cortex (plural: cortices; L., bark)
Ganglion (plural: ganglia; Gr., swelling)
Layer
Nucleus (plural: nuclei)

Terms used to refer to white matter

These five terms are used to refer to bundles of axons:

Column
Fasciculus (L., fascia, band or bundle)
Funiculus (L., funis, cord)
Lemniscus (L. from Gr., lemniskos, fillet)
Tract

These terms also refer to bundles of axons, but they are usually used to refer to bundles that can be seen from the surface of the brain:

Brachium (L., arm)
Peduncle (L., pes, foot, stalk)

These terms refer to the crossing of axons from one side of the CNS to the other. A **commissure** contains axons crossing from one location to its counterpart on the other side. A **decussation** contains axons that travel to a contralateral location different from their origin.

Commissure (L., joining together)
Decussation (L., decussare, to cross in the form of an "X")

Many nuclei and tracts in the central nervous system are much longer than they are wide, calling to mind a column. (Note that the word 'column' is used to refer to both white matter and gray matter.) Although the terms that refer to white matter structures are not used interchangeably, they all refer to essentially the same constituent—axons (often in a compact bundle) connecting one area of gray matter to another.
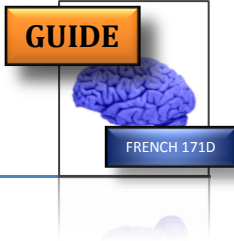
Laboratory Guide
A Brief Survey of Human Brain Anatomy

Internal anatomy of the forebrain

For the rest of this *Guide*, we will discuss the appearance of sections through the forebrain, so that you can learn to identify the structures that are not visible on a surface view. The anatomy of the forebrain as seen in sections is relatively simple; however the geometry of some of these deep structures can be a challenge to appreciate. For example, simply note the appearance of the **hippocampal formation** and the **lateral ventricle** in the view of partially dissected brain in **Figure 12**. You will soon learn why these structures appear where they do.
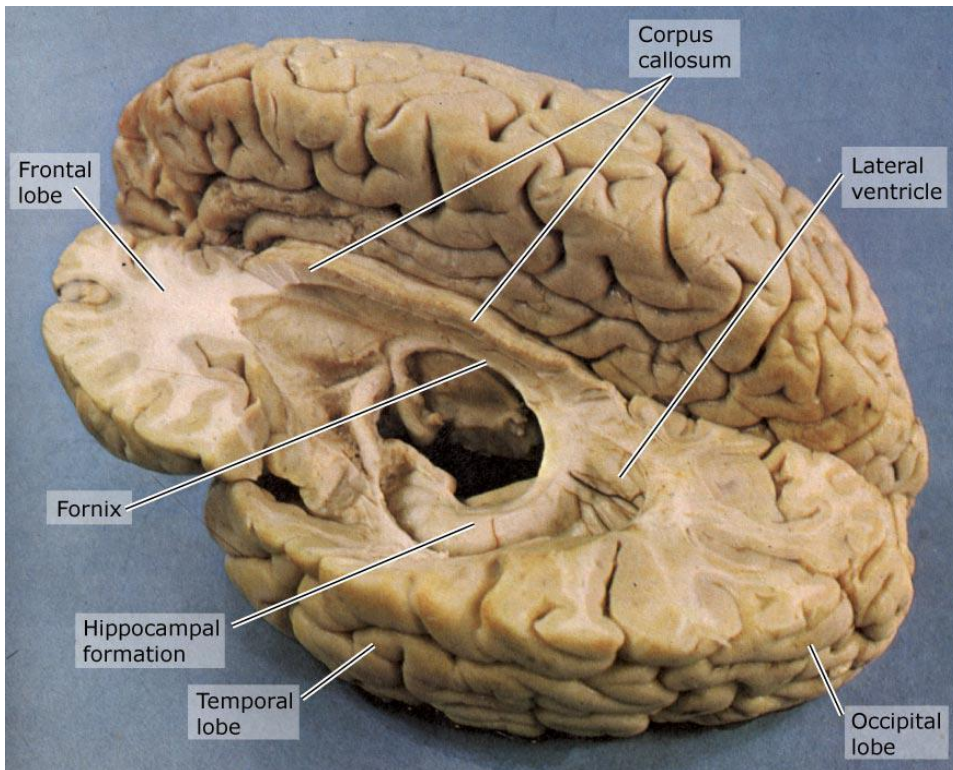
Figure 12. Brain partially dissected to show the location of the hippocampus and other structures that follow the course of the lateral ventricle into the temporal lobe. The hippocampus (one component of the hippocampal formation) lies in the 'floor' of the lateral ventricle. The fornix is a bundle of axons that arises in the hippocampus and travels to the diencephalon. Notice the white bundle tract (unlabeled) coursing across the midline just anterior to the most anterior part of the fornix—this is the anterior commissure.

As you work through the remainder of this narrative, be sure to recognize and locate the following structures on sections cut in any of the three standard planes:

	Gray Matter	White Matter	Ventricle
Cerebral hemispheres	**Cerebral cortex; Hippocampus; Amygdala** **Basal ganglia:** **caudate nucleus, putamen, nucleus accumbens, globus pallidus**	**Corpus callosum** **Anterior commissure** **Fornix** **Internal capsule**	**Lateral ventricle**
Diencephalon	**Thalamus** **Hypothalamus**		**Third ventricle**

Laboratory Guide
A Brief Survey of Human Brain Anatomy

Let's begin our study of internal forebrain anatomy with the **cerebral cortex**.   The cerebral cortex is a thin layer of gray matter that covers the entire surface of the hemispheres.   Most of the cortex that is visible from the surface in humans is known as **neocortex**, cortex which is made up of six layers of neurons.   Phylogenetically older cortex, which has fewer cell layers, is found on the inferior surface of the temporal lobe, separated from neocortex by the rhinal fissure (**Figure 13**).   The cortex with the fewest layers (three) is known as the **hippocampus** (paleocortex of the parahippocampal gyrus); it is folded into the medial aspect of the temporal lobe and is visible only in dissected brains (see **Figure 12**) or in sections.
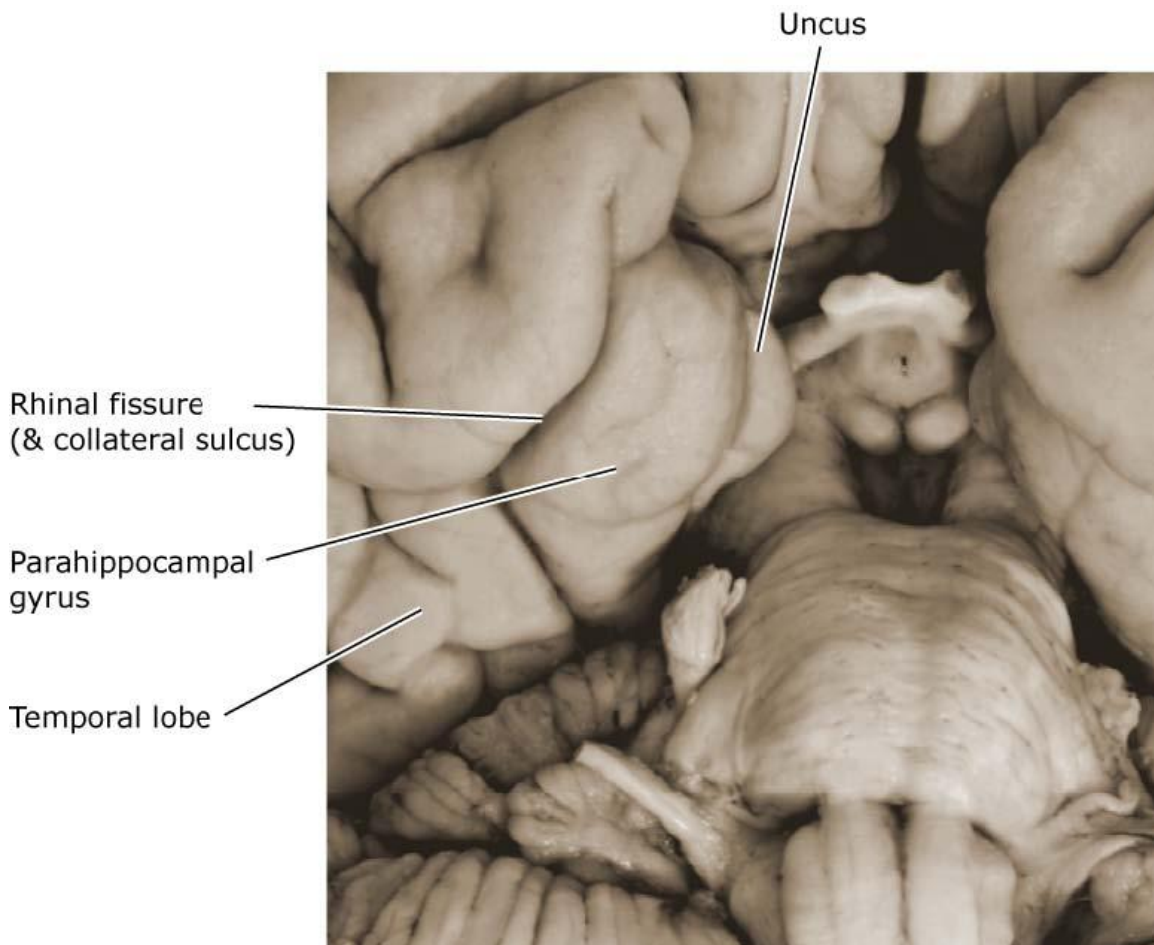
Figure 13. Enlargement of Figure 10 to illustrate the rhinal fissure, which separates the lateral neocortex from the medial paleocortex. The medial protuberance in the parahippocampal gyrus is called the uncus.

Laboratory Guide
A Brief Survey of Human Brain Anatomy

The cortex is made up of neuronal cell bodies, their dendrites, and the terminal arborizations of axons coming from the thalamus and other sources, mainly from other neurons in the cerebral cortex.   Indeed, many neurons in the cortex send axons that travel some considerable distance in the central nervous system to make synaptic connections with other neurons.   Axons that enter and leave the cortex form the white matter that makes up a large part of the hemispheres.   We often speak of axons as though they were moving, using words such as 'entering,' 'leaving,' 'descending,' 'traveling,' 'projecting,' etc.   Of course, their place is fixed in the adult, and what we are actually referring to are the directions in which action potentials normally propagate along the axons.

Buried deep within the hemispheres are the **basal ganglia** (**Figure 14**), which are large gray matter structures concerned with modulating thalamic interactions with the frontal lobe.   (The term 'ganglion' is *not* usually used f clusters of neurons inside the central nervous system; this is an exception.)   The basal ganglia lie partly rostral and partly lateral to the diencephalon (refer to the chart on page 1 for their embryonic relations).   They can be divided into four main structures: the **caudate**, the **putamen**, the **nucleus accumbens**, and the **globus pallidus**.
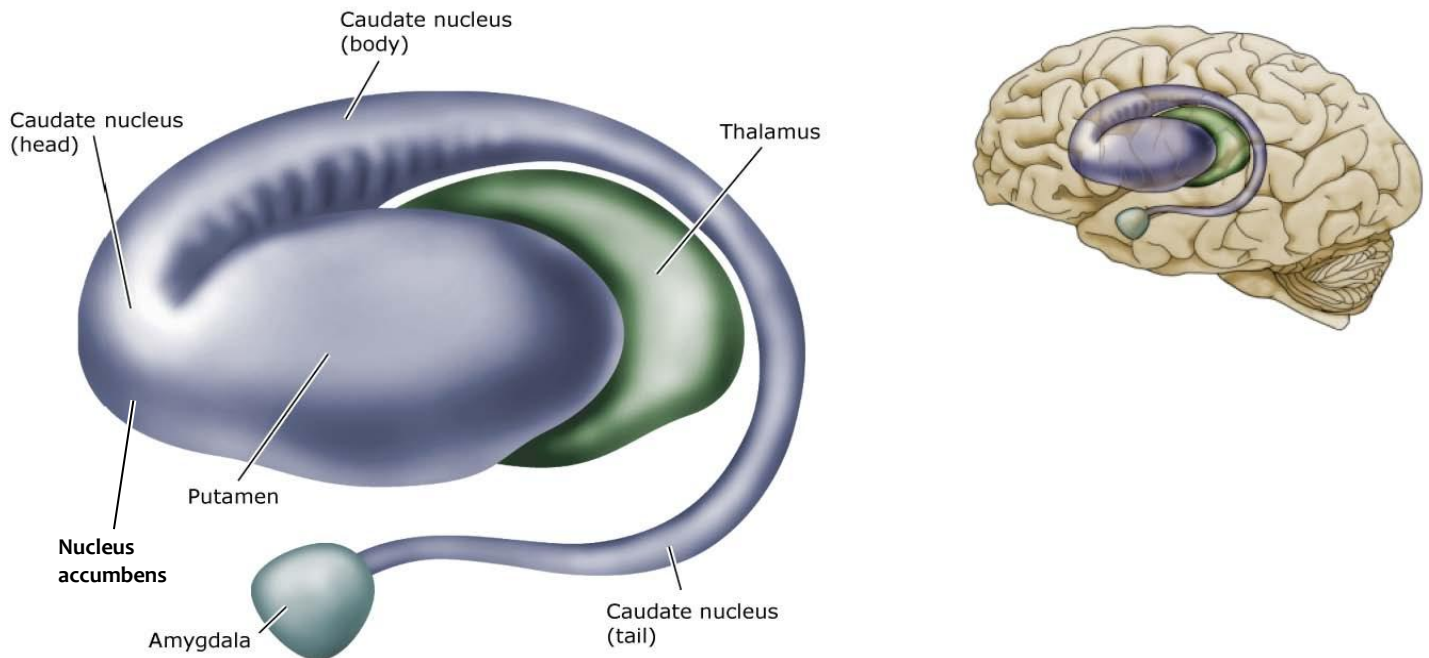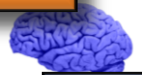

Figure 14. The basal ganglia and thalamus drawn with all of the cortex and white matter of the hemispheres stripped away; viewed from the side (refer to the inset for orientation). The head of the caudate is in the frontal lobe; its body lies just dorsal to the thalamus, and its tail descends into the temporal lobe. The amygdala is an additional structure deep in the anterior temporal lobe that is situated near the anterior tip of the caudate's tail (but it really is not part of the caudate as this illustration might imply). The nucleus accumbens is located at the anterior, inferior junction of the caudate nucleus and putamen. The globus pallidus is hidden from view by the putamen, which is lateral to it. The groove between the putamen and the caudate—and between the putamen (and globus pallidus) and the thalamus—is occupied by a massive fan-like array of white matter, called the internal capsule (omitted from this depiction to illustrate the body of the caudate nucleus and the thalamus). (illustration after Figure 17-4 in Carpenter, M.B. and Sutin, J., *Human Neuroanatomy, 8*th *Ed.*, Williams & Wilkins, Baltimore MD, 1983; courtesy of Pyramis Studios, Durham NC)

Laboratory Guide
A Brief Survey of Human Brain Anatomy

Structurally and functionally, the caudate, putamen and nucleus accumbens are similar, and they are often referred to collectively as the **striatum**, because of the stripes or "striations" of gray matter that run through a prominent bundle of white matter (the internal capsule) that otherwise separates the caudate from the putamen. (The caudate and putamen are also called the "neostriatum" to emphasize their evolutionary and functional relation to neural circuits in the neocortex.) Ventral to the caudate and putamen are additional divisions of the striatum, which are important for understanding motivated behavior and addiction. The most prominent of these structures in this so-called ventral striatum is the **nucleus accumbens**.

There are three bundles of axons in the hemisphere that have already been identified on sagittal views: the corpus callosum, anterior commissure and fornix. One additional system of axonal fibers should now be appreciated. Many of the axons entering or leaving the cortex do not assemble into compact bundles, except in the vicinity of the thalamus and the basal ganglia, where they form a structure known as the **internal capsule**.

The internal capsule lies just lateral to the diencephalon, and as mentioned briefly above, a portion of it separates the caudate from the putamen. Many of the axons in the internal capsule terminate or arise in the thalamus. Other systems of axons descending from the cortex, course through the internal capsule, and continue past the diencephalon to enter the **cerebral peduncles** of the midbrain. Between the cortex and the internal capsule, the axons of the white matter are not so tightly packed. Here they are sometimes called the 'corona radiata', a reference to the way they appear to radiate out from the compact internal capsule to reach multiple areas of cortex. (Individual groups of axons may also be indicated in this way. For example, you will hear reference to the visual radiations or the auditory radiations, axons that travel from the thalamus to the visual and auditory cortices, respectively.) We will return to consider the internal capsule in relation to the important deep gray matter structures after reviewing cross-sectional views through the forebrain.

There are several other bundles of axons that run through the white matter of the forebrain longitudinally in each cerebral hemisphere, connecting different cortical areas (associational white matter); but you need not be concerned with identifying them.

That is almost it for structures in the cerebral hemispheres!

There are two other gray matter structures that you will learn about later in the course, which will be mentioned now. One is a group of complex nuclei, known as the **basal forebrain nuclei**, which have become associated with the signs and symptoms of diseases such as Alzheimer's disease. Like the basal ganglia, the basal forebrain nuclei are made up of clusters of cells (rather than layers); but unlike the basal ganglia, these clusters are much smaller and typically much less compact. They are located ventral to the anterior commissure and below the basal ganglia, between the ventral striatum and the hypothalamus. The other is the **amygdala**, which is a large mass of gray matter buried in the anterior-medial part of the temporal lobe, anterior to the lateral ventricle and the hippocampus (see **Figure 14**). The amygdala is an important component of ventral-medial forebrain circuitry and it is involved in the experience and expression of emotion. It was once classified as part of the basal ganglia; however, it is structurally and functionally heterogeneous, with systems of neurons and intrinsic connections that are comparable to those in striatum and the cerebral cortex.
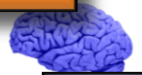
Laboratory Guide
A Brief Survey of Human Brain Anatomy

Finally, before taking on the challenge of viewing the forebrain in cross-sections, consider the three-dimensional configuration of the ventricular system within the forebrain and brainstem (**Figure 15**). It is important to appreciate the relationships among these structures so that you will understand why cross-sections through the brain in various planes appear as they do (as you do so, you may want to again refer to the chart on page 1).

Figure 15. The ventricular system. (A) Location of the ventricles as seen in a transparent left lateral view. Note the presence of choroid plexus in each ventricle, which is the vascularized tissue that produces cerebrospinal fluid. (B) Dorsal view of the ventricles. (illustration courtesy of Pyramis Studios, Durham NC)

Duke Institute for Brain Sciences
Duke University School of Medicine

Laboratory Guide
A Brief Survey of Human Brain Anatomy

(A)

Central part of left lateral ventricle

Frontal horn of lateral ventricle

Choroid plexus

Interventricular foramen of Monro

Third ventricle

Temporal horn of lateral ventricle

Right lateral ventricle

Left lateral ventricle

Occipital horn of lateral ventricle

Cerebral aqueduct

Fourth ventricle

Central canal

Choroid plexus

(B)

Interventricular foramen of Monro

Postcentral gyrus

Frontal horn of lateral ventricle

Third ventricle

Temporal horn of lateral ventricle

Right cerebral hemisphere

Occipital horn of lateral ventricle

Fourth ventricle

Cerebral aqueduct

Left cerebral hemisphere

Central sulcus

Laboratory Guide
A Brief Survey of Human Brain Anatomy

Coronal sections through the brain

The five coronal sections through the brain shown, beginning on the next page (**Figure 16–20**), were taken from *Sylvius4* and should resemble the brains that are available for examination in the laboratory. Remember, areas with little or no myelin appear dark and are considered gray matter, and areas containing myelinated axons appear light and are called white matter.

Challenge 6—internal capsule and deep gray matter

One of the most difficult challenges in human brain anatomy is gaining an appreciation for the **3D** arrangement of deep gray and white matter within the forebrain. But be encouraged! There is a principled means of simplifying this challenge. You must first understand the positional relations among the major components of the *basal ganglia* (caudate nucleus, putamen, globus pallidus), *thalamus*, and the *internal capsule*. Then, you should recognize how the lateral ventricle fits in. Once you do so, you can interpret any section through the forebrain in any plane of section, be it a standard anatomical plane or an oblique plane.

Here's the key to framing your **3D** understanding: the deep gray matter structures identified above are always found on one side of the internal capsule or the other.

> *Specifically, the caudate nucleus and the thalamus are medial to the internal capsule and the putamen and globus pallidus are lateral to the internal capsule.*

These relations reflect the course of the outgrowing axons that formed the internal capsule in fetal development as they navigated through the anlage of deep gray matter in the embryonic brain. As you carefully inspect sections through the forebrain (in the next few pages and in lab), note the appearance of the internal capsule and the deep gray matter. There are several additional details to observe and remember:

(1)   the caudate and putamen become continuous around the rostral margin of the internal capsule, reflecting their similar histological structure and functions;

(2)   the globus pallidus is a relatively small structure located near the middle of the basal ganglia;

(3)   the globus pallidus is located between the internal capsule and the putamen;

(4)   the thalamus occupies a more posterior volume of brain-space than the bulk of the basal ganglia; and

(5)   the caudate nucleus has a long "tail" that follows the course of the lateral ventricle into the temporal lobe.

Now, ***work through points 1–5 above in actual sections through the forebrain that are available in the lab***.

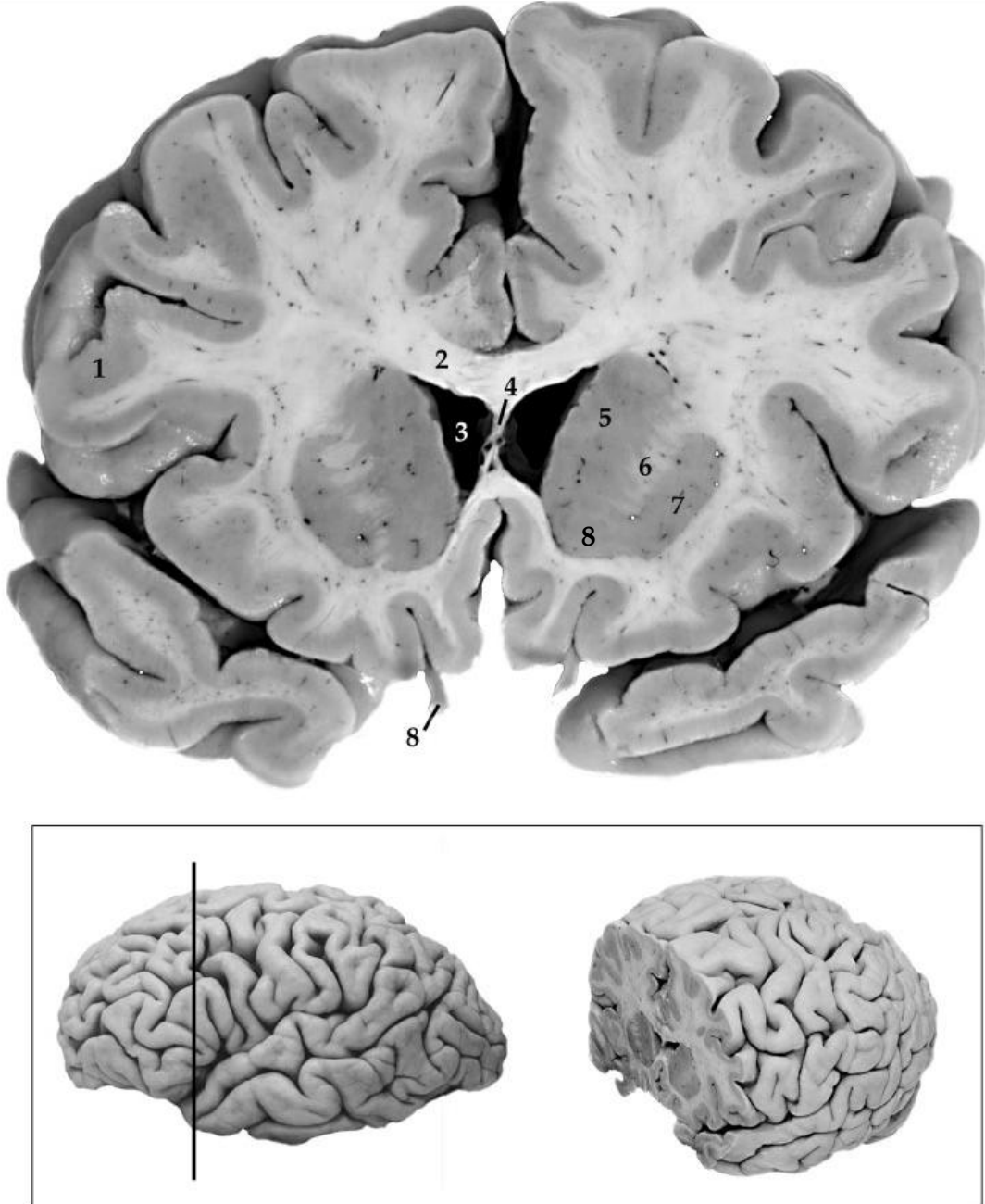## Laboratory Guide
A Brief Survey of Human Brain Anatomy

Figure 16. This first section is anterior to the region where the anterior commissure crosses the midline so only the hemispheres are present, and the diencephalon is not seen. The basal ganglia, which form part of the hemispheres, are very large here in the frontal lobes. Key: 1. Cerebral cortex of the frontal lobe; 2. Corpus callosum; 3. Lateral ventricle; 4. Septum pellucidum (which separates the two lateral ventricles); 5. Caudate nucleus (which bulges into the lateral ventricle); 6. Anterior limb of internal capsule (which separates the caudate and putamen from one another; recall that the 'stripes' of gray matter stretching across the internal capsule between these two nuclei are the inspiration for the term 'striatum'); 7. Putamen; 8. Nucleus accumbens. (Image is "Coronal 3" from *Sylvius4*)

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Laboratory Guide
A Brief Survey of Human Brain Anatomy
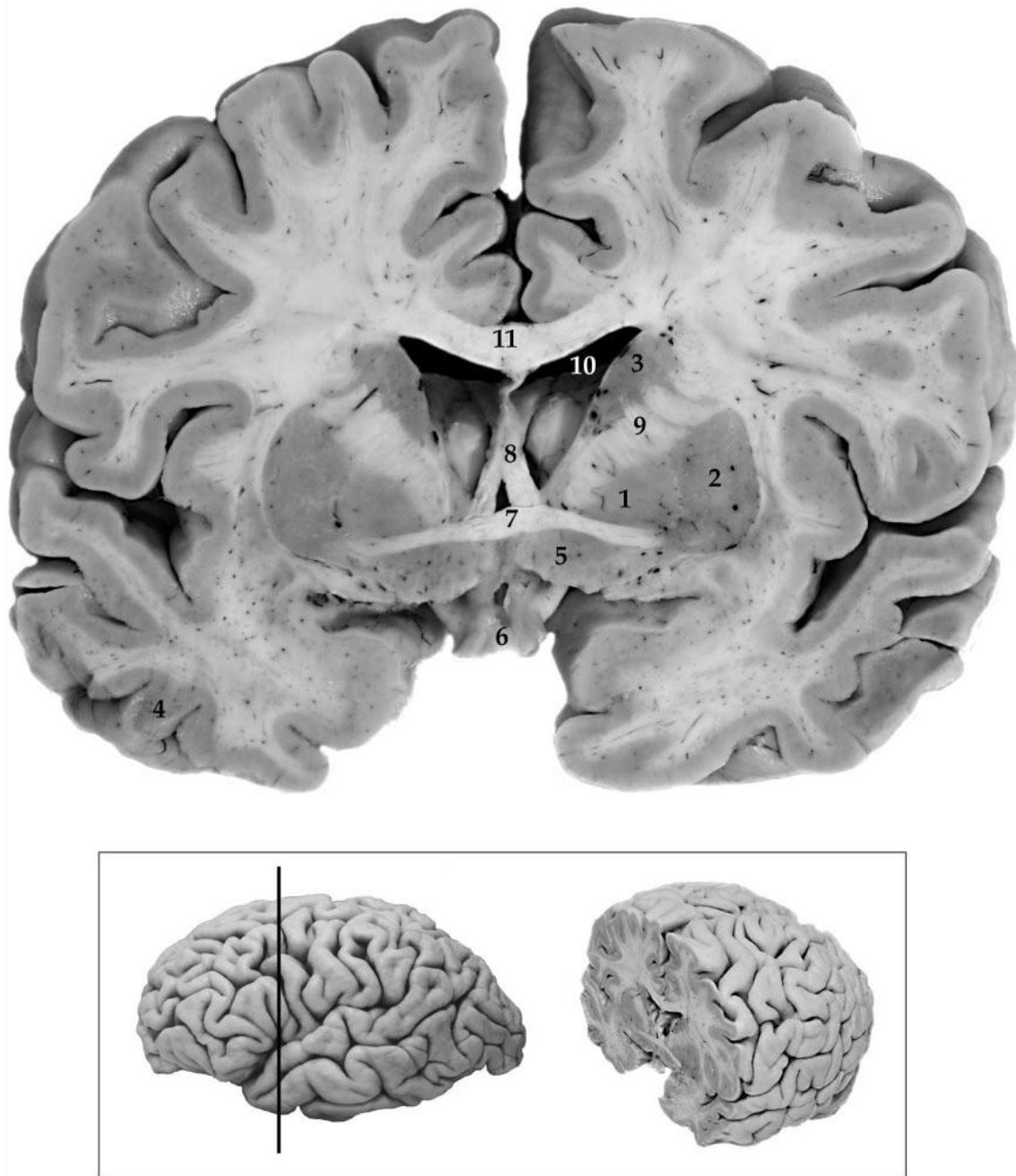
Figure 17. The second section in the series is at the level where the anterior commissure crosses the midline. Locate the caudate and putamen and the globus pallidus. Also find the internal capsule, the lateral ventricles, the corpus callosum, and the fornix. (You see the fornix only once on each side in this section. Why?) You can also see the optic chiasm. Nuclei of the basal forebrain are located in the inferior frontal lobe (below the anterior commissure). Key: 1. Globus pallidus; 2. Putamen; 3. Caudate; 4. Cortex of temporal lobe; 5. region of basal forebrain nuclei; 6. Optic chiasm; 7. Anterior commissure; 8. Fornix; 9. Internal capsule; 10. Lateral ventricle; 11. Corpus callosum. (Image is "Coronal 4" from *Sylvius4*)

Laboratory Guide
A Brief Survey of Human Brain Anatomy
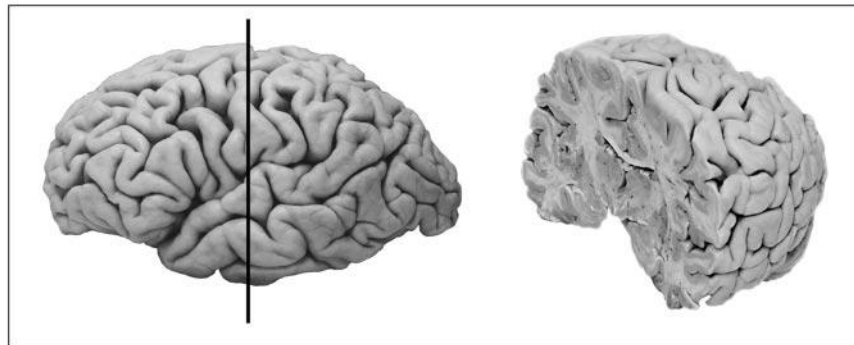
Figure 18. The third section in the series lies about halfway through the brain. Since this section lies posterior to the anterior commissure, the diencephalon appears next to the midline. The thalamus is separated from the putamen and globus pallidus by the internal capsule. The hypothalamus lies ventral to the thalamus. Lateral to the hypothalamus is the area known as the subthalamus. The cortex in the medial aspect of the temporal lobe is known as the hippocampus. Key: 1. Internal capsule; 2. Thalamus; 3. Hypothalamus (mammillary body); 4. Subthalamus; 5. Hippocampus; 6. Caudate; 7. Putamen, 8. Globus pallidus; 9. Corpus callosum; 10. Fornix; 11 & 12. Lateral ventricle. (Image is "Coronal 5" from *Sylvius4*)

Laboratory Guide
A Brief Survey of Human Brain Anatomy
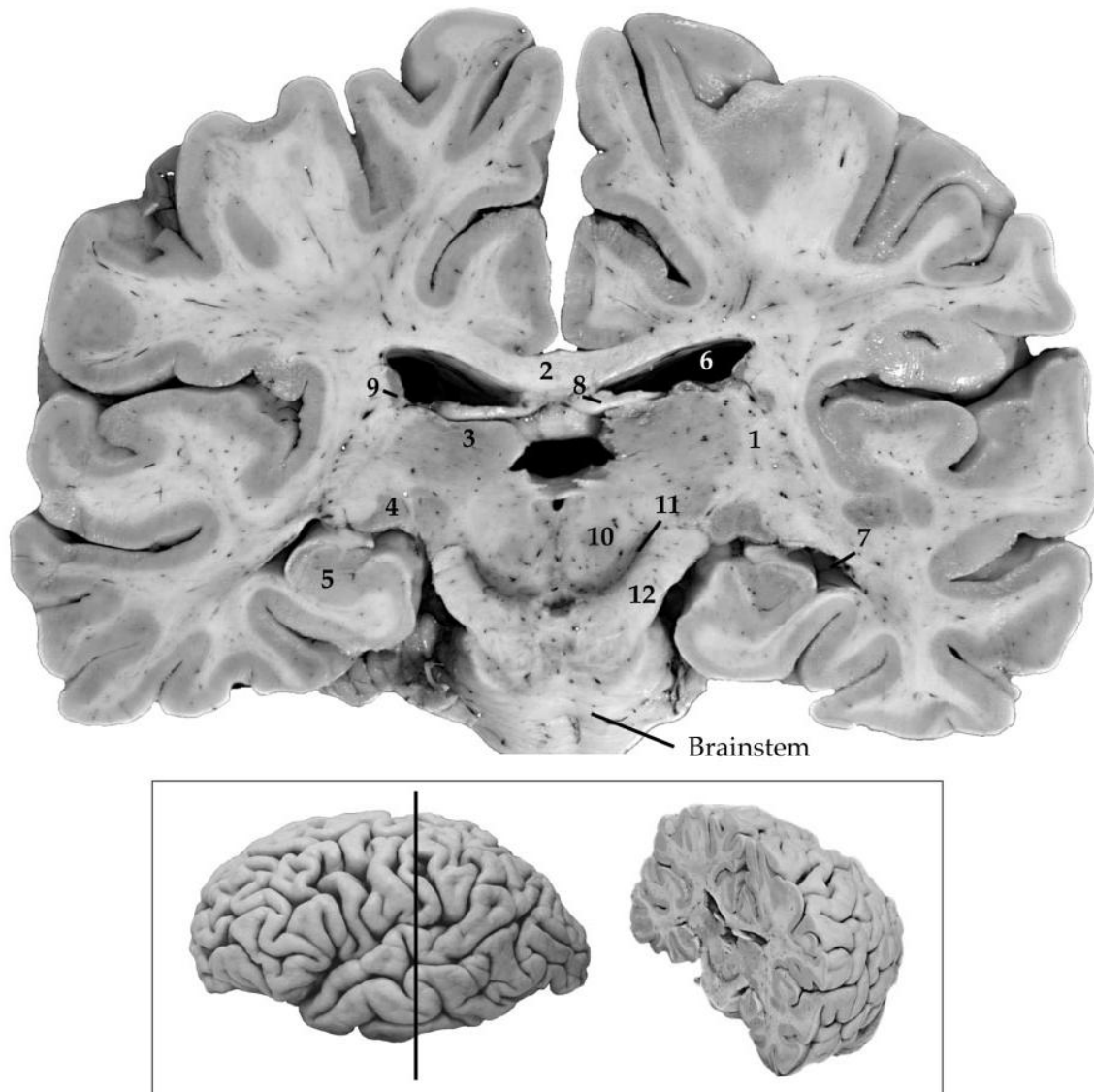
Figure 19. In this section, you can see the transition from the diencephalon to the midbrain of the brainstem. (Some of the structures of the midbrain are labeled in the figure; they will be covered in more detail in Chapter 5 of this *Laboratory Guide*.) In the forebrain, some of the same structures that were seen in more anterior sections can still be identified, although the basal ganglia have almost disappeared. Only a small portion of the caudate nucleus can still be seen. One important part of the thalamus, the lateral geniculate nucleus, is seen. Key: 1. Internal capsule; 2. Corpus callosum; 3. Thalamus; 4. Lateral geniculate nucleus (part of the thalamus); 5. Hippocampus; 6, 7. Lateral ventricle; 8. Fornix; 9. Caudate; 10. Midbrain; 11. Substantia nigra; 12. Cerebral peduncle. (Image is "Coronal 5" from *Sylvius4*)

Laboratory Guide
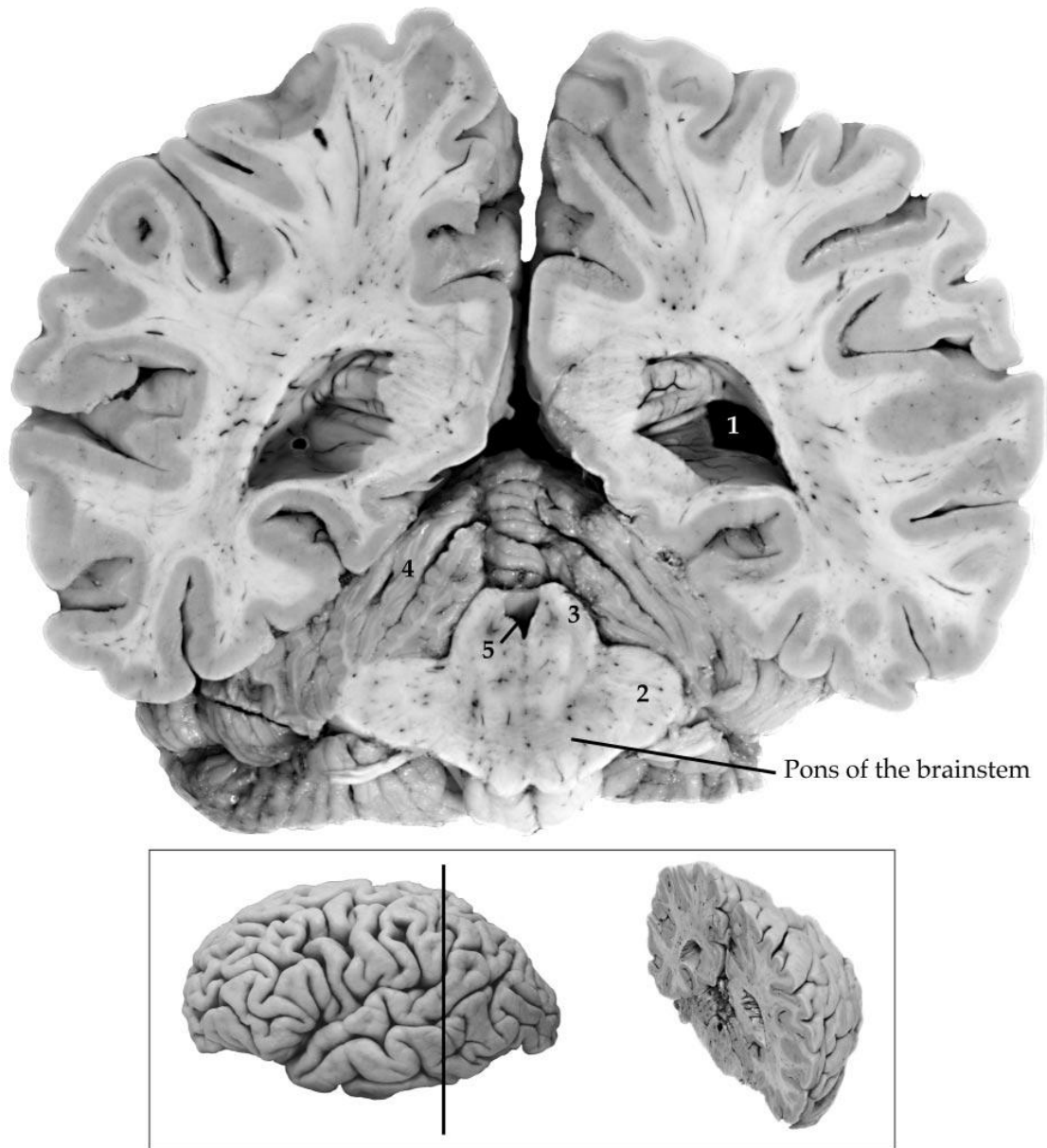## A Brief Survey of Human Brain Anatomy

Figure 20. The most posterior section in the series is cut through the parietal lobes. Since the cut is posterior to the corpus callosum, the two hemispheres are not connected to each other. In the forebrain, only the gray and white matter and the posterior horn of the lateral ventricle are seen; none of the deep gray matter structures are present. The section also passes through the brainstem. This part of the brainstem is known as the pons; it lies ventral to the cerebellum. Key: 1. Lateral ventricle (posterior or occipital horn); 2. Middle cerebellar peduncle; 3. Superior cerebellar peduncle; 4. Cerebellum (cerebellar cortex); 5. Fourth ventricle (most rostral recess continuous with the cerebral aqueduct). (Image is "Coronal 5" from *Sylvius4*)

Laboratory Guide
A Brief Survey of Human Brain Anatomy

Challenge 7—amygdala & hippocampus

Lay out in front of you on a tray a set of coronal or axial sections through a cerebral hemisphere.   Now that you are oriented to the basal ganglia, thalamus and internal capsule, you are ready for a simpler challenge.   *Turn your attention to the medial portions of the temporal lobe and identify the amygdala and the hippocampus*.   As you sort out where these structures are and what they look like, address the following set of questions:

- Which is more *anterior*, the amygdala or the hippocampus?
- Do the amygdala or the hippocampus overlap?
- Is the amygdala cortex, basal ganglia, or something different?
- Why is the amygdala called the amygdala? (Latin for "almond")
- What is the relationship between the hippocampus and the lateral ventricle?
- Why is the hippocampus called the hippocampus? (Latin—from the Greek—for "sea horse" or "sea monster")
- How do the amygdala and the hippocampus communicate with structures in the hypothalamus and nearby ventral-medial forebrain?

Let's discuss the answers to these questions.

Non-invasive imaging views of the human central nervous system

The following pages contain T1-weighted, magnetic resonance imaging (MRI) views of the head from the **MR Atlas** in *Sylvius4*.   Sets of scans in the coronal, sagittal, and horizontal planes are shown, with insets to remind you of their orientation.   See if you can find some of the same structures that you just identified in **Figures 16-20** in these final three plates of images.
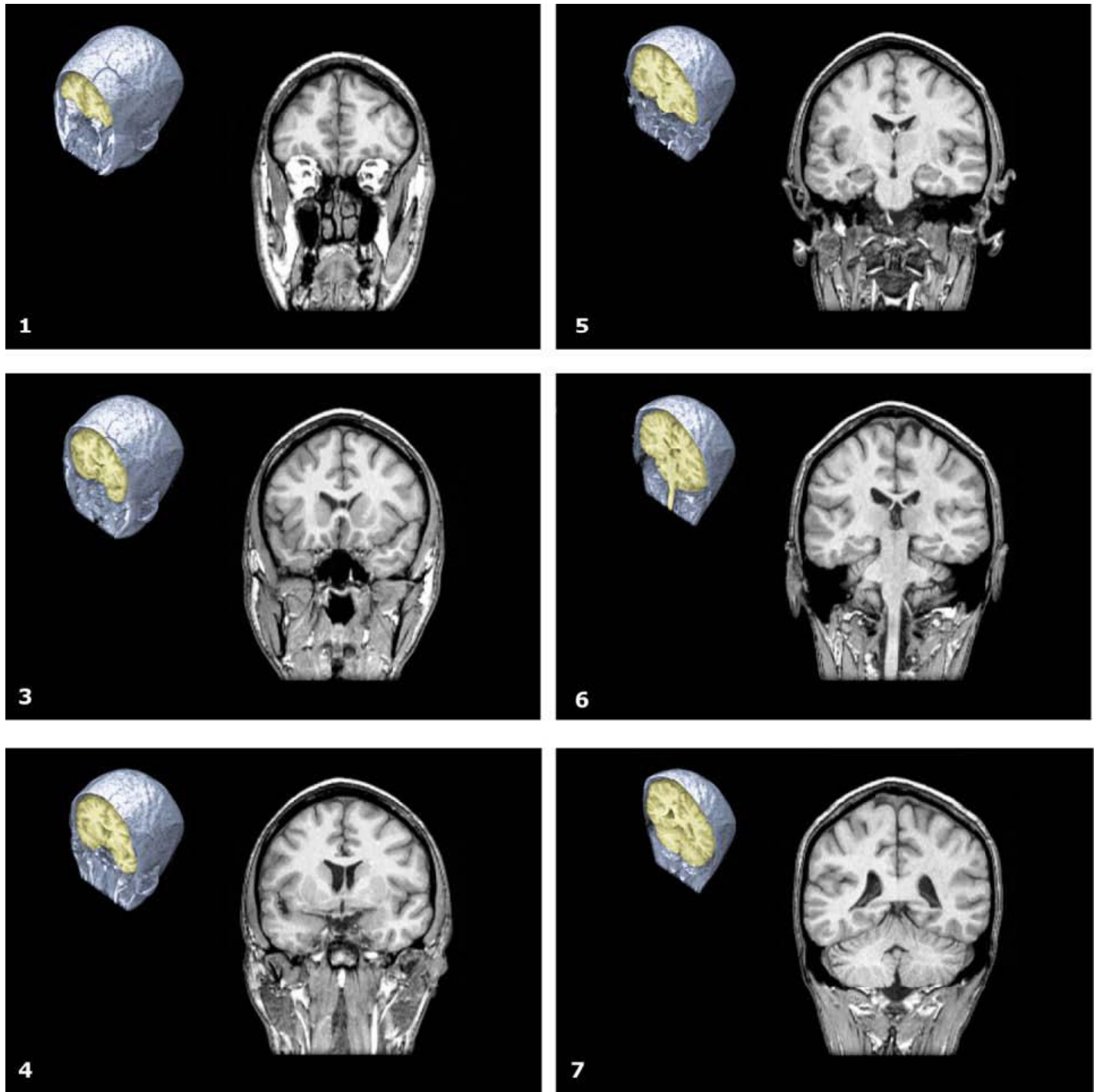
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Laboratory Guide
A Brief Survey of Human Brain Anatomy

Coronal sections.

These scans are in the frontal (coronal) plane. Section 1 is the most anterior in the series, and section 7 is the most posterior. Such scans are conventionally viewed as though from the front. Therefore, the subject's right side is on the left side of the scan, and the subject's left side is on the right side of the scan.
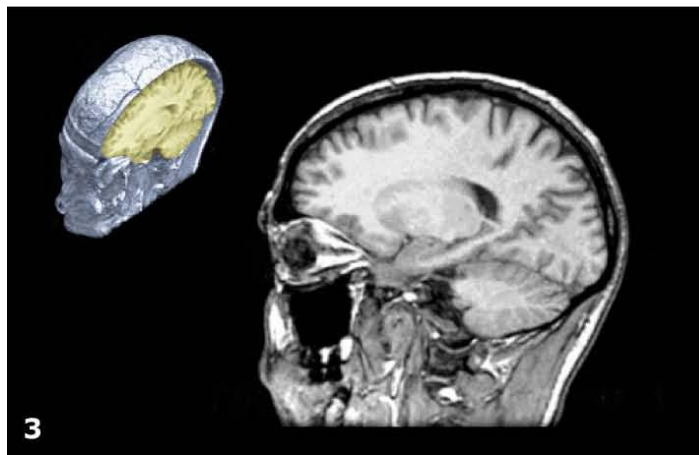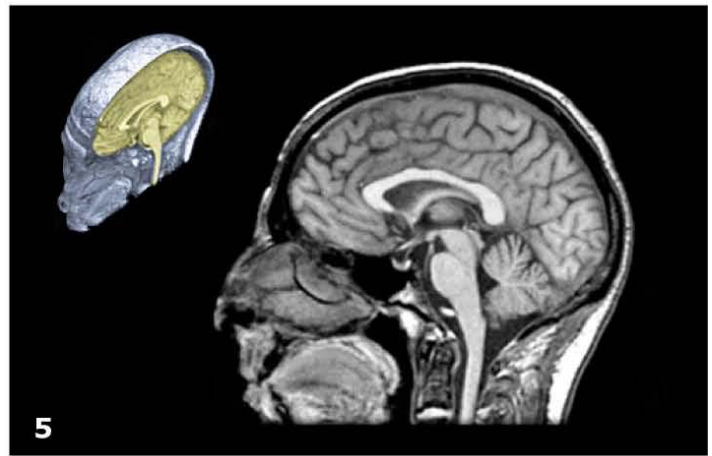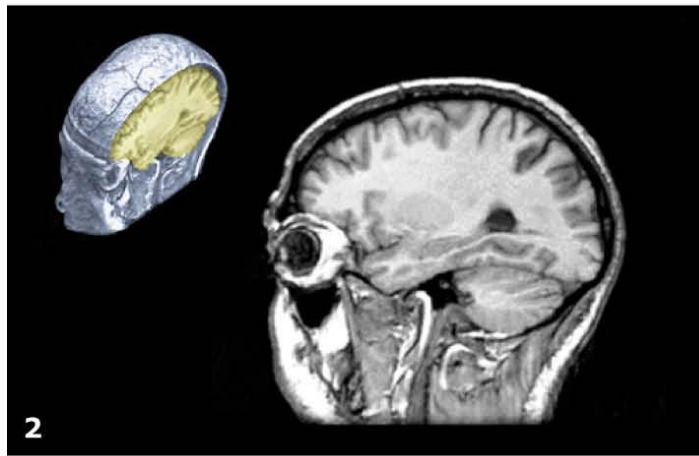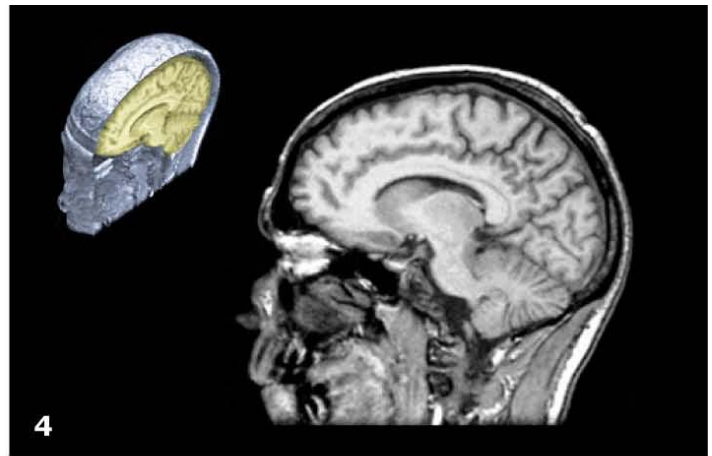
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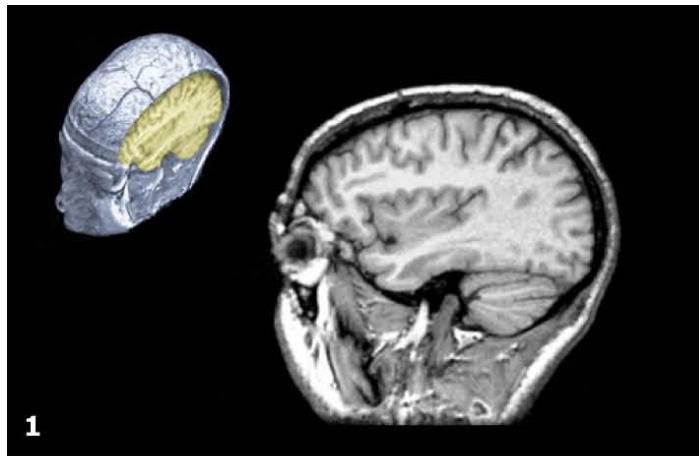Duke University School of Medicine

Laboratory Guide
A Brief Survey of Human Brain Anatomy

Sagittal sections.
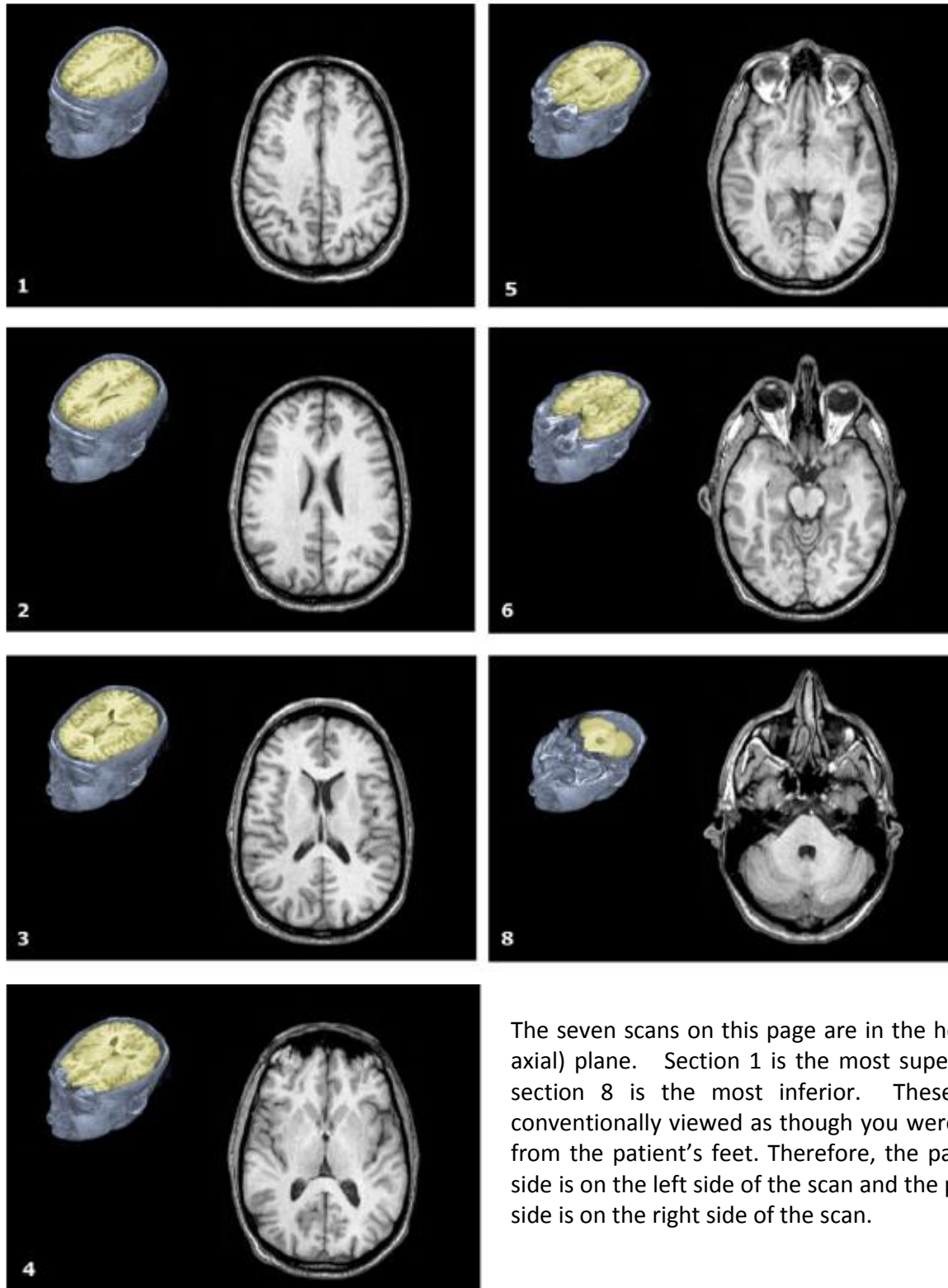

The five scans on this page are in the sagittal plane. Section 1 is the most lateral section and 5 is the most medial section in the series.

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Laboratory Guide
A Brief Survey of Human Brain Anatomy

Horizontal sections.

The seven scans on this page are in the horizontal (or axial) plane. Section 1 is the most superior section; section 8 is the most inferior. These scans are conventionally viewed as though you were looking up from the patient's feet. Therefore, the patient's right side is on the left side of the scan and the patient's left side is on the right side of the scan.