Section A

ORIENTATION

INTRODUCTION

An understanding of the ***central nervous system*** — the CNS — and how it functions requires knowing its component parts and their specialized operations, and the contribution of each of the parts to the function of the whole. The first section of this atlas introduces the student to the CNS from an anatomical and functional viewpoint. The subsequent section (Section B) will use these components to build the various systems, such as the sensory and motor systems. The blood supply and the detailed anatomical organization are found in Section C. Emotional behavior is discussed in Section D.

FUNCTIONAL NEUROHISTOLOGY

The major cell of the CNS is the **neuron**. Human brains have billions of neurons. A neuron has a cell body (also called soma, or **perikaryon**); **dendrites**, which extend a short distance from the soma; and an **axon**, which connects one neuron with others. Neuronal membranes are specialized for electro-chemical events, which allow these cells to receive and transmit messages to other neurons. The dendrites and cell bodies of the neurons receive information, and the axons transmit the firing pattern of the cell to the next neuron. Generally, each neuron receives synaptic input from hundreds or perhaps thousands of neurons, and its axon distributes this information via collaterals (branches) to hundreds of neurons.

Within the CNS, neurons that share a common function are usually grouped together; such groupings are called **nuclei** (singular **nucleus**, which is somewhat confusing as it does not refer to the part of a cell). In other parts of the brain, the neurons are grouped at the surface, forming a **cortex**. In a cortical organization, neurons are arranged in layers and the neurons in each layer are functionally alike and different from those in other layers. Older cortical areas have three layers (e.g., the cerebellum); more recently evolved cortices have six layers (the cerebral cortex) and sometimes sublayers.

Some neurons in the nervous system are directly linked to sensory (afferent) or motor (efferent) functions. In the CNS, the overwhelming majority of neurons interconnect, that is, form circuits that participate in the processing of information. These neurons are called **interneurons**, and more complex information processing, such as occurs in the human brain, is correlated with the dramatic increase in the number of interneurons in our brains.

Communication between neurons occurs almost exclusively at specialized junctions called **synapses**, using biological molecules called **neurotransmitters**. These modify ion movements across the neuronal membranes of the synapse and alter neurotransmission — they can be excitatory or inhibitory in their action, or modulate synaptic excitability. The post-synaptic neuron will modify its firing pattern depending on the summative effect of all the synapses acting upon it at any moment in time. The action of neurotransmitters depends also on the specific receptor type; there is an ever increasing number of receptor subtypes allowing for even more complexity of information processing within the CNS. Drugs are being designed to act on those receptors for therapeutic purposes.

Much of the substance of the brain consists of **axons**, also called **fibers**, which connect one part of the brain with other areas. These fibers function so that the various parts of the brain communicate with each other, some going a short distance linking neurons locally and others traveling a long distance connecting different areas of the brain and spinal cord. Many of the axons are myelinated, an "insulation," which serves to increase the speed of axonal conduction; the thicker the **myelin sheath**, the faster the conduction. Axons originating from one area (cortex or nucleus) and destined for another area usually group together and form a **tract**, also called a **pathway** (or fasciculus).

The other major cells of the CNS are **glia**; there are more glia than neurons. There are two types of glial cells:

- **Astrocytes**, which are involved in supportive structural and metabolic events
- **Oligodendrocytes**, which are responsible for the formation and maintenance of the myelin that ensheaths the axons

Some of the early maturation that we see in infants and children can be accounted for by the progressive myelination of the various pathways within the CNS throughout childhood.

FUNCTIONAL NEUROANATOMY OF THE CNS

One approach to an understanding of the nervous system is to conceptualize that it is composed of a number of functional modules, starting with simpler ones and evolving in higher primates and humans to a more complex organizational network of cells and connections. The function of each part is dependent upon and linked to the function of all the modules acting in concert.

The basic unit of the CNS is the **spinal cord** (see Figure 1 and Figure 2), which connects the CNS with the skin and muscles of the body. Simple and complex reflex circuits are located within the spinal cord. It receives sensory information (**afferents**) from the skin and body wall, which are then transmitted to higher centers of the brain. The spinal cord receives movement instructions from the higher centers and sends motor commands (**efferents**) to the muscles. Certain motor patterns are organized in the spinal cord, and these are under the influence of motor areas in other parts of the brain. The autonomic nervous system, which supplies the internal organs and the glands, is also found within the spinal cord.

As the functional systems of the brain become more complex, new control "centers" have evolved. These are often spoken of as higher centers. The first set of these is located in the **brainstem**, which is situated above the spinal cord and within the skull (in humans). The brainstem includes three distinct areas — the **medulla**, **pons**, and **midbrain** (see Figure OA, Figure OL, Figure 6, and Figure 7). Some nuclei within the brainstem are concerned with essential functions such as pulse, respiration, and the regulation of blood pressure. Other nuclei within the brainstem are involved in setting our level of arousal and play an important role in maintaining our state of consciousness. Special nuclei in the brainstem are responsible for some basic types of movements in response to gravity or sound. In addition, most of the **cranial nerves** and their nuclei, which supply the structures of the head, are anchored in the brainstem (see Figure 8A and Figure 8B). Many nuclei in the brainstem are related to the cerebellum.

The **cerebellum** has strong connections with the brainstem and is situated behind the brainstem (inside the skull) in humans (see Figure OA, Figure OL, and Figure 9A). The cerebellum has a simpler form of cortex, which consists of only three layers. Parts of the cerebellum are quite old in the evolutionary sense, and parts are relatively newer. This "little brain" is involved in motor coordination and also in the planning of movements. How this is accomplished will be understood once the input/output connections of the various parts of the cerebellum are studied.

Next in the hierarchy of the development of the CNS is the area of the brain called the **diencephalon** (see Figure OA, Figure OL, and Figure 11). Its largest part, the **thalamus**, develops in conjunction with the cerebral hemispheres and acts as the gateway to the cerebral cortex. The thalamus consists of several nuclei, each of which projects to a part of the cerebral cortex and receives reciprocal connections from the cortex. The **hypothalamus**, a much smaller part of the diencephalon, serves mostly to control the neuroendocrine system via the pituitary gland, and also organizes the activity of the autonomic nervous system. Parts of the hypothalamus are intimately connected with the expression of basic drives (e.g., hunger and thirst), with the regulation of water in our bodies, and with the manifestations of "emotional" behavior as part of the limbic system (see below).

With the continued evolution of the brain, the part of the brain called the forebrain undergoes increased development, a process called encephalization. This has culminated in the development of the **cerebral hemispheres**, which dominate the brains of higher mammals, reaching its zenith (so we think) in humans. The neurons of the cerebral hemispheres are found at the surface, the **cerebral cortex** (see Figure 13 and Figure 14A), most of which is six-layered (also called the **neocortex**). In humans, the cerebral cortex is thrown into ridges (gyri, singular **gyrus**) and valleys (sulci, singular **sulcus**). The enormous expansion of the cerebral cortex in the human, both in terms of size and complexity, has resulted in this part of the brain becoming the dominant controller of the CNS, capable, so it seems, of overriding most of the other regulatory systems. We need our cerebral cortex for almost all interpretations and actions related to the functioning of the sensory and motor systems, for consciousness, language, and thinking.

Buried within the cerebral hemispheres are the **basal ganglia**, large collections of neurons (see Figure OA, Figure OL, and Figure 22) that are involved mainly in the initiation and organization of motor movements. These neurons affect motor activity through their influence on the cerebral cortex.

A number of areas of the brain are involved in behavior, which is characterized by the reaction of the animal or person to situations. This reaction is often termed "emotional" and, in humans, consists of both psychological and physiological changes. Various parts of the brain are involved with these activities, and collectively they have been named the **limbic system**. This network includes the cortex, various subcortical areas, parts of the basal ganglia, the hypothalamus and parts of the brainstem. (The limbic system is described in Section D of this atlas.)

In summary, the nervous system has evolved so that its various parts have "assigned tasks." In order for the nervous system to function properly, there must be communication between the various parts. Some of these links are the major sensory and motor pathways, called **tracts** (or fascicles). Much of the mass of tissue in our hemispheres is made up of these **pathways** (e.g., see Figure 33 and Figure 45).

Within all parts of the CNS there are the remnants of the neural tube from which the brain developed; these spaces are filled with **cerebrospinal fluid (CSF)**. The spaces in the cerebral hemispheres are actually quite large and are called **ventricles** (see Figure OA, Figure OL, Figure 20A, Figure 20B, and Figure 21).

The CNS is laced with blood vessels as neurons depend upon a continuous supply of oxygen and glucose. This aspect will be discussed further with the section on vasculature (e.g., see Figure 58).

STUDY OF THE CNS

Early studies of the normal brain were generally descriptive. Brain tissue does not have a firm consistency, and the brain needs to be fixed for gross and microscopic examination. One of the most common fixatives used to preserve the brain for study is formalin, after which it can be handled and sectioned. Areas containing predominantly neuronal cell bodies (and their dendrites and synapses) become grayish in appearance after formalin fixation, and this is traditionally called **gray matter**. Tracts containing myelinated axons become white in color with formalin fixation, and such areas are likewise simply called the **white matter** (see Figure 27 and Figure 29).

We have learned much about the normal function of the human CNS through diseases and injuries to the nervous system. Diseases of the nervous system can involve the neurons, either directly (e.g., metabolic disease) or by reducing the blood supply, which is critical for the viability of nerve cells. Some degenerative diseases affect a particular group of neurons. Other diseases can affect the cells supporting the myelin sheath, thereby disrupting neurotransmission. Biochemical disturbances may disrupt the balance of neurotransmitters and cause functional disease states.

The recent introduction of functional imaging of the nervous system is revealing fascinating information about the functional organization of the CNS. We are slowly beginning to piece together an understanding of what is considered by many as the last and most important frontier of human knowledge, an understanding of the brain.

CLINICAL ASPECT

Certain aspects of clinical neurology will be included in this atlas, both to amplify the text and to indicate the importance of knowing the functional anatomy of the CNS. Knowing where a lesion is located (the localization) often indicates the nature of the disease (the diagnosis), leading to treatment and allowing the physician to discuss the prognosis with the patient.

FIGURE OA

OVERVIEW — ANTERIOR VIEW

Constructing a three-dimensional visualization of the brain and its various parts is a challenging task for most people, and this diagram and its companion (the next illustration) are designed to assist the learner in this task.

This is a semi-anatomic representation of the brain and the parts of the CNS. This general diagrammatic view should be consulted as the learner is orienting to the placement of the structures within the brain. These same structures are viewed from the lateral perspective with the next illustration.

The cerebral hemispheres: The large cerebral hemispheres, with its extensive **cerebral cortex**, is by far the most impressive structure of the CNS and the one that most are referring to when speaking about "the brain." In fact there are two cerebral hemispheres that are connected across the midline by a massive communication link called the **corpus callosum** (see Figure 16 and Figure 19A). The hemispheres are discussed with Figure 13–Figure 19 of the Orientation section.

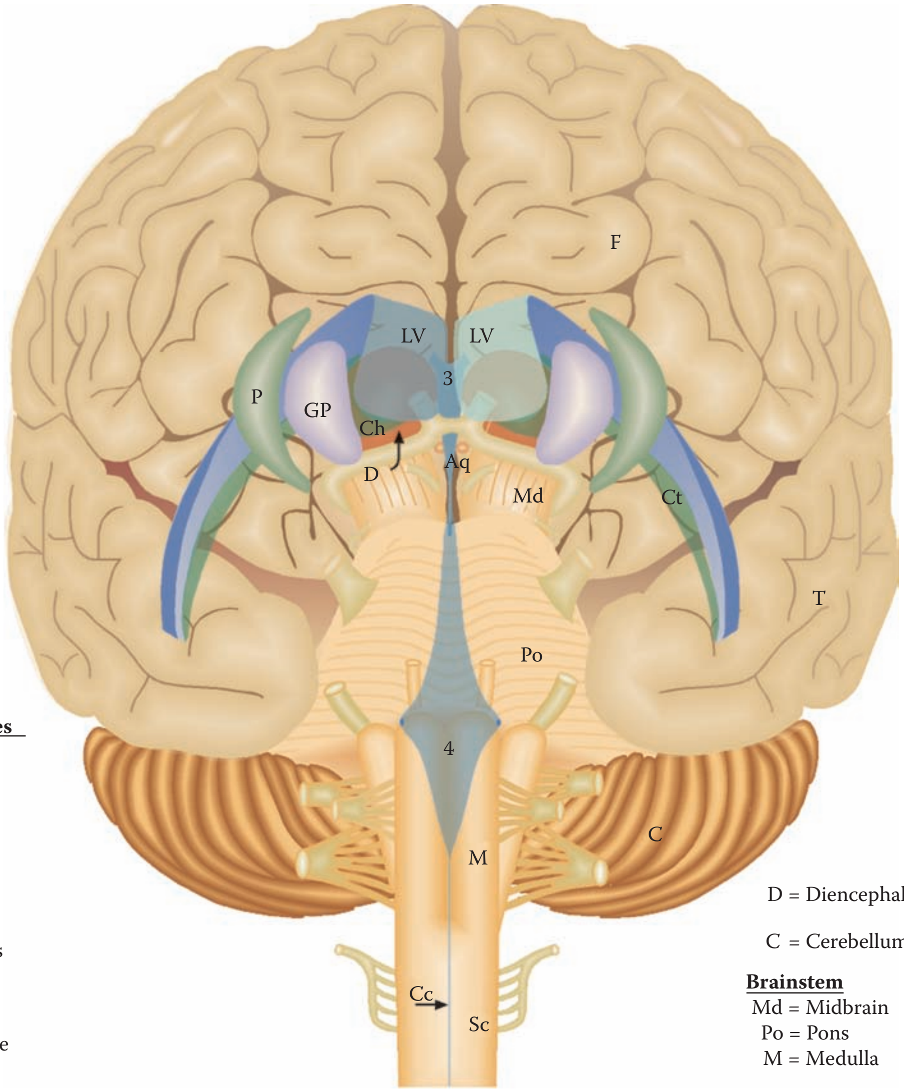
Many parts of the brain are found deep inside the hemispheres. This illustration is done so that these structures should be visualized "within" the hemispheres. Included are:

- **Basal ganglia**: These large neuronal areas are found within the brain; its three parts are shown — the **caudate** nucleus (head and tail), the **putamen**, and the **globus pallidus**. The basal ganglia are discussed with Figure 22–Figure 30 of the Orientation section.
- **Ventricles of the brain**: Each hemisphere has within it a space remaining from the neural tube, from which the brain developed, called a ventricle — the **lateral ventricle** (also called ventricles 1 and 2). The ventricles are presented in this anterior perspective with Figure 20B.

The massive cerebral hemispheres hide the other parts of the brain from view, when looking from the anterior perspective, although some of these parts can be seen if the brain is viewed from below (see Figure 15A and Figure 15B). These structures include:

- **Diencephalon**: The largest part of the diencephalon is the **thalamus**; in fact, this is a paired structure. The unpaired third ventricle should be noted between the thalamus of each side. The thalamus is discussed with Figure 11 and Figure 12 of the Orientation section.
- **Brainstem**: By definition, the brainstem consists of the **midbrain**, **pons**, and **medulla**; the cranial nerves are attached to the brainstem. The brainstem and cranial nerves are considered in Figure 6–Figure 10 of the Orientation section. The ventricular space within the brainstem is the fourth ventricle.
- **Cerebellum**: Part of the **cerebellum** can be seen from this perspective. This "little brain" is usually considered with the brainstem and is discussed with Figure 9A and Figure 9B of the Orientation section.
- **Spinal cord**: This long extension of the CNS continues from the medulla and is found in the vertebral canal. The **spinal cord** is discussed with Figure 1–Figure 5 of the Orientation section.

Note on the safe handling of brain tissue: Current guidelines recommend the use of disposable gloves when handling any brain tissue, to avoid possible contamination with infectious agents, particularly the "slow" viruses. In addition, formalin is a harsh fixative and can cause irritation of the skin. Many individuals can react to the smell of the formalin and may develop an asthmatic reaction. People who handle formalin-fixed tissue must take extra precautions to avoid these problems. In most labs, the brains are soaked in water before being put out for study.



Cerebral hemispheres
F = Frontal lobe
T = Temporal lobe

Basal Ganglla
Ch = Caudate head
Ct = Caudate tail
P = Putamen
GP = Globus pallidus

Ventricles
LV = Lateral ventricle
3 = 3rd ventricle
Aq = Aqueduct
4 = 4th ventricle

D = Diencephalon (thalamus)

C = Cerebellum

Brainstem
Md = Midbrain
Po = Pons
M = Medulla

Sc = Spinal cord
Cc = Central canal

FIGURE OA: Overview Diagram — Anterior View

FIGURE OL

OVERVIEW — LATERAL VIEW

This is the companion diagram to the previous illustration, created to assist the learner in placing the brain and its various divisions in a three-dimensional construct.

This is a semi-anatomic view of the brain from the lateral perspective. The front pole of the brain is on the left side of this illustration; the posterior pole is on the right side. The structures included are:

- **Cerebral hemispheres**: The extensive cerebral hemisphere of one side is seen, with the top edge of the other hemisphere in view (this same view is presented in Figure 14). The lower part of the hemisphere seen on this view is the temporal lobe.
- **Lateral ventricles**: The shape of the ventricles within the hemispheres is now clearly seen (like a reversed letter C), with its continuation into the temporal lobe. The ventricle of the other hemisphere is seen as a "shadow." (A similar view is presented in Figure 20B.)
- **Basal ganglia**: The three parts of the basal ganglia are represented in this view. The caudate (head, body, and tail) follows the ventricle. The putamen can be seen from the lateral perspective, but the globus pallidus is hidden from view because it lies medial to the putamen; its position is indicated by the dashed ellipse. (A similar view is presented in Figure 25.) The two nuclei together are called the **lentiform** or **lenticular nucleus**.

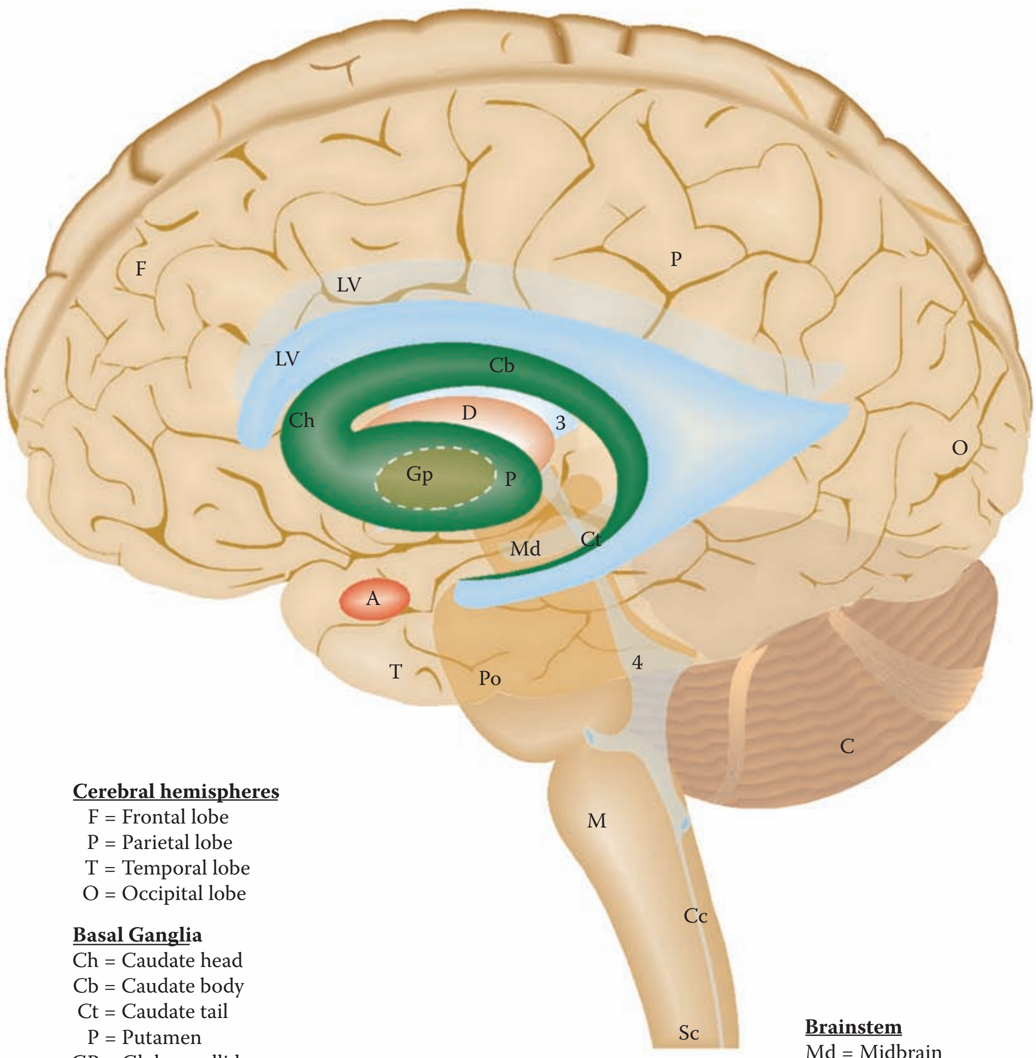
One additional nucleus belonging, by definition, with the basal ganglia is seen within the temporal lobe — the amygdala. It will be discussed with the limbic system (in Section D).

- **Diencephalon**: The thalamus of one side can be visualized from this perspective, almost completely hidden from view by the putamen and the globus pallidus, the lentiform nucleus. The third ventricle is seen just behind it, occupying the midline (see Figure 25).
- **Brainstem**: The upper parts of the brainstem, namely the midbrain and upper pons, cannot be seen from this view of the brain, but their position is shown as if one could "see through" the temporal lobe. The lower part of the pons and the medulla may be seen. The shape of the fourth ventricle within the brainstem should also be noted.
- **Cerebellum**: Only the lower portion of one of the hemispheres of the cerebellum can be seen from this lateral perspective, below the cerebral hemispheres.

The brainstem and cerebellum occupy the posterior cranial fossa of the skull.

- **Spinal cord**: The spinal cord continues from the bottom of the medulla. A view similar to this is seen in a neuroradiologic image in Figure 3.

Note to the Learner: These overview illustrations are only sometimes referred to in this atlas but should be consulted as often as necessary while developing a three-dimensional understanding of the various parts of the brain.



Cerebral hemispheres
F = Frontal lobe
P = Parietal lobe
T = Temporal lobe
O = Occipital lobe

Basal Ganglia
Ch = Caudate head
Cb = Caudate body
Ct = Caudate tail
P = Putamen
GP = Globus pallidus

Ventricles
LV = Lateral ventricle
3 = 3rd ventricle
4 = 4th ventricle

A = Amygdata

D = Diencephalon (thalamus)

C = Cerebellum

Brainstem
Md = Midbrain
Po = Pons
M = Medulla

Sc = Spinal cord
Cc = Central canal

FIGURE OL: **Overview Diagram** — Lateral View

FIGURE 1
SPINAL CORD 1

SPINAL CORD: LONGITUDINAL VIEW

The spinal cord is the extension of the CNS below the level of the skull. It is an elongated structure that is located in the vertebral canal, covered with the **meninges** — dura, arachnoid, and pia — and surrounded by the **subarachnoid space** containing cerebrospinal fluid (CSF) (see Figure 21). There is also a space between the dura and vertebra, known as the **epidural space**. Both of these spaces have important clinical implications (see Figure 2C and Figure 3).

The spinal cord, notwithstanding its relatively small size compared with the rest of the brain, is absolutely essential for our normal function. It is the connector between the central nervous system and our body (other than the head). On the sensory (afferent) side, the information arriving from the skin, muscles, and viscera informs the CNS about what is occurring in the periphery; this information then “ascends” to higher centers in the brain.

On the motor (efferent) side, the nerves leave the spinal cord to control our muscles. Although the spinal cord has a functional organization within itself, these neurons of the spinal cord receive their “instructions” from higher centers, including the cerebral cortex, via several descending tracts. This enables us to carry out normal movements, including normal walking and voluntary activities. The spinal cord also has a motor output to the viscera and glands, part of the autonomic nervous system (see Figure 4).

UPPER INSET: CERVICAL SPINAL CORD CROSS-SECTION

The neurons of the spinal cord are organized as nuclei, the **gray matter**, and the various pathways are known as **white matter**. In the spinal cord, the gray matter is found on the inside, with the white matter all around. The divisions of the gray matter are introduced with Figure 4; the functional aspects will be described with the sensory (see Figure 32) and motor (see Figure 44) systems. The tracts of the spinal cord are described with the pathways in Section B (e.g., see Figure 33 and Figure 45). All the pathways are summarized in one cross-section (see Figure 68). Histological cross-sections of the spinal cord are also presented (see Figure 69).

LOWER INSET: NERVE ROOTS

The **dorsal root** (sensory) and **ventral root** (motor) unite within the intervertebral foramina to form the (mixed) **spinal nerve** (see also Figure 5). The nerve cell bodies for the dorsal root are located in the **dorsal root ganglion** (**DRG**). Both the roots and the dorsal root ganglion belong to the peripheral nervous system (PNS) (where the Schwann cell forms and maintains the myelin).

DEVELOPMENTAL PERSPECTIVE

During early development, the spinal cord is the same length as the vertebral canal and the entering/exiting nerve roots correspond to the spinal cord vertebral levels. During the second part of fetal development, the body and the bony spine continue to grow, but the spinal cord does not. After birth, the spinal cord only fills the vertebral canal to the level of L2, the second lumbar vertebra (see also Figure 3). The space below the termination of the spinal cord is the **lumbar cistern**, filled with cerebrospinal fluid.

Therefore, as the spinal cord segments do not correspond to the vertebral segments, the nerve roots must travel in a downward direction to reach their proper entry/exit level between the vertebra, more so for the lower spinal cord roots (see the photographic view in Figure 2A and Figure 2C). These nerve roots are collectively called the **cauda equina**, and they are found in the lumbar cistern (see Figure 2A, Figure 2C, and Figure 3).

CLINICAL ASPECT

The four vertebral levels — cervical, thoracic, lumbar, and sacral — are indicated on the left side of the illustration. The spinal cord levels are indicated on the right side. One must be very aware of which reference point — the vertebral or spinal — is being used when discussing spinal cord injuries.

Nerve roots can be anesthetized by injection of a local anesthetic into their immediate vicinity. One of the locations for this is in the epidural space. The sensory nerve roots to the perineal region, which enter the cord at the sacral level, are often anesthetized in their epidural location during childbirth. This procedure requires a skilled anesthetist.

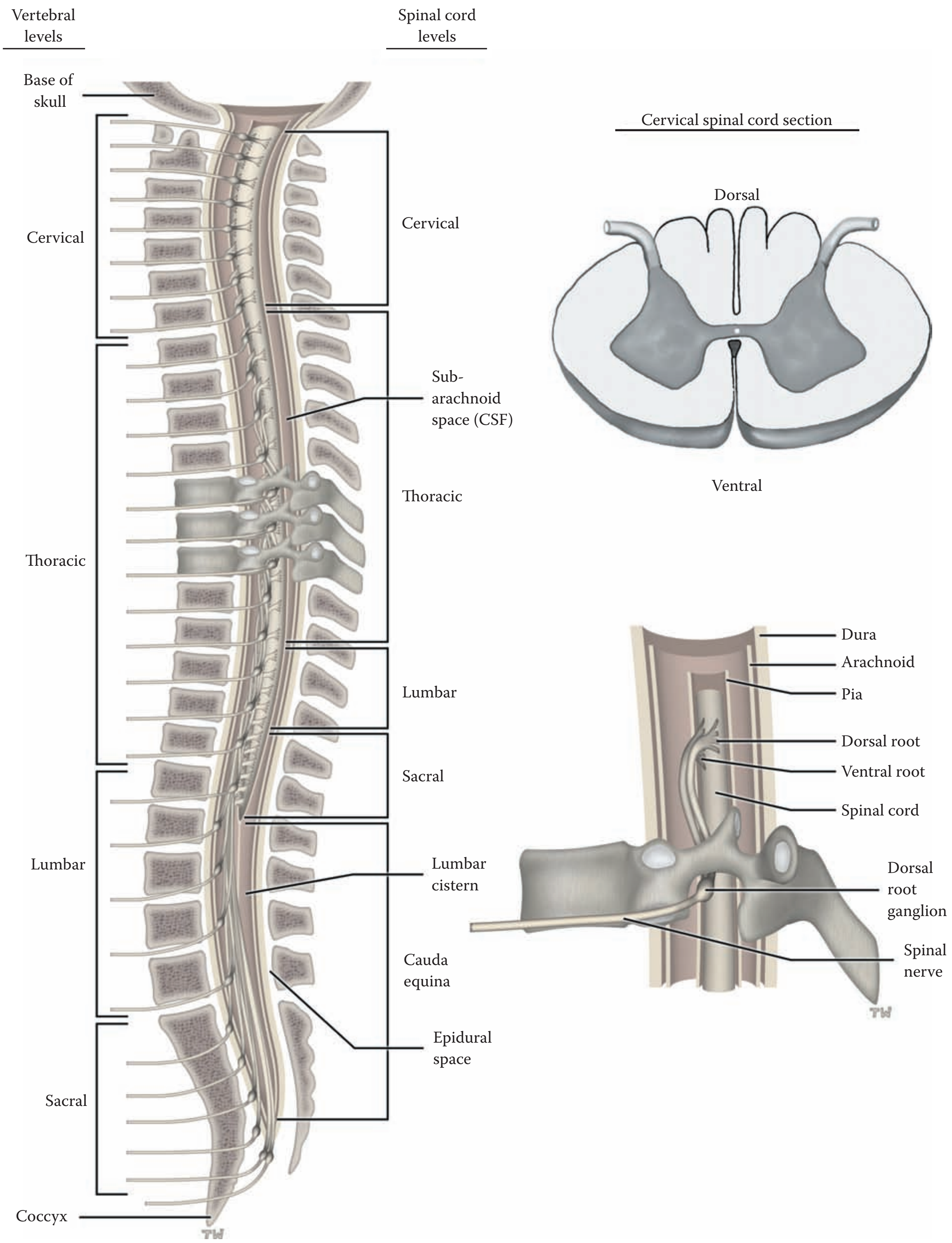


FIGURE 1: **Spinal Cord 1** — Longitudinal (Vertebral) View

FIGURE 2A
SPINAL CORD 2

SPINAL CORD: LONGITUDINAL VIEW (PHOTOGRAPH)

This is a photographic image of the spinal cord removed from the vertebral canal. The dura-arachnoid has been opened and the anterior aspect of the cord is seen, with the attached spinal roots; from this anterior perspective, most of the roots seen are the ventral (i.e., motor) roots.

The spinal cord is divided into parts according to the region innervated: cervical (8 spinal roots), thoracic (12 spinal roots), lumbar (5 spinal roots), sacral (5 spinal roots), and coccygeal (1 root).

The nerve roots attached to the spinal cord, connecting the spinal cord with the skin and muscles of the body, give the cord a segmented appearance. This segmental organization is reflected onto the body in accordance with embryological development. Areas of skin are supplied by certain nerve segments — each area is called a **dermatome** (e.g., inner aspect of the arm and hand = C8; umbilical region = T10), with overlap from adjacent segments. The muscles are supplied usually by two adjacent segments, called **myotomes** (e.g., biceps of the upper limb = C5 and C6; quadriceps of the lower limb = L3 and L4). This known pattern is very important in the clinical setting (see below).

There are two enlargements of the cord: at the cervical level for the upper limb (seen at greater magnification in Figure 2B), the roots of which will form the **brachial plexus**, and at the lumbosacral level for the lower limb, the roots of which form the **lumbar and sacral plexuses**. The cord tapers at its ending, and this lowermost portion is called the **conus medullaris**. Below the vertebral level of L2 in the adult, inside the vertebral canal, are numerous nerve roots, both ventral and dorsal, collectively called the **cauda equina**; these are found within the **lumbar cistern**, an expansion of the subarachnoid space, a space containing CSF (see Figure 1, and shown at a greater magnification and discussed in Figure 2C; also shown in the MRI in Figure 3).

CLINICAL ASPECT

The segmental organization of the spinal cord and the known pattern of innervation to areas of skin and to muscles allows a knowledgeable practitioner, after performing a detailed neurological examination, to develop an accurate localization of the injury or disease (called the lesion) at the spinal cord (segmental) level.

The spinal cord can be affected by tumors, either within the cord (intramedullary), or outside the cord (extramedullary). There is a large plexus of veins on the outside of the dura of the spinal cord (see Figure 1), and this is a site for metastases from pelvic (including prostate) tumors. These press upon the spinal cord as they grow and cause symptoms as they compress and interfere with the various pathways (see Section B).

Traumatic lesions of the spinal cord occur following car and bicycle accidents and still occur because of diving accidents into shallow water (swimming pools). Protruding discs can impinge upon the spinal cord. Other traumatic lesions involve gunshot and knife wounds. If the spinal cord is completely transected (i.e., cut through completely), all the tracts are interrupted. For the ascending pathways, this means that sensory information from the periphery is no longer available to the brain. On the motor side, all the motor commands cannot be transmitted to the anterior horn cells, the final common pathway for the motor system. The person therefore is completely cut off on the sensory side and loses all voluntary control, below the level of the lesion. Bowel and bladder control are also lost.

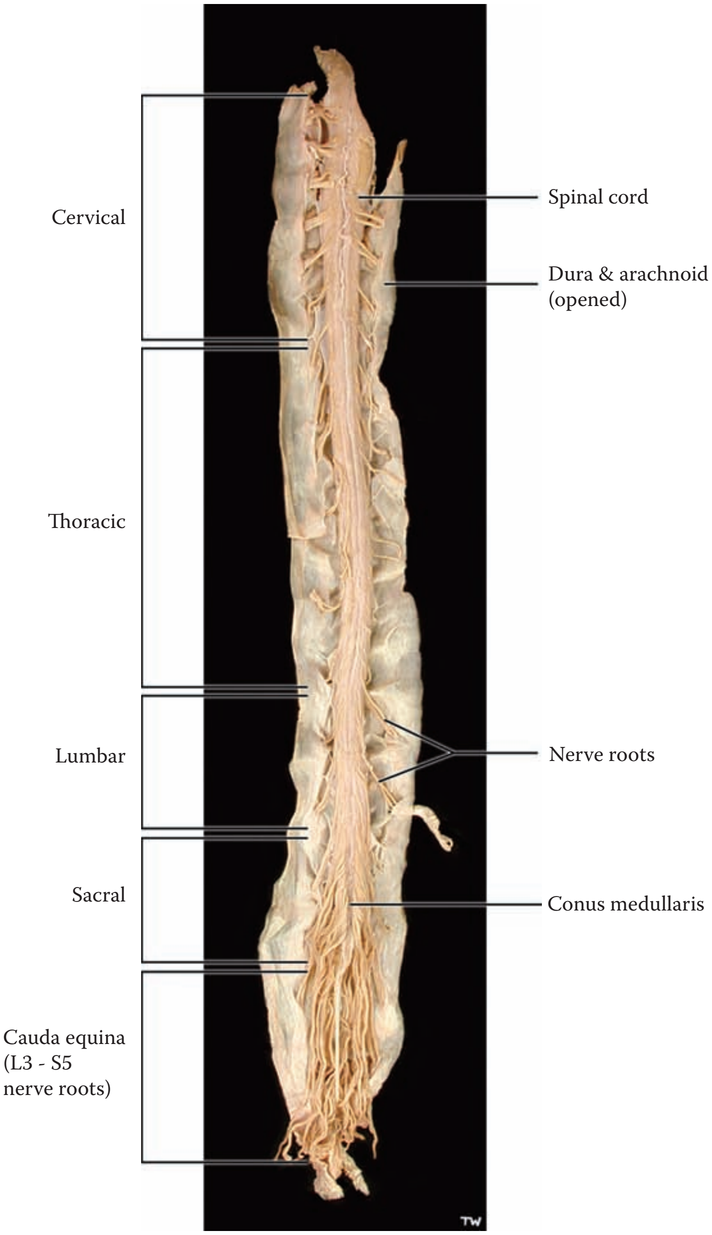


FIGURE 2A: **Spinal Cord 2** — Longitudinal View (photograph)

FIGURE 2B
SPINAL CORD 3

SPINAL CORD: CERVICAL REGION (PHOTOGRAPH)

This is a higher magnification photographic image of the cervical region of the spinal cord. Most of the attached roots are the motor/ventral roots, coming from the ventral horn of the spinal cord (discussed with Figure 4); a few of the dorsal/sensory roots can be seen, which enter the cord in the dorsal horn. These roots exit the vertebral canal and carry a sleeve of arachnoid-dura with them for a very short distance, as they head for the intervertebral spaces (see Figure 1).

The somewhat tortuous artery running down the midline of the cord is the **anterior spinal artery**. This artery, which is the major blood supply to the ventral portion of the upper part of the cord, is formed by a branch from each of the vertebral arteries (see Figure 58). This artery receives supplementary branches from the aorta along its way, called radicular arteries, which follow the nerve roots. There are two very small posterior spinal arteries. The most vulnerable area of the spinal cord blood supply is around the mid-thoracic level. There is a particularly important branch off the aorta that supplies this critical region of the spinal cord. This is important clinically (see below).

The pia is attached directly to the spinal cord. Sheets of pia are found in the subarachnoid space, between the ventral and dorsal roots, and can be seen attaching to the inner aspect of the arachnoid — these pial extensions are called **denticulate ligaments**. These ligaments, which are located at intervals along the cord, are thought to tether the cord, perhaps to minimize movement of the cord.

CLINICAL ASPECT

Because of its tenuous blood supply, the spinal cord is most vulnerable in the mid-thoracic portion. A dramatic drop in blood pressure, such as occurs with a cardiac arrest or excessive blood loss, may lead to an infarction of the spinal cord. The result can be just as severe as if the spinal cord was severed by a knife. The most serious consequence of this would be the loss of voluntary motor control of the lower limbs, known as paraplegia. The clinical picture will be understood once the sensory and motor tracts of the spinal cord have been explained (in Section B).

Surgeons who operate on the abdominal aorta, for example, for aortic aneurysm, must make every effort to preserve the small branches coming off the aorta as these are critical for the vascular supply of the spinal cord. One would not want the end result of an aneurysmal repair to be a paraplegic patient.

DEVELOPMENTAL ASPECT

Embryologically, the spinal cord commences as a tube of uniform size. In those segments that innervate the limbs (muscles and skin), all the neurons reach maturity. However, in the intervening portions, there is massive programmed cell death during development because there is less peripheral tissue to be supplied. In the adult, therefore, the spinal cord has two “enlargements”: the cervical for the upper limb, and the lumbosacral for the lower limb, each giving rise to the nerve plexus for the upper and lower limbs, respectively.

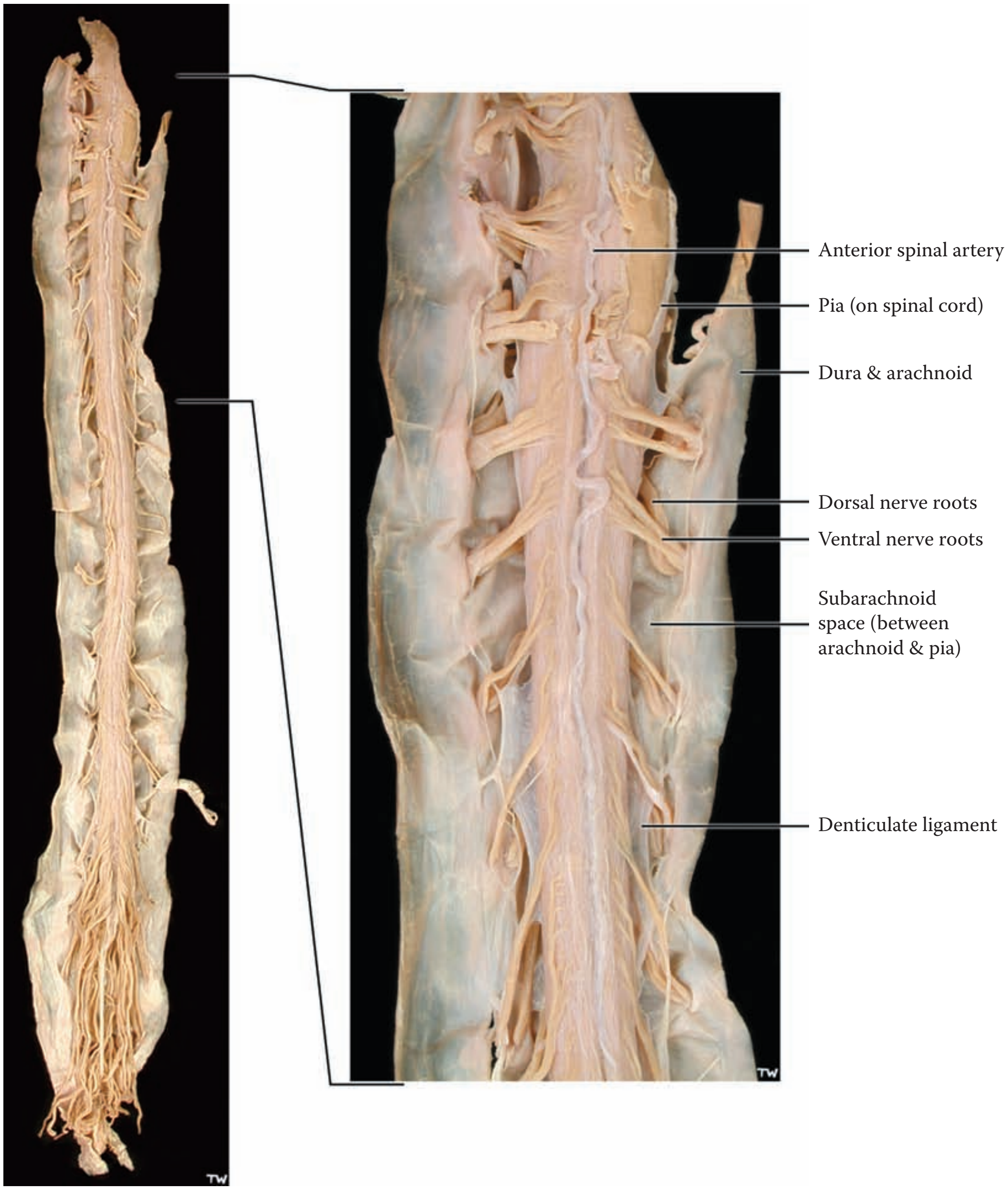


FIGURE 2B: Spinal Cord 3 — Cervical Region (photograph)

FIGURE 2C
SPINAL CORD 4

SPINAL CORD: CAUDA EQUINA (PHOTOGRAPH)

This is a higher magnification photographic image of the lowermost region of the spinal cord, the sacral region. The tapered end of the spinal cord is called the **conus medullaris**, and this lower portion of the cord corresponds approximately to the sacral segments.

The collection of dorsal and ventral nerve roots, below the level of the termination of the cord, is collectively called the **cauda equina**. These roots, which belong to the lumbar and sacral segments of the spinal cord, fill the expanded subarachnoid space in this region, known as the **lumbar cistern** (see Figure 3). The roots are traveling from the spinal cord levels to exit at their appropriate (embryological) intervertebral level (see Figure 1). The roots are floating in the CSF of the lumbar cistern.

The pia mater of the cord gathers at the tip of the conus medullaris into a ligament-like structure, the **filum terminale**, which attaches to the dura-arachnoid at the termination of the vertebral canal, at the level of (vertebral) S2. The three meningeal layers then continue and attach to the coccyx as the coccygeal ligament.

CLINICAL ASPECT

Sampling of CSF for the diagnosis of meningitis, an inflammation of the meninges, or for other neurological diseases, is done in the lumbar cistern. This procedure is called a **lumbar puncture** and must be performed using sterile technique. A trochar (which is a large needle with a smaller needle inside) is inserted *below* the termination of the spinal cord at L2, in the space between the vertebra, usually between the vertebra L4–L5 (see Figure 1). The trochar must pierce the very tough ligamentum flavum (shown in the next illustration), then the dura-arachnoid, and then "suddenly" enters into the lumbar cistern; the (inner) needle is withdrawn and CSF drips out to be collected in sterile vials. This is not a pleasant procedure for a patient and is especially unpleasant, if not frightening, when performed on children.

The nerve roots exit the spinal cord at the appropriate intervertebral level. The roots to the lower extremity, those exiting between L4–L5 and L5–S1, are the ones most commonly involved in the everyday back injuries that affect many adults. The student should be familiar with the signs and symptoms that accompany degenerative disc disease in the lumbar region (see also Figure 1).

Occasionally, neurologic deficits are seen in a pediatric patient, which indicates that the filum terminale is pulling on the spinal cord. If this is suspected clinically, further imaging studies are done, and in some cases the filum terminale must be surgically cut to relieve the tension on the spinal cord.

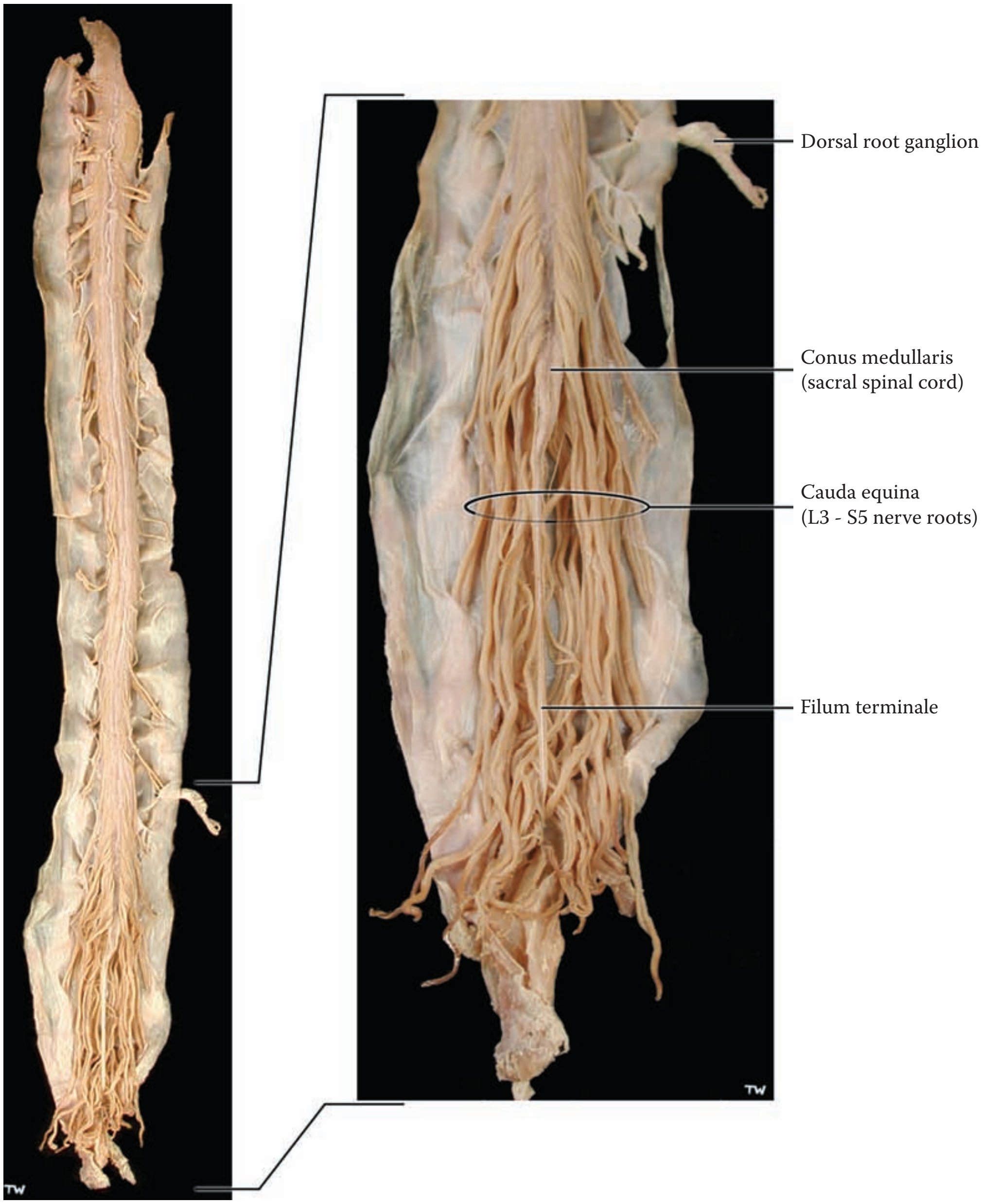


FIGURE 2C: **Spinal Cord 4** — Cauda Equina (photograph)

FIGURE 3
SPINAL CORD 5

SPINAL CORD MRI – T1: LONGITUDINAL VIEW (RADIOGRAPH)

This is a **magnetic resonance image** (MRI) of the vertebral column and spinal cord, viewed in a midsagittal plane. This is called a **TI**-weighted image, in which the cerebrospinal fluid (CSF) is dark. (The various radiological techniques used to image the nervous system are discussed below.) This image is from an adult, in which no pathology was found in the spinal cord radiological examination.

Because of the length of the spinal cord, it is being shown in two parts — upper and lower. The vertebral bodies, the intervertebral discs and the spinous processes posteriorly have been labeled, as well as the ligamentum flavum (discussed with the previous illustration). The vertebral bodies have been numbered at various levels — C2, T1, L1, and S1.

The UPPER portion shows the spinal cord to be a continuation of the medulla of the brainstem, at the lowermost border of the skull, the foramen magnum. The pons, medulla, and cerebellum are seen above foramen magnum occupying the posterior cranial fossa.

The spinal cord tissue is located in the middle of the vertebral column, surrounded by the meninges (which can dimly be visualized), with the dura-arachnoid separating the subarachnoid space containing CSF from the space outside the meninges, the epidural space, between the meninges and vertebra (see Figure 1). The epidural space in the lower thoracic region and in the lumbar and sacral regions often contains fat (epidural fat), which is seen as bright on this image.

The LOWER portion of the spinal cord shows the spinal cord itself, tapering as the conus medullaris and terminating around the level of vertebra L1–L2. Below that level is the enlarged subarachnoid space — called a cistern, the **lumbar cistern** — within which are the nerve roots, dorsal and ventral, for the lower extremity (shown in the previous illustration).

ADDITIONAL DETAIL

The sphenoid air sinus of the skull has been identified, as well as the air-containing (dark) nasal portion of the pharynx (the nasopharynx). The aorta (dark) is also labeled.

RADIOLOGICAL IMAGING

Ordinary x-rays show the skull and its bony structures but not the brain. A remarkable revolution occurred in clinical neurology and our understanding of the brain when imaging techniques were developed that allowed for visualization of the brain. This now includes:

- **Computed tomography (CT)** (often pronounced as a "CAT" scan, meaning computer assisted tomography see Figure 28A). This is done using x-rays, and there is a computer reconstruction of the brain after a series of views are taken from a large number of perspectives. In this view the bones of the skull are bright and the CSF is dark, with the brain tissue "gray" but not clear. This image can be obtained in several seconds, even with a very sick patient.
- **Magnetic resonance imaging (MRI)** does not use x-rays; the image is created by capturing the energy of the hydrogen ions of water. An extremely strong magnet is used for MRI, and capturing the images requires more time. Again, there is a computer reconstruction of the images. The brain itself looks "anatomic." This view can be *weighted* during the acquisition of the image so as to produce a **TI** image, in which the CSF is dark (this illustration), or a **T2** image, in which the CSF is bright (see Figure 28B). With MRI, the bones of the skull are dark, while fatty tissue (including the bone marrow) is bright. Other settings are now available to visualize the brain, such as FLAIR.

As imaging and technology improve, we are able to visualize the brain during functional activity — **functional MRIs** are becoming more widely available; this allows us to "see" which areas of the brain are particularly active during a certain task, based upon the increased blood supply to that area during the active period.

Other techniques are also used to visualize the living brain and its activity, such as positron emission tomography (**PET scan**); this technique utilizes a very short-acting radioactive compound, which is injected into the venous system. Its use is usually restricted to specialized neurological centers involved in research on the human brain.

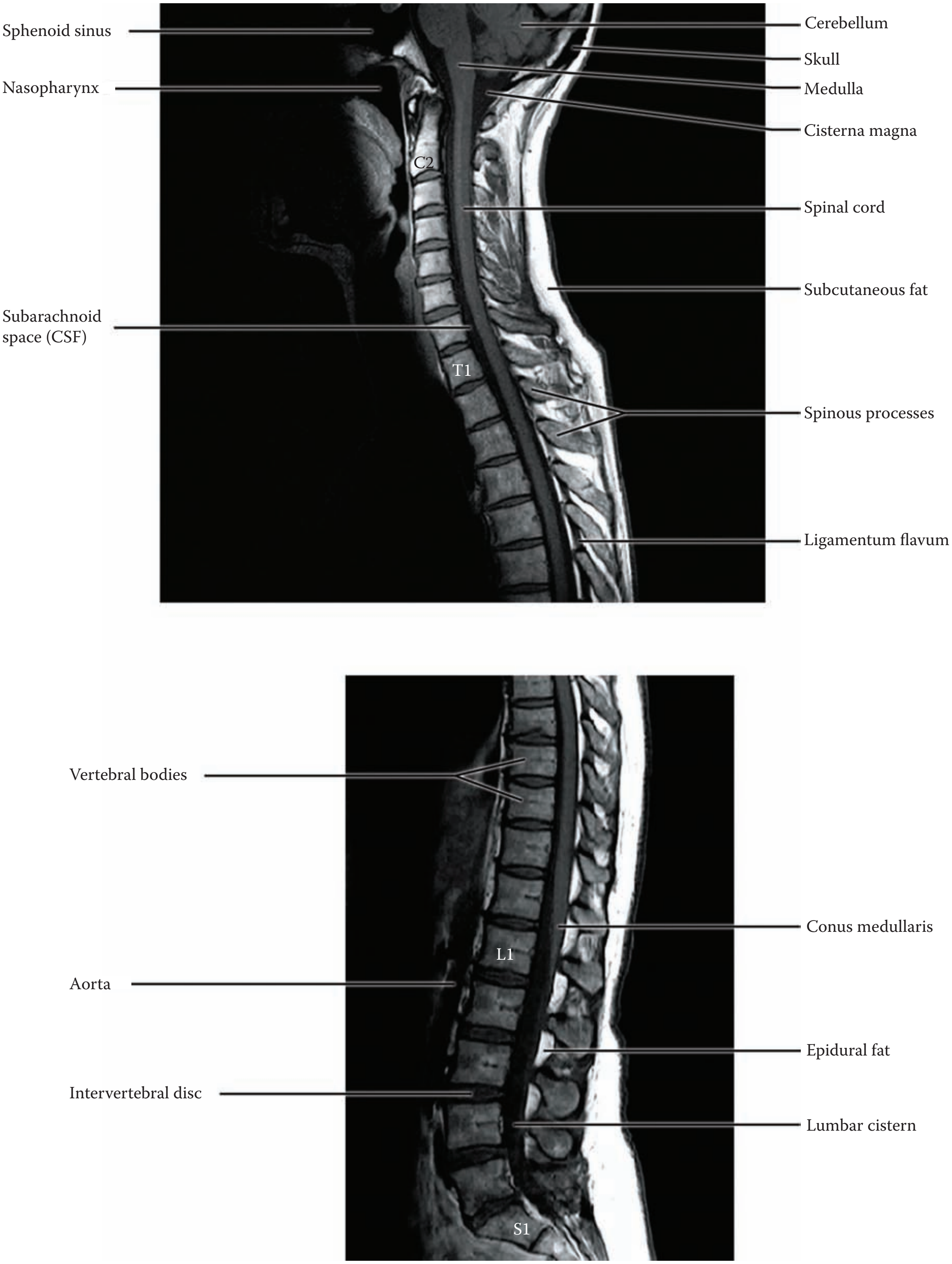


FIGURE 3: Spinal Cord 5 — MRI: Longitudinal View (radiograph)

FIGURE 4
SPINAL CORD 6

SPINAL CORD: CROSS-SECTIONAL VIEWS

UPPER DIAGRAM

The upper diagram is a cross-section through the spinal cord at the C8 level, the eighth cervical segmental level of the spinal cord (not the vertebral level, see Figure 1). The gray matter is said to be arranged in the shape of a butterfly (or somewhat like the letter H). The gray matter of the spinal cord contains a variety of cell groups (i.e. nuclei), which subserve different functions. Although it is rather difficult to visualize, these groups are continuous longitudinally throughout the length of the spinal cord.

The dorsal region of the gray matter, called the **dorsal or posterior horn**, is associated with the incoming (*afferent*) dorsal root, and is thus related to sensory functions. The cell body of these sensory fibers is located in the **dorsal root ganglion** (see Figure 1). The dorsal horn is quite prominent in this region because of the very large sensory input to this segment of the cord from the upper limb, particularly from the hand. The situation is similar in the lumbar region (as shown in the middle of the three lower illustrations).

The ventral gray matter, called the **ventral or anterior horn**, is the motor portion of the gray matter. The ventral horn has the large motor neurons, the anterior horn cells, which are *efferent* to the muscles (see Figure 44). These neurons, because of their location in the spinal cord, which is "below" the brain, are also known as **lower motor neurons**. (We will learn that the neurons in the cerebral cortex, at the "higher" level, are called upper motor neurons — discussed with Figure 45.) The ventral horn is again prominent at this level because of the large number of motor neurons supplying the small muscles of the hand. The situation is similar in the lumbar region, with the motor neurons supplying the large muscles of the thigh (as shown in the illustration below).

The area in between is usually called the **intermediate gray** and has a variety of cell groups with some association-type functions (see Figure 32 and Figure 44).

The **autonomic** nervous system to the organs of the chest, abdomen, and pelvis is controlled by neurons located in the spinal cord.

- Preganglionic **sympathetic** neurons form a distinctive protrusion of the gray matter, called the **lateral horn**, which extends throughout the thoracic region, from spinal cord level T1 to L2 (as shown in the first of the three lower illustrations). The post-ganglionic nerves supply the organs of the thorax, abdomen, and pelvis.
- **Parasympathetic** preganglionic neurons are located in the sacral area and do not form a separate horn (as shown in the illustration). This region of the spinal cord in the area of the conus medullaris (the last of the three lower illustrations) controls bowel and bladder function, subject to commands from higher centers, including the cerebral cortex.

The parasympathetic control of the organs of the thorax and abdomen comes from the vagus nerve, CN X, a cranial nerve (see Figure 6 and Figure 8A).

The central canal of the spinal cord (see Figure 20A, Figure 20B, and Figure 21) is located in the center of the commissural gray matter. This represents the remnant of the neural tube and is filled with CSF. In adults, the central canal of the spinal cord is probably not patent throughout the whole length of the spinal cord. A histological view of these levels of the spinal cord is shown in Figure 69 in Section C.

Note to the Learner: The white matter, which contains the ascending sensory and descending motor pathways, will be described with the pathways in Section B; a summary diagram with all the tracts is shown in Section C (see Figure 68).

ADDITIONAL DETAIL

The parasympathetic supply to the salivary glands travels with cranial nerves (CN) VII and IX (see Figure 8A).

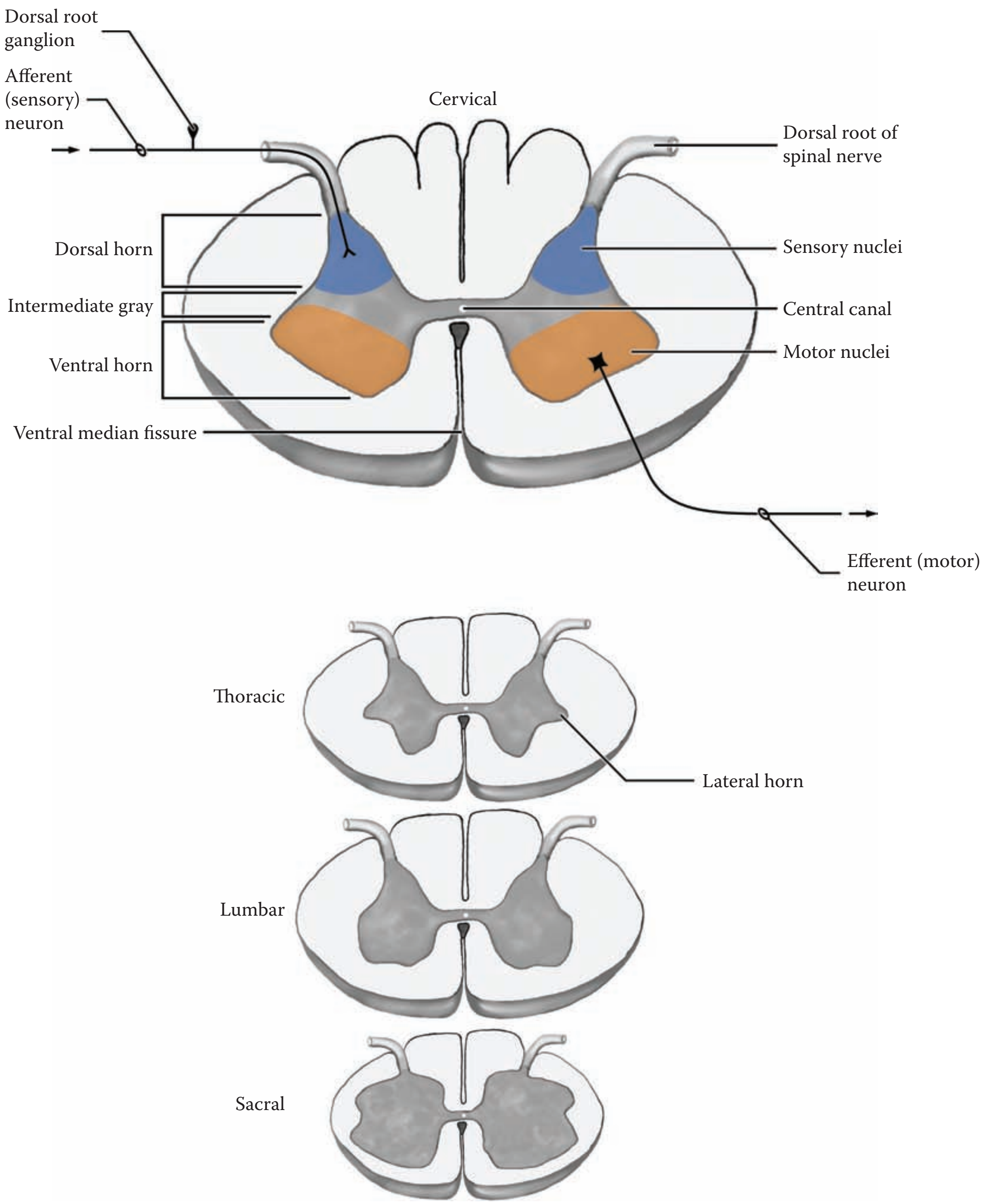


FIGURE 4: **Spinal Cord 6** — Cross-Sectional Views

FIGURE 5
SPINAL CORD 7

SPINAL CORD MRI – T2: AXIAL VIEWS (RADIOGRAPH)

MRI views of the spinal cord are shown in the axial plane at the C4 (fourth cervical vertebral) level; the orientation should be noted with anterior (ventral) at the top. The CSF is bright in these **T2**-weighted images. The position of the spinal cord can be easily visualized within the vertebral canal, with the surrounding CSF space. The vertebral bodies and lamina are dark; the muscles of the neck can be visualized.

In both images it is possible to see the "butterfly" shape of the gray matter of the spinal cord (see Figure 1 and Figure 4). The orientation of the cord should be noted. In the upper image, the dorsal root and ventral root can be seen, as they head for the intervertebral foramen to form the spinal nerve (see Figure 1); neuroradiologists often call this the neural foramen. In the lower image, taken just a few millimeters below, the spinal nerve can be seen in the intervertebral (neural) foramen.

Note to the Learner: In viewing these radiographs, the left side of the image is in fact the right side of the patient and likewise on the other side — this is the convention. The veins, internal jugular and external jugular, appear white with MRI imaging; the common carotid artery appears dark because of the rapid flow of blood in the arteries; note the presence of the vertebral artery (dark) in the foramen in the transverse process.

CLINICAL ASPECT

Any abnormal protrusion of a vertebra or disc could be visualized, as well as tumors within the vertebral canal or of the cord itself (see also Figure 3). An enlargement of the central canal, called syringomyelia, is an unusual though not rare disease of the upper cord (discussed with Figure 32). A small arterio-venous (A-V) malformation may also be visualized with MRI within the spinal cord.

As discussed previously, the spinal cord may be transected following traumatic injuries. The immediate effect of an acute complete spinal cord transection in the human is a complete shutdown of all spinal cord activity. This is referred to as **spinal shock**. Neurologically, there is a loss of all muscle tone and an absence of all deep tendon reflexes, and no plantar response (i.e., no Babinski sign; discussed in Section B, Part III, Introduction). After a few weeks, intrinsic spinal reflexes appear, now no longer modified from higher control centers. (The details of the pathways involved will be discussed in Section B of this atlas.) The end result is a dramatic increase in muscle tone (spasticity) and hyperactive deep tendon reflexes (discussed with Figure 49B and also with Figure 68). Thereafter, there occur a number of abnormal or excessive reflex responses. Such patients require exceptional care by the nursing staff.

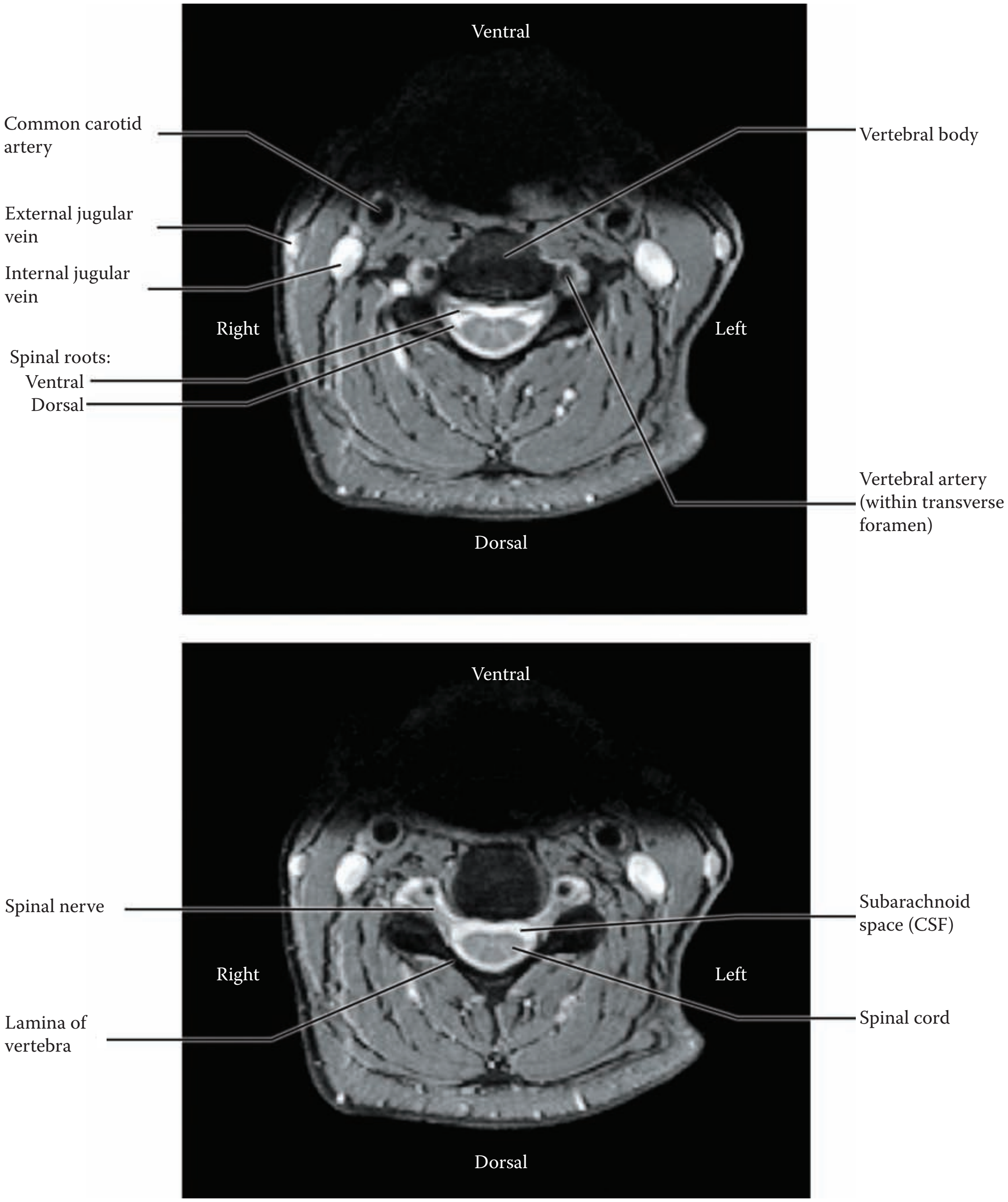


FIGURE 5: Spinal Cord 7 — MRI: Axial View (radiograph)

FIGURE 6
BRAINSTEM 1

BRAINSTEM AND DIENCEPHALON: VENTRAL VIEW

The brainstem is the lowermost part of the brain and is located above the spinal cord. It can be seen by viewing the brain from below (see Figure 15A; also Figure OA and Figure OL). This specimen has been obtained by dissecting out the brainstem, and cerebellum, along with the diencephalon; a photographic view of this specimen is shown in the next illustration (Figure 7). The diencephalon will be described subsequently (see Figure 11 and Figure 12).

In the human brain, the brainstem is a relatively small mass of brain tissue compared to the large hemispheres, but it is packed with various nuclei and tracts. Among these nuclei are those of 10 of the **cranial nerves** (CN III to CN XII). Many basic brain activities are located in the brainstem, including key vital functions (control of blood pressure, pulse, and respiration). Some motor functions are found at various brainstem levels, some as part of the reticular formation; the reticular formation is also part of a system that is responsible for consciousness. Most important, the ascending sensory and descending motor tracts/pathways that connect the spinal cord with "higher" areas of the brain pass through the brainstem (described in Section B). In addition, many of the connections to the cerebellum, including pathways and nuclei, are found in the brainstem. Finally, each part of the brainstem has a part of the ventricular system.

The brainstem is divided anatomically into three parts — the narrow midbrain, which is located under the diencephalon; the pons, with its ventral bulge; and the medulla, which connects with the spinal cord. Each of the parts has distinctive features that allow for the identification of the parts, both on the gross brain specimen or a microscopic cross-section.

- The **midbrain** region (mesencephalon) has two large "pillars" anteriorly called the cerebral peduncles, which consist of millions of axons descending from the cerebral cortex to various levels of the brainstem and spinal cord.
- The **pons** portion is distinguished by its bulge anteriorly, the pons proper, an area that is composed of nuclei (the pontine nuclei) that connect to the cerebellum.
- The **medulla** has two distinct elevations on either side of the midline, known as the pyramids; the direct voluntary motor pathway from the cortex to the spinal cord, the cortico-spinal tract, is located within the pyramid. Behind each is a prominent bulge, called the olive, the inferior olivary nucleus, which connects with the cerebellum.

CRANIAL NERVES AND THEIR ATTACHMENT

The cranial nerves of the brainstem will be presented in numerical order, starting at the midbrain level.

Midbrain Level

- CN III, the **oculomotor nerve**, emerges ventrally between the cerebral peduncles (in the interpeduncular fossa).
- CN IV, the **trochlear nerve**, which exits posteriorly, is a thin nerve that wraps around the lowermost border of the cerebral peduncle.

Pontine Level

- CN V, the **trigeminal nerve**, is a massive nerve attached along the middle cerebellar peduncle.
- CN VI, the **abducens nerve**, is seen exiting anteriorly at the junction between the pons and medulla.
- CN VII, the **facial nerve**, and CN VIII (the **vestibulocochlear nerve**), are both attached to the brainstem at the ponto-cerebellar angle.

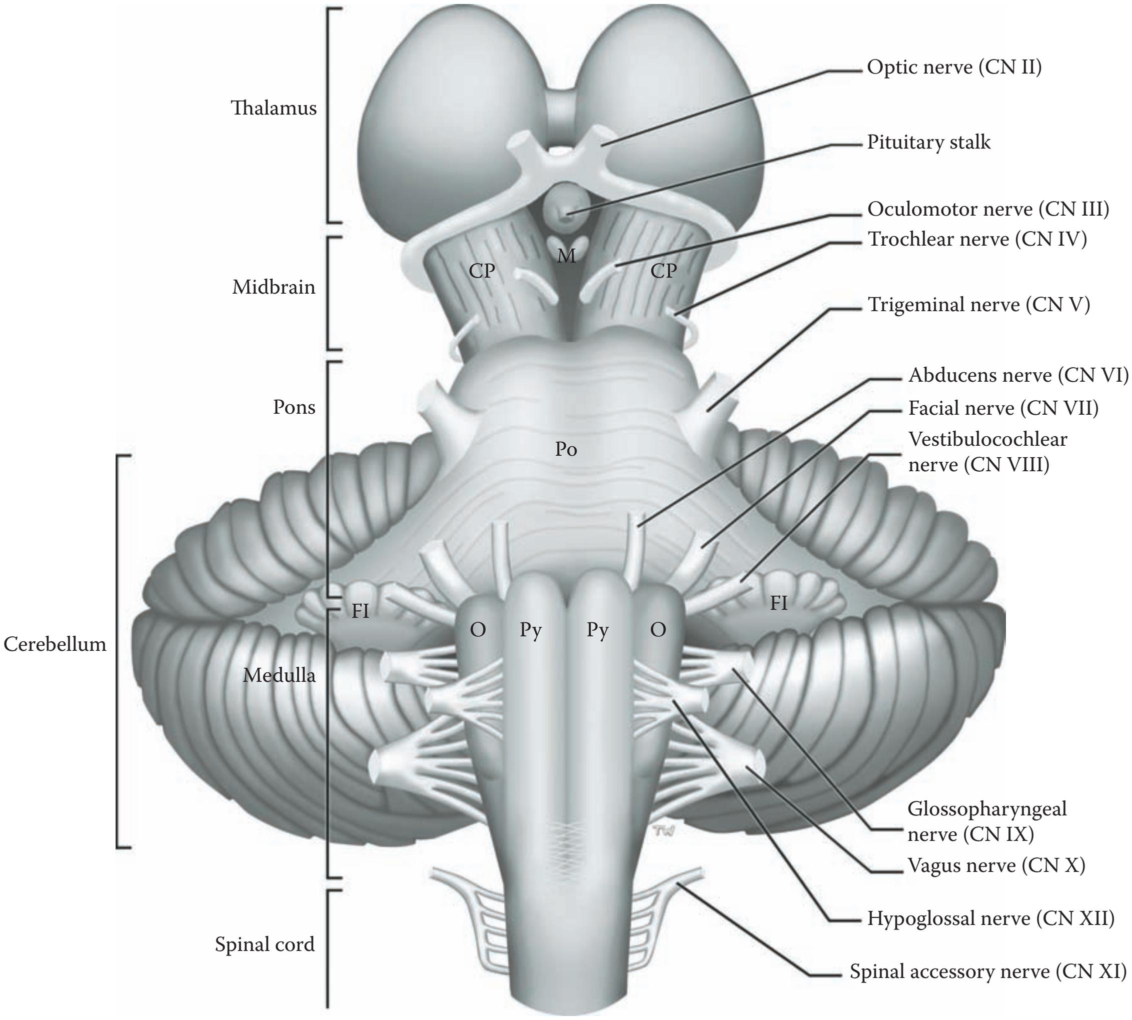
Medullary Level

- CN IX, the **glossopharyngeal**, and CN X, the **vagus**, are attached to the lateral margin of the medulla, behind the inferior olive.
- CN XI, the **spinal accessory nerve**, from the uppermost region of the spinal cord, enters the skull and then exits from the skull as if it were a cranial nerve; by convention it is included as a cranial nerve.
- CN XII, the **hypoglossal nerve**, emerges by a series of rootlets between the inferior olive and the pyramid.

Information concerning the function of the cranial nerves will be discussed with Figure 8A and Figure 8B. The nuclei of the brainstem, including the cranial nerve nuclei, will be studied in cross-sections of the brainstem in Section C of this atlas (see Figure 64–Figure 67).

ADDITIONAL DETAIL

Structures labeled, such as the flocculus of the cerebellum, the pituitary stalk, and the mammillary bodies (nuclei), will be considered at the appropriate time.



M = Mammillary bodies
CP = Cerebral peduncle
Po = Pons
Py = Pyramid
O = Olive
FI = Flocculus

FIGURE 6: **Brainstem 1** — Ventral View with Cranial Nerves

FIGURE 7
BRAINSTEM 2

BRAINSTEM AND DIENCEPHALON: VENTRAL (PHOTOGRAPHIC) VIEW

This specimen has been obtained by isolating the brainstem (and cerebellum) along with the diencephalon from the remainder of the brain. It is the same specimen as in the previous diagrammatic illustration (see Figure 6). The three parts of the brainstem can be differentiated on this ventral view (from above downward):

- The midbrain region has the two large "pillars" anteriorly called the **cerebral peduncles**. These contain fibers descending from the cerebral cortex to the spinal cord (cortico-spinal tract, see Figure 45), to the brainstem (cortico-bulbar tract, see Figure 46), and to the pontine nuclei (cortico-pontine fibers, see Figure 55).
- The pontine portion is distinguished by its bulge anteriorly, the **pons proper**, an area that is composed of the pontine nuclei; these relay to the cerebellum (see Figure 55).
- The medulla is distinguished by the **pyramids**, two distinct elevations on either side of the midline. The direct voluntary motor pathway from the cortex to the spinal cord, the cortico-spinal tract, actually forms these pyramids (see Figure 45). Behind each pyramid is the **olive**, a protrusion of the inferior olivary nucleus (discussed with Figure 55).

It should be noted that the cortico-spinal tract, from cortex to spinal cord, travels through the whole brainstem (see Figure 45), including the cerebral peduncles (see Figure 65A), within the pons proper (see Figure 66B), and then forms the pyramids in the medulla (see Figure 67C). This tract crosses the midline as the **pyramidal decussation**, demarcating the end of the medulla and the beginning of the spinal cord.

CRANIAL NERVE FUNCTIONS

Knowledge of the attachment of each cranial nerve (**CN**) to the brainstem is a marker of the location of the cranial nerve nucleus within the brainstem (see Figure 8A and Figure 8B), in almost all cases. In addition, it is necessary to know the function of each of the nerves.

Midbrain Level

- CN III, the oculomotor nerve, supplies several of the extraocular muscles, which move the eyeball. A separate part, called the Edinger-Westphal nucleus, provides parasympathetic fibers to the pupil.
- CN IV, the trochlear nerve, supplies one extraocular muscle.

Pontine Level

- CN V, the trigeminal nerve — its major nucleus subserves a massive sensory function for structures of the face and head. A smaller nucleus supplies motor fibers to jaw muscles.
- CN VI, the abducens nerve, supplies one extraocular muscle.
- CN VII, the facial nerve — of its several nuclei, one supplies the muscles of the face and another nucleus is parasympathetic to salivary glands; a third nucleus subserves the sense of taste.
- CN VIII, the vestibulocochlear nerve — for the special senses of balance and hearing.

Medullary Level

- CN IX, the glossopharyngeal, and CN X, the vagus nerve — of its several nuclei, one supplies the muscles of the pharynx and larynx; the vagus nerve is primarily a parasympathetic nerve to the organs of the thorax and abdomen.
- CN XI, the spinal accessory nerve, innervates some of the muscles of the neck.
- CN XII, the hypoglossal nerve, supplies motor fibers to the muscles of the tongue.

More details concerning the innervation of each of the cranial nerves is given with Figure 8A for the motor cranial nerve nuclei, and with Figure 8B for the sensory cranial nerve nuclei.

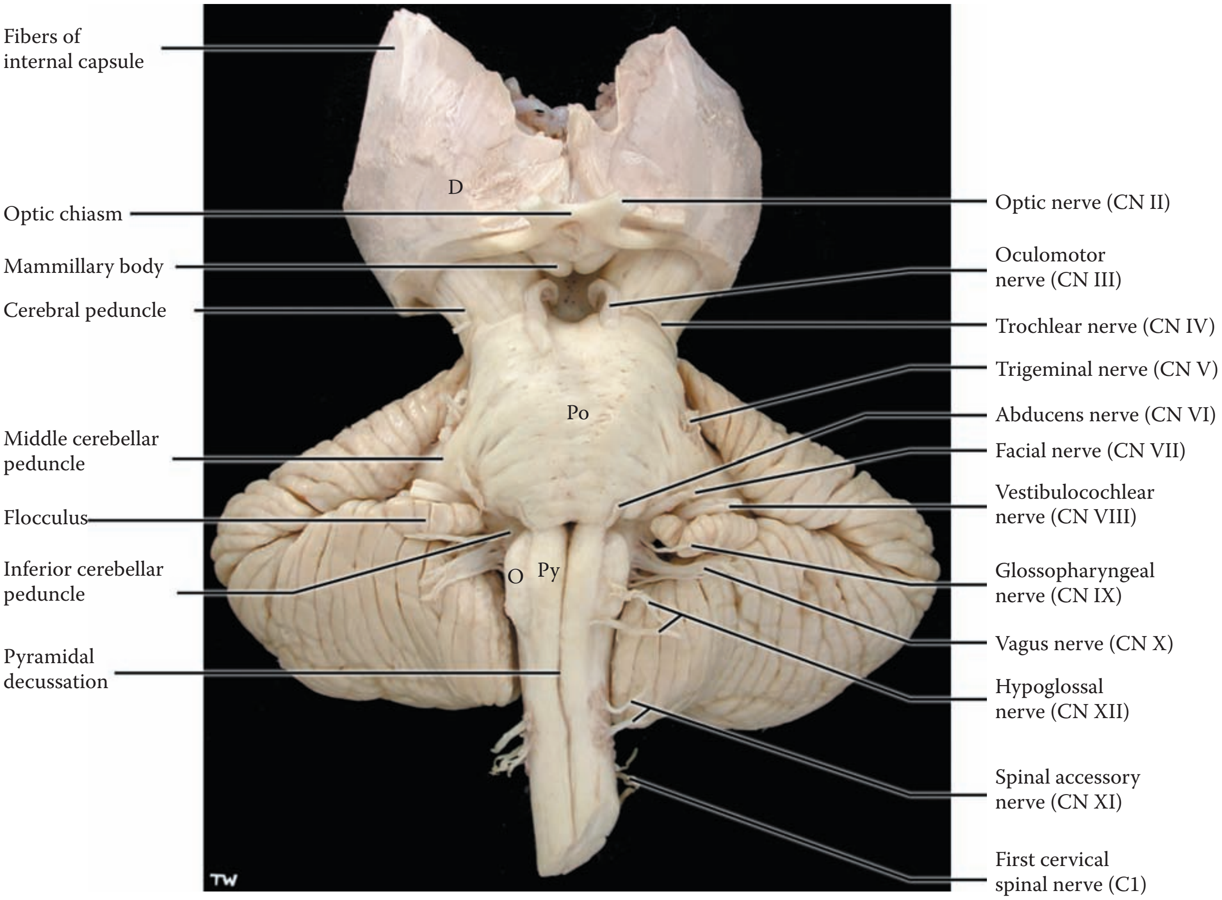
CLINICAL ASPECT

Knowing the attachment of the cranial nerves to each part of the brainstem is fundamental to diagnosing lesions of the brainstem. For almost all of the cranial nerves, this attachment coincides with the location of the nucleus/nuclei of the cranial nerve within the brainstem. Not only does this assist in understanding the neuroanatomy of this region, but this knowledge is critical in determining the localization of a lesion of the brainstem region (discussed further in Section C of this atlas).

A lesion of the brainstem is likely to interrupt either one or more sensory or motor pathways as they pass through the brainstem. Because of the close relationship with the cerebellum, there may be cerebellar signs as well.

ADDITIONAL DETAIL

Structures belonging to the cerebellum are explained in Figure 54–Figure 57.



D = Diencephalon
Po = Pons
Py = Pyramid
O = Inferior olive

FIGURE 7: **Brainstem 2** — Ventral View (photograph)

FIGURE 8A
BRAINSTEM 3

CRANIAL NERVE NUCLEI: MOTOR

The cranial nerves are peripheral nerves that supply the head region, except for the olfactory (CN I) and optic (CN II) nerves. Each cranial nerve is unique and may have one or more functional components, either sensory, motor, or both, and some also have an autonomic (parasympathetic) component.

There are two kinds of motor functions:

1. The **motor** supply to the muscles derived from **somites**, including CN III, IV, VI, and XII, and to the muscles derived from the branchial arches, called **branchiomotor**, including CN V, VII, IX, and X (no distinction will be made between these muscle types in this atlas).
2. The **parasympathetic** supply to smooth muscles and glands of the head, a part of CN III, VII, and IX, and the innervation of the viscera in the thorax and abdomen with CN X.

This diagram shows the location of the motor nuclei of the cranial nerves, superimposed upon the ventral view of the brainstem. These nuclei are also shown in Figure 40, in which the brainstem is presented from a dorsal perspective. The details of the location of the cranial nerve nuclei within the brainstem will be described in Section C of this atlas (Neurological Neuroanatomy) with Figure 64–Figure 67.

MIDBRAIN LEVEL

- CN III, the oculomotor nerve, has both motor and autonomic fibers. The motor nucleus, which supplies most of the muscles of the eye, is found at the upper midbrain level. The parasympathetic nucleus, known as the **Edinger-Westphal nucleus**, supplies the pupillary constrictor muscle and the muscle that controls the curvature of the lens; both are part of the accommodation reflex (discussed with Figure 41C).
- CN IV, the trochlear nerve, is a motor nerve to one eye muscle, the superior oblique muscle. The trochlear nucleus is found at the lower midbrain level (see Figure 65B).

PONTINE LEVEL

- CN V, the trigeminal nerve, has a motor component to the muscles of mastication. The nucleus is located at the midpontine level; the small motor nerve is attached to the brainstem at this level, along the middle cerebellar peduncle, with the much larger sensory root.
- CN VI, the abducens nerve, is a motor nerve that supplies one extraocular muscle, the lateral rectus muscle. The nucleus is located in the lower pontine region.
- CN VII, the facial nerve, is a mixed cranial nerve. The motor nucleus, which supplies the muscles of facial expression, is found at the lower pontine level. The parasympathetic fibers, to salivary and lacrimal glands, are part of CN VII (see Additional Details below).

MEDULLARY LEVEL

- CN IX, the glossopharyngeal nerve, and CN X, the vagus nerve, are also mixed cranial nerves. These supply the muscles of the pharynx (IX) and larynx (X), originating from the **nucleus ambiguus**. In addition, the parasympathetic component of CN X, coming from the **dorsal motor nucleus** of the vagus, supplies the organs of the thorax and abdomen. Both nuclei are found throughout the mid and lower portions of the medulla.
- Cranial nerve XI, the spinal accessory nerve, originates from a cell group in the upper 4–5 segments of the cervical spinal cord. This nerve supplies the large muscles of the neck (the sternomastoid and trapezius). As mentioned previously, CN XI enters the skull and exits again, as if it were a true cranial nerve.
- CN XII, the hypoglossal nerve, innervates all the muscles of the tongue. It has an extended nucleus in the medulla situated alongside the midline.

Note to the Learner: In this diagram, it appears that the nucleus ambiguus is the origin for CN XII. This is not the case but is a visualization problem. A clearer view can be found in Figure 48 and in the cross-sectional views (see Figure 67B and Figure 67C).

ADDITIONAL DETAIL

Two small parasympathetic nuclei are also shown but are rarely identified in brain sections — the superior and inferior salivatory nuclei. The superior nucleus supplies secretomotor fibers for cranial nerve VII (to the submandibular and sublingual salivary glands, as well as nasal and lacrimal glands). The inferior nucleus supplies the same fibers for cranial nerve IX (to the parotid salivary gland).

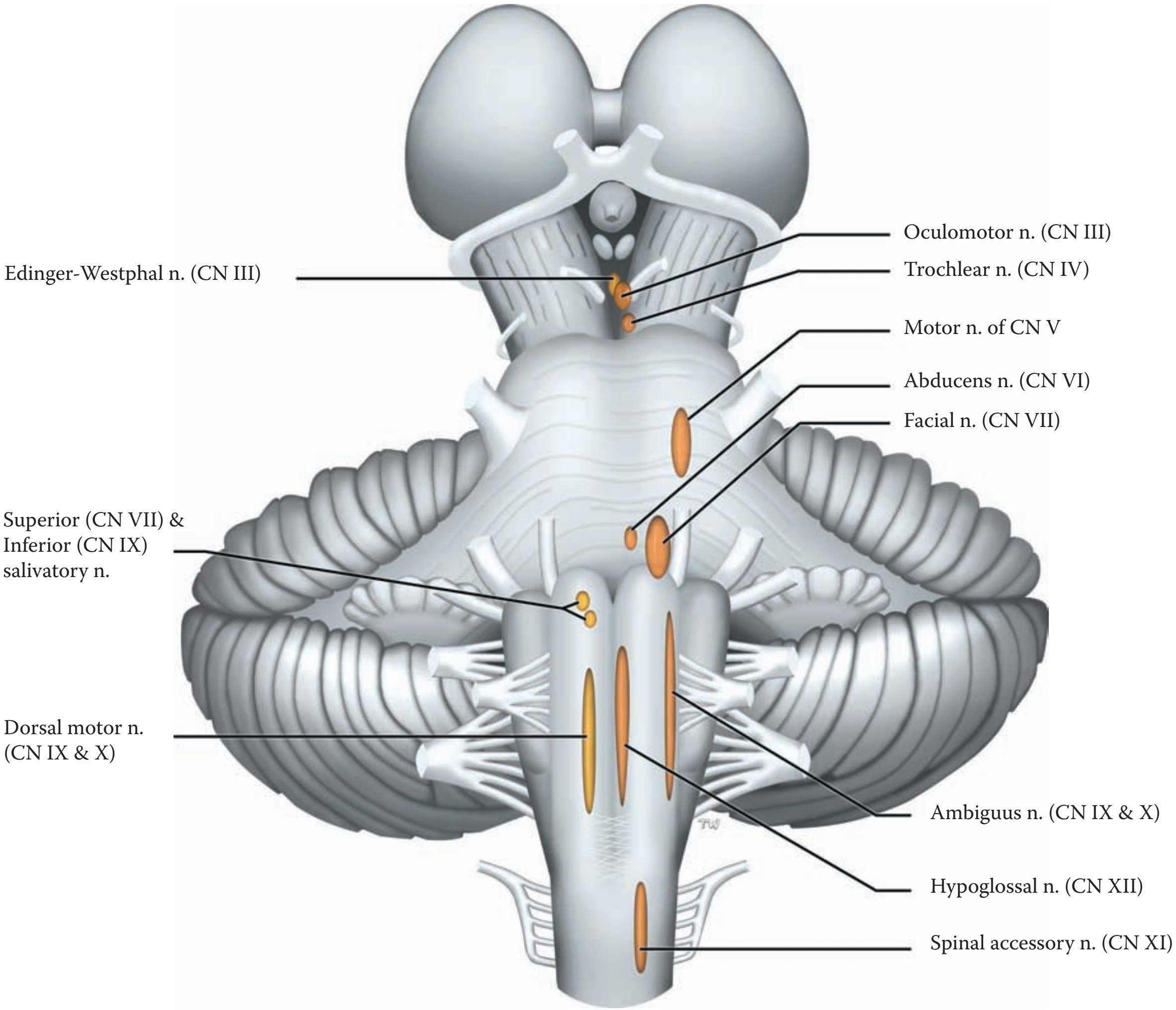


FIGURE 8A: Brainstem 3 — Cranial Nerves Nuclei — Motor

FIGURE 8B
BRAINSTEM 4

CRANIAL NERVE NUCLEI: SENSORY

The cranial nerve nuclei with sensory functions are discussed in this diagram. It should be noted that the olfactory nerve (CN I) and the optic nerve (CN II) are not attached to the brainstem and not considered at this stage. Sensory information from the region of the head and neck includes the following:

- **Somatic afferents**: general sensations, consisting of touch (both discriminative and crude touch), pain and temperature; these come from the skin and the mucous membranes, via branches of the trigeminal nerve, CN V.
- **Visceral afferents**: sensory input from the pharynx and other homeostatic receptors of the neck (e.g., for blood pressure), and from the organs of the thorax and abdomen; this afferent input is carried mainly by the vagus, CN X, but also by the glossopharyngeal nerve, CN IX.
- **Special senses**: auditory (hearing) and vestibular (balance) afferents with the vestibulochoclear nerve, CN VIII, as well as the special sense of taste with CN VII and IX.

This diagram shows the location of the sensory nuclei of the cranial nerves, superimposed upon the ventral view of the brainstem. It is important to note that the location of the sensory nucleus of the cranial nerves inside the brainstem does not correspond exactly to the level of attachment of the nerve to the brainstem as seen externally, particularly in the case of CN V. (These nuclei are also shown in Figure 40, in which the brainstem is presented from a dorsal perspective.) The details of the location of the cranial nerve nuclei within the brainstem will be described in Section C of this atlas (Neurological Neuroanatomy) with Figure 64–Figure 67.

CN V, Trigeminal Nerve

The major sensory nerve of the head region is the trigeminal nerve, CN V, through its three divisions peripherally (ophthalmic, maxillary, and mandibular). The sensory ganglion for this nerve, the trigeminal ganglion, is located inside the skull. The nerve supplies the skin of the scalp and face, the conjunctiva of the eye and the eyeball, the teeth, and the mucous membranes inside the head, including the surface of the tongue (but not taste — see below).

The sensory components of the trigeminal nerve are found at several levels of the brainstem. (See trigeminal pathways, Figure 35 and Figure 36):

- The **principal nucleus**, which is responsible for the discriminative aspects of touch, is located at the midpontine level, adjacent to the motor nucleus of CN V.
- A long column of cells that relays pain and temperature information, known as the **spinal nucleus of V** or the **descending trigeminal nucleus**, descends through the medulla and reaches the upper cervical levels of the spinal cord.
- Another group of cells extends into the midbrain region, the **mesencephalic** nucleus of V. These cells appear to be similar to neurons of the dorsal root ganglia and are thought to be the sensory proprioceptive neurons for the muscles of mastication.

CN VIII, Vestibulocochlear Nerve

Cochlear nuclei: The auditory fibers from the spiral ganglion in the cochlea are carried to the CNS in CN VIII, and form their first synapses in the cochlear nuclei, as it enters the brainstem at the uppermost level of the medulla (see Figure 6). The auditory pathway is presented in Section B (see Figure 37 and Figure 38).

Vestibular nuclei: Vestibular afferents enter the CNS as part of CN VIII. There are four nuclei: the medial and inferior, located in the medulla; the lateral, located at the ponto-medullary junction; and the small superior nucleus, located in the lower pontine region. The vestibular afferents terminate in these nuclei. The vestibular nuclei will be further discussed in Section B with the motor systems (see Figure 51A and Figure 51B).

Visceral Afferents and Taste: Solitary Nucleus

The special sense of taste from the surface of the tongue is carried in CN VII and CN IX, and these terminate in the solitary nucleus in the medulla (see Figure 67A).

Clinical Aspect

Trigeminal neuralgia is discussed with Figure 10.

Additional Detail

The visceral afferents with CN IX and X from the pharynx, larynx, and internal organs are also received in the solitary nucleus (see Figure 67B and Figure 67C).

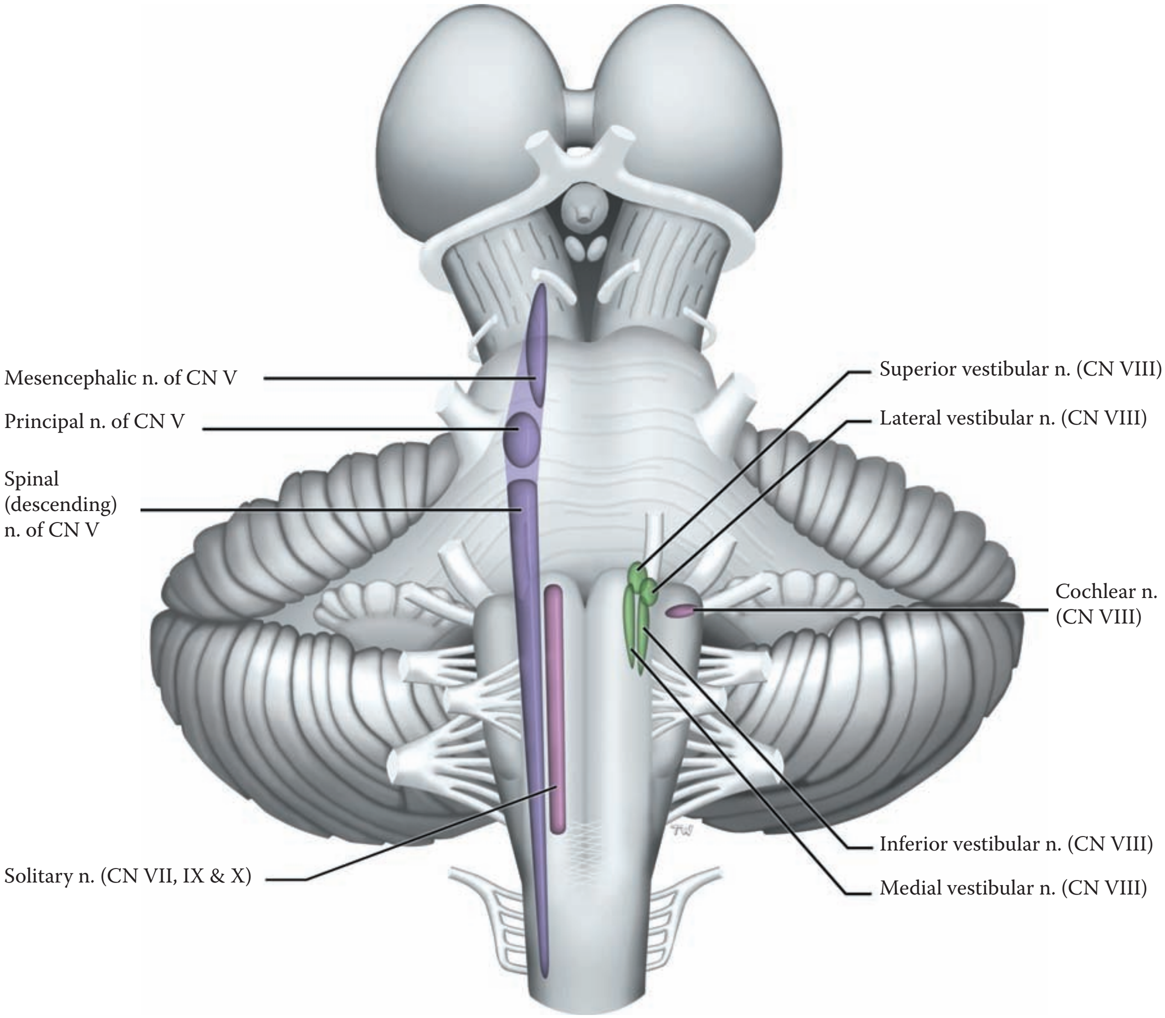


FIGURE 8B: Brainstem 4 — Cranial Nerves Nuclei — Sensory

FIGURE 9A
BRAINSTEM 5

BRAINSTEM AND CEREBELLUM: DORSAL (PHOTOGRAPHIC) VIEW

This specimen of the brainstem and diencephalon, with the cerebellum attached, is being viewed from the dorsal or posterior perspective. The third ventricle, the ventricle of the diencephalon, separates the thalamus of one side from that of the other (see Figure OA and Figure 20A; also Figure 17 and Figure 21, where the brain is separated down the midline in the midsagittal plane). The diencephalon is to be discussed with Figure 11.

Additional structures of the brainstem are seen from this perspective:

- The dorsal part of the midbrain is seen to have four elevations, named the superior and inferior colliculi (see also Figure 10). The upper ones are the **superior colliculi**, and they are functionally part of the visual system, a center for visual reflexes (see Figure 41C and Figure 51B). The lower ones are the **inferior colliculi**, and these are relay nuclei in the auditory pathway (see Figure 38). These colliculi form the "**tectum**," a term often used; a less frequently used term for these colliculi is the quadrigeminal plate. The **pineal**, a glandular structure, hangs down from the back of the diencephalon and sits between the colliculi.
- Although not quite in view in this illustration, the trochlear nerves (CN IV) emerge posteriorly at the lower level of the midbrain, below the inferior colliculi (see Figure 10).

This view also shows the back edge of the cerebral peduncle, the most anterior structure of the midbrain (see Figure 6 and Figure 7).

The posterior aspect of the pons and the medulla are hidden by the cerebellum — some of these structures will be seen in the next illustration (a photographic view, Figure 9B), and some are seen in a diagram with the cerebellum removed (Figure 10).

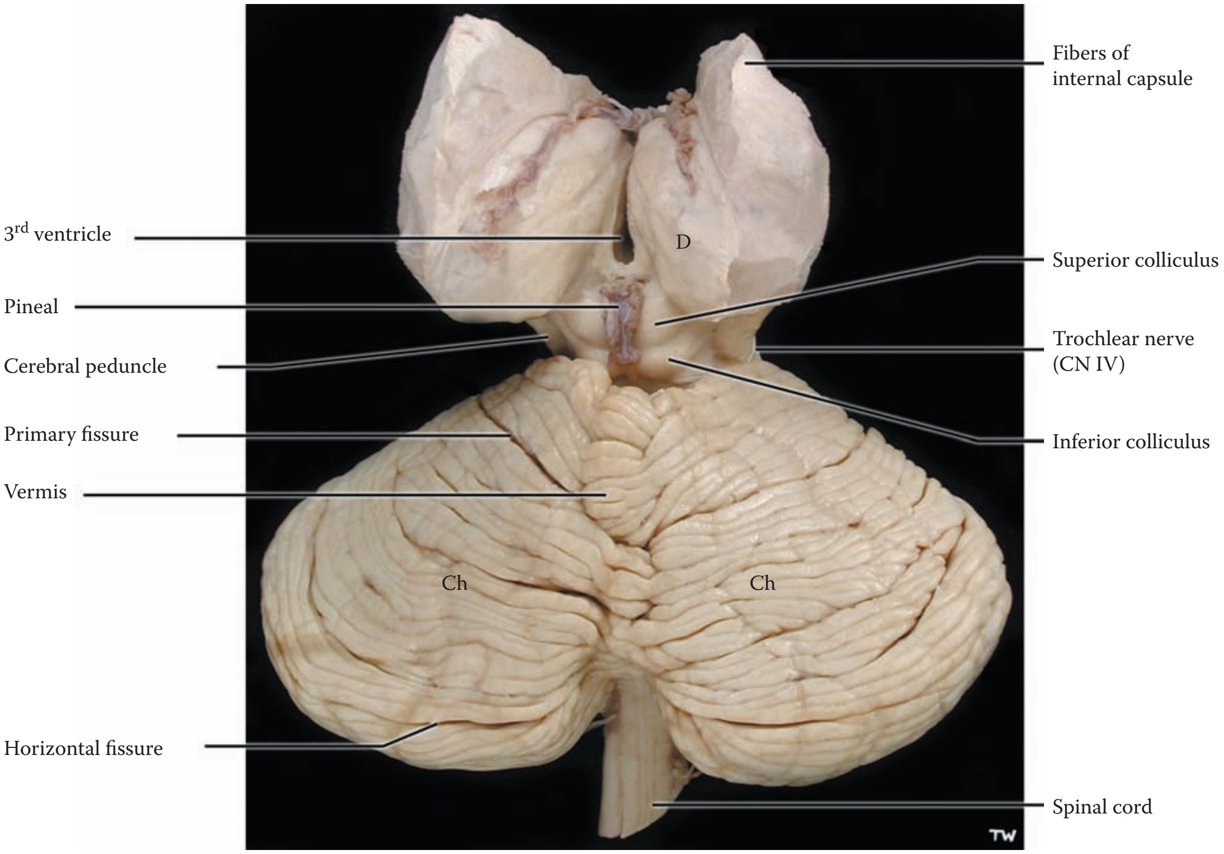
The Cerebellum

The cerebellum, sometimes called the "little brain," is easily recognizable by its surface, which is composed of narrow ridges of cortex, called **folia** (singular **folium**). The cerebellum is located beneath a thick sheath of the meninges, the tentorium cerebelli, inferior to the occipital lobe of the hemispheres (see Figure 17 and Figure 30), in the posterior cranial fossa of the skull.

The cerebellum is involved with motor control and is part of the motor system, influencing posture, gait, and voluntary movements (discussed in more detail in Section B). Its function is to facilitate the performance of movements by coordinating the action of the various participating muscle groups. This is often spoken of simply as "smoothing out" motor acts. Although it is rather difficult to explain in words what the cerebellum does in motor control, damage to the cerebellum leads to quite dramatic alterations in ordinary movements (discussed with Figure 57). Lesions of the cerebellum result in the decomposition of the activity, or fractionation of movement, so that the action is no longer smooth and coordinated. Certain cerebellar lesions also produce a tremor, which is seen when performing voluntary acts, better known as an intention tremor.

Anatomically, the cerebellum can be described by looking at its appearance in a number of ways. The human cerebellum *in situ* has an upper or superior surface, as seen in this photograph, and a lower or inferior surface (shown in the next illustration). The central portion is known as the **vermis**. The lateral portions are called the **cerebellar hemispheres**.

Sulci separate the folia, and some of the deeper sulci are termed fissures. The **primary fissure** is located on the superior surface of the cerebellum, which is the view seen in this photograph. The **horizontal fissure** is located at the margin between the superior and inferior surfaces. Using these sulci and fissures, the cerebellar cortex has traditionally been divided into a number of different lobes, but many (most) of these do not have a distinctive functional or clinical importance, so only a few will be mentioned when the cerebellum is discussed (see Figure 54–Figure 57).



D = Diencephalon
Ch = Cerebellar hemisphere

FIGURE 9A: **Brainstem 5** — Dorsal View with Cerebellum (photograph)

FIGURE 9B
BRAINSTEM 6

BRAINSTEM AND CEREBELLUM: DORSAL INFERIOR (PHOTOGRAPHIC) VIEW

This is a photograph of the same specimen as Figure 9A, but the specimen is tilted to reveal the inferior aspect of the cerebellum and the posterior aspect of the medulla. The posterior aspect of the pons is still covered by the cerebellum (see Figure 10). The posterior aspect of the midbrain can no longer be seen. The upper end of the thalamus is still in view.

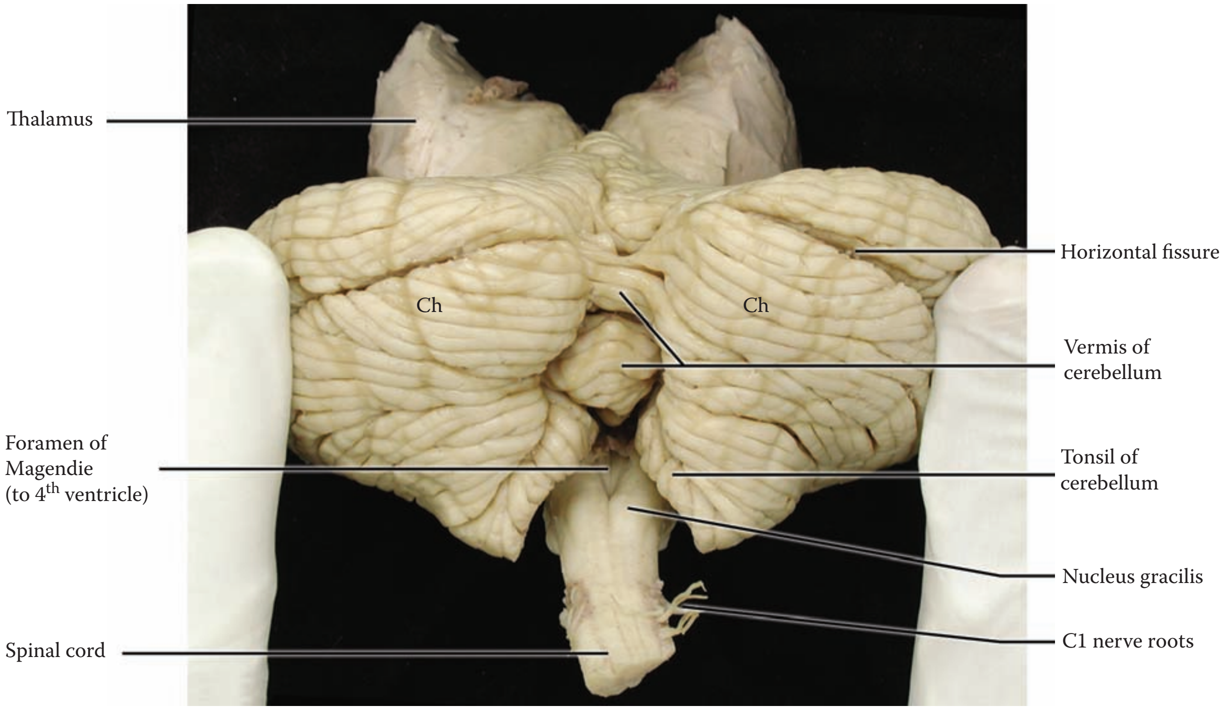
The horizontal fissure of the cerebellum is now clearly seen; it is used as an approximate divider between the superior and inferior surfaces of the cerebellum (see Figure 54). The vermis of the cerebellum is clearly seen between the hemispheres. Just below the vermis is an opening into a space — the space is the fourth ventricle (which will be described with Figure 20A, Figure 20B, and Figure 21) The opening is between the ventricle and the subarachnoid space outside the brain (discussed with Figure 21); the name of the opening is the **Foramen of Magendie**.

The part of the brainstem immediately below the foramen is the medulla, its posterior or dorsal aspect. The most significant structure seen here is a small elevation, representing an important sensory relay nucleus, the **nucleus gracilis**. The pathway for discriminative touch sensation, called the gracilis tract (or fasciculus) continues up the posterior aspect of the spinal cord and synapses in the nucleus of the same name; the pathway then continues up to the cerebral cortex. (The details of this pathway will be discussed with Figure 33 and Figure 40). Beside it is another nucleus for a similar pathway with the same function, the nucleus cuneatus (see Figure 10). These nuclei will be discussed with the brainstem cross-sections in Section C (see Figure 67C). The medulla ends and the spinal cord begins where the C1 nerve roots emerge.

The cerebellar lobules adjacent to the medulla are known as the **tonsils** of the cerebellum (see ventral view of the cerebellum, Figure 7). The tonsils are found just inside the foramen magnum of the skull.

CLINICAL ASPECT

Should there be an increase in the mass of tissue occupying the posterior cranial fossa (e.g., a tumor, hemorrhage), the cerebellum would be pushed downward. This would force the cerebellar tonsils into the foramen magnum, thereby compressing the medulla. The compression, if severe, may lead to a compromising of function of the vital centers located in the medulla (discussed with Figure 6). The complete syndrome is known as **tonsillar herniation**, or coning. This is a life-threatening situation that may cause cardiac or respiratory arrest.



Ch = Cerebellar hemisphere

FIGURE 9B: **Brainstem 6** — Dorsal Inferior View with Cerebellum (photograph)

FIGURE 10
BRAINSTEM 7

BRAINSTEM: DORSAL VIEW — CEREBELLUM REMOVED

This diagram shows the brainstem from the dorsal perspective, with the cerebellum removed. A similar view of the brainstem is used for some of the later diagrams (see Figure 40 and Figure 48). This dorsal perspective is useful for presenting the combined visualization of many of the cranial nerve nuclei and the various pathways of the brainstem.

Midbrain Level

The posterior aspect of the midbrain has the superior and inferior colliculi, as previously seen, as well as the emerging fibers of CN IV, the trochlear nerve. The posterior aspect of the cerebral peduncle is clearly seen.

Pontine Level

Now that the cerebellum has been removed, the dorsal aspect of the pons is seen. The space separating the pons from the cerebellum is the fourth ventricle — the ventricle has been "unroofed." (The ventricles of the brain will be discussed with Figure 20A, Figure 20B, and Figure 21.) The roof of the upper portion of the fourth ventricle is a sheet of nervous tissue and bears the name **superior medullary velum**; more relevant, it contains an important connection of the cerebellum, the superior cerebellar peduncles (discussed with Figure 57). The lower half of the roof of the fourth ventricle has choroid plexus (see Figure 21).

As seen from this perspective, the fourth ventricle has a "floor"; noteworthy are two large bumps, called the facial colliculus, where the facial nerve, CN VII, makes an internal loop (to be discussed with Figure 48 and also with the pons in Section C of this atlas, see Figure 66C).

As the cerebellum has been removed, the cut surfaces of the middle and inferior cerebellar peduncles are seen. The **cerebellar peduncles** are the connections between the brainstem and the cerebellum, and there are three pairs of them. The **inferior** cerebellar peduncle connects the medulla and the cerebellum, and the prominent **middle** cerebellar peduncle brings fibers from the pons to the cerebellum. Both can be seen in the ventral view of the brainstem (see Figure 7). Details of the information carried in these pathways will be outlined when the functional aspects of the cerebellum are studied with the motor systems (see Figure 55). The **superior** cerebellar peduncles convey fibers from the cerebellum to the thalamus, passing through the roof of the fourth ventricle and the midbrain (see Figure 57). This peduncle can only be visualized from this perspective.

CN V emerges through the middle cerebellar peduncle (see also Figure 6 and Figure 7).

Medullary Level

The lower part of the fourth ventricle separates the medulla from the cerebellum (see Figure 21). The special structures below the fourth ventricle are two large protuberances on either side of the midline — the **gracilis and cuneatus nuclei**, relay nuclei which belong to the ascending somatosensory pathway (discussed with Figure 9B, Figure 33, and Figure 40).

The cranial nerves seen from this view include the entering nerve CN VIII. More anteriorly, from this oblique view, are the fibers of the glossopharyngeal (CN IX) and vagus (CN X) nerves, as these emerge from the lateral aspect of the medulla, behind the inferior olive.

A representative cross-section of the spinal cord is also shown, from this dorsal perspective.

Additional Detail

The acoustic stria (not labeled) shown in the floor of the fourth ventricle are fibers of CN VIII, the auditory portion, which take an alternative route to relay in the lower pons, before ascending to the inferior colliculi of the midbrain.

Two additional structures are shown in the midbrain — the red nucleus (described with Figure 47 and Figure 65A), and the brachium of the inferior colliculus, a connecting pathway between the inferior colliculus and the medial geniculate body, all part of the auditory system (fully described with Figure 37 and Figure 38).

The medial and lateral geniculate nuclei belong with the thalamus (see Figure 11 and Figure 12). The lateral geniculate body (nucleus) is part of the visual system (see Figure 41A and Figure 41C).

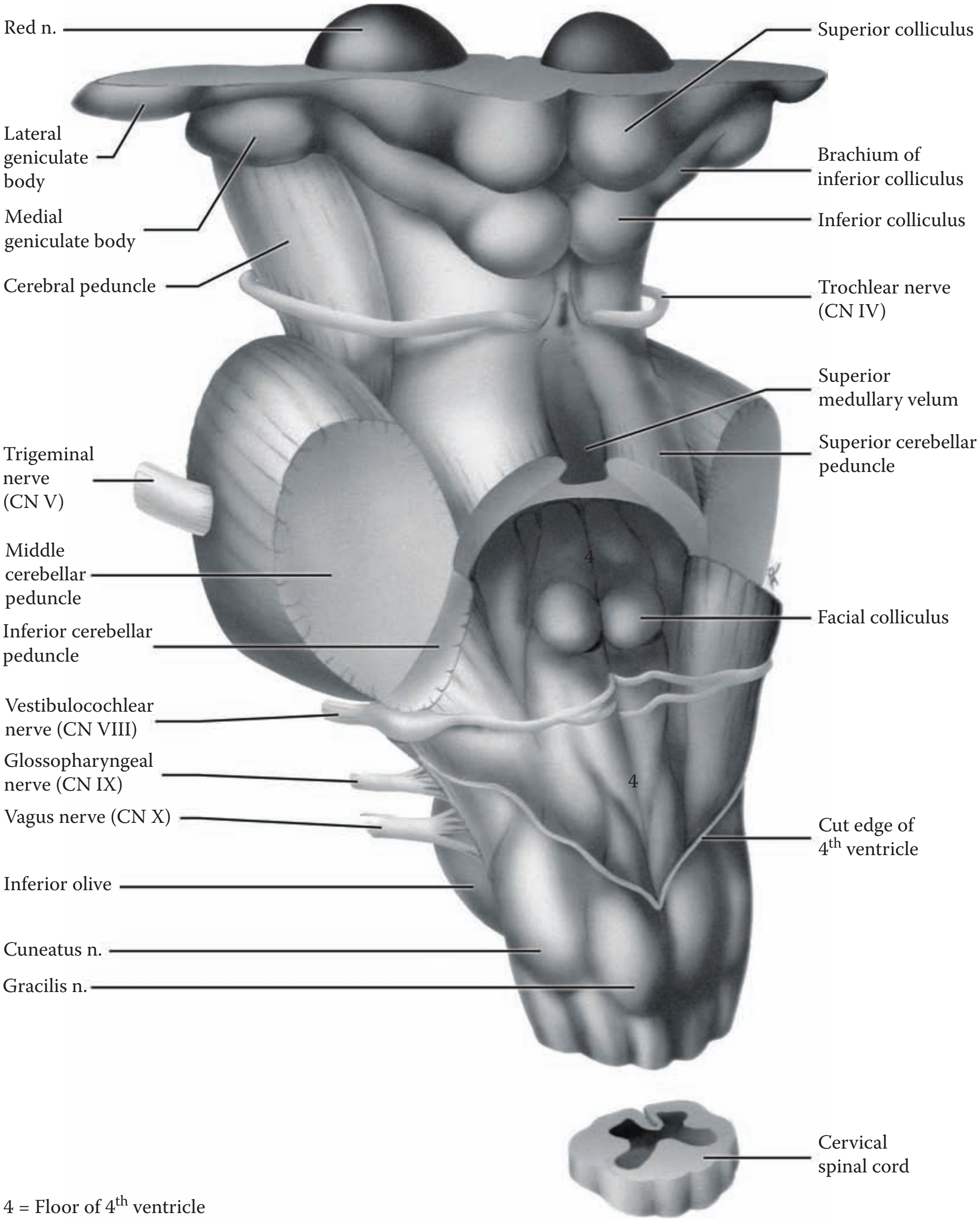


FIGURE 10: **Brainstem 7** — Dorsal View — Cerebellum Removed

FIGURE 11
THE DIENCEPHALON: THALAMUS 1

THALAMUS: ORIENTATION

The diencephalon, which translates as "between brain," is the next region of the brain to consider. The diencephalon, including both thalamus and hypothalamus and some other subparts, is situated between the brainstem and the cerebral hemispheres, deep within the brain.

As shown diagrammatically (see Figure 6) and photographically (see Figure 7 and Figure 9A), the diencephalon sits "atop" the brainstem. The enormous growth of the cerebral hemispheres in the human brain has virtually hidden or "buried" the diencephalon (somewhat like a weeping willow tree) so that it can no longer be visualized from the outside except from the inferior view (see pituitary stalk and mammillary bodies in Figure 15A and Figure 15B, which are part of the hypothalamus).

In this section of the atlas, we will consider the **thalamus**, which makes up the bulk of the diencephalon. It is important to note that there are two thalami, one for each hemisphere of the brain, and these are often connected across the midline by nervous tissue, the massa intermedia (as seen in Figure 6). As has been noted, the third ventricle is situated between the two thalami (see Figure 9 and Figure 20B).

The thalamus is usually described as the gateway to the cerebral cortex (see Figure 63). This description leaves out an important principle of thalamic function, namely that most thalamic nuclei that project to the cerebral cortex also receive input from that area — these are called reciprocal connections. This principle does not apply, however, to all of the nuclei (see below).

The major function of the thalamic nuclei is to process information before sending it on to the select area of the cerebral cortex. This is particularly so for all the sensory systems, except the olfactory sense. It is possible that crude forms of sensation, including pain, are "appreciated" in the thalamus, but localization of the sensation to a particular spot on the skin surface requires the involvement of the cortex. Likewise, two subsystems of the motor systems, the basal ganglia and the cerebellum, relay in the thalamus before sending their information to the motor areas of the cortex. In addition, the limbic system has circuits that involve the thalamus.

Other thalamic nuclei are related to areas of the cerebral cortex, which are called association areas, vast areas of the cortex that are not specifically related either to sensory or motor functions. Parts of the thalamus play an important role in the maintenance and regulation of the state of consciousness, and also possibly attention, as part of the ascending reticular activating system (ARAS, see Figure 42A).

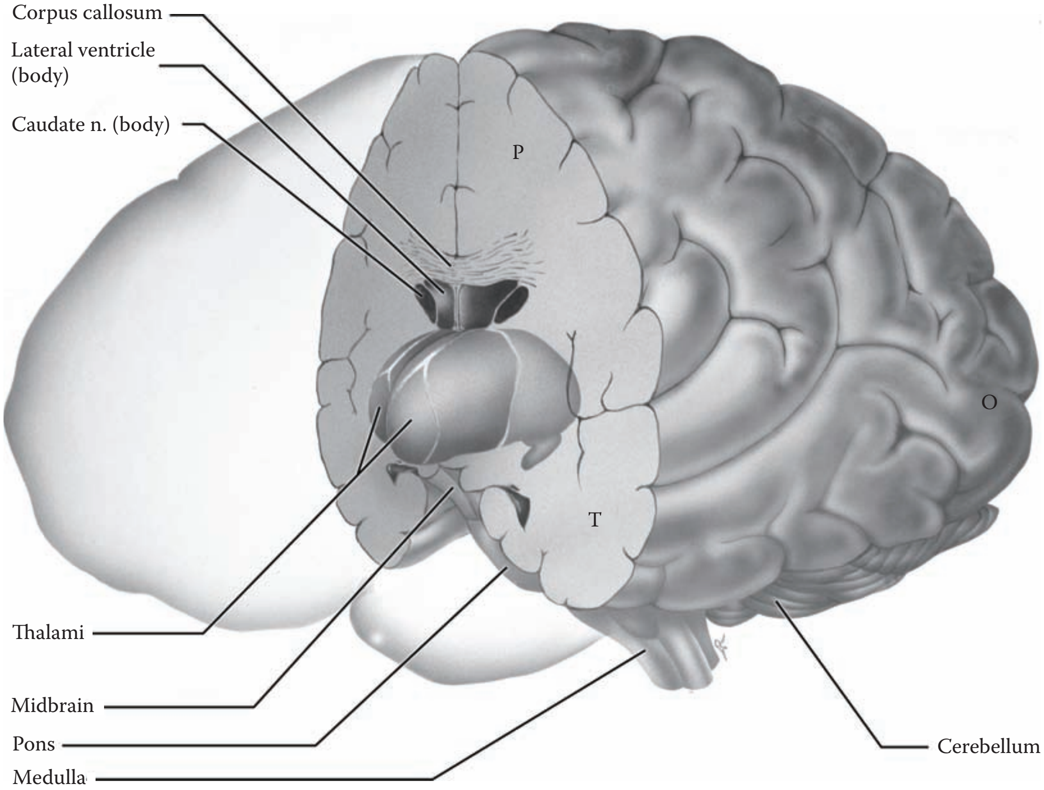
Other parts of the Diencephalon:

- The **hypothalamus**, one in each hemisphere, is composed of a number of nuclei that regulate homeostatic functions of the body, including water balance. It will be discussed with the limbic system in Section D of this atlas (see Figure 78A).
- The **pineal** (visible in Figure 9A) is sometimes considered a part of the diencephalon. This gland is thought to be involved with the regulation of our circadian rhythm. Many people now take melatonin, which is produced by the pineal, to regulate their sleep cycle and to overcome jetlag.
- The **subthalamic nucleus** is described with the basal ganglia (see Figure 24).

ADDITIONAL DETAIL

As shown in the diagram, the diencephalon is situated within the brain below the level of the body of the lateral ventricles (see also Figure 17, Figure 18, and Figure 19A). In fact, the thalamus forms the "floor" of this part of the ventricle (see Figure 29). In a horizontal section of the hemispheres, the two thalami are located at the same level as the lentiform nucleus of the basal ganglia (see Figure OA and Figure OL; also Figure 26 and Figure 27). This important point will be discussed with the internal capsule (see Figure 26 and Figure 27).

Note to the Learner: The location of the thalamus within the substance of the brain is important for the understanding of the anatomical organization of the brain. This topographic information will make more sense after studying the hemispheres (see Figure 13–Figure 19) and basal ganglia (see Figure 22–Figure 30). The suggestion is made to review this material at that time.



P = Parietal lobe
T = Temporal lobe
O = Occipital lobe

FIGURE 11: **Thalamus 1** — Orientation

FIGURE 12
THALAMUS 2

THALAMUS: NUCLEI

In order to lay the groundwork for understanding the functional organization of the sensory and motor pathways (in Section B), it is necessary to have a familiarity with the nuclei of the thalamus, their organization, and names.

There are two ways of dividing up the nuclei of the thalamus, namely, topographically and functionally.

A. Topographically, the thalamus is subdivided by bands of white matter into a number of component parts. The main white matter band that runs within the thalamus is called the **internal medullary lamina** and it is shaped like the letter Y (see also the previous illustration). It divides the thalamus into a lateral mass, a medial mass, and an anterior group of nuclei.

B. Functionally, the thalamus has three different types of nuclei:
   - **Specific relay nuclei**. These nuclei relay sensory and motor information to specific sensory and motor areas of the cerebral cortex. Included with these are the medial and lateral geniculate bodies, relay nuclei for the auditory and visual systems. In addition, motor regulatory information from the basal ganglia and cerebellum is also relayed in the thalamus as part of this set of nuclei. These nuclei are located in the lateral nuclear mass.
   - **Association nuclei**. These are connected to broad areas of the cerebral cortex known as the association areas. One of the most important nuclei of this group is the dorsomedial nucleus, located in the medial mass of the thalamus.
   - **Nonspecific nuclei**. These scattered nuclei have other or multiple connections. Some of these nuclei are located within the internal medullary lamina and are often referred to as the **intralaminar** nuclei. This functional group of nuclei does not have the strong reciprocal connections with the cortex like the other nuclei. Some of these nuclei form part of the ascending reticular activating system, which is involved in the regulation of our state of consciousness and arousal (discussed with Figure 42A). The reticular nucleus, which lies on the outside of the thalamus is also part of this functional system.

The following detailed classification system is given at this point but will only be understood as the functional systems of the CNS are described (see Note to the Learner below).

Specific Relay Nuclei (and Function)

Their cortical connections are given at this point for information (<---> symbolizes a connection in both directions).

VA — ventral anterior (motor) <---> premotor area and supplementary motor area
VL — ventral lateral (motor) <---> precentral gyrus and premotor area
VPL — ventral posterolateral (somatosensory) <---> postcentral gyrus
VPM — ventral posteromedial (trigeminal) <---> postcentral gyrus
MGB — medial geniculate (body) nucleus (auditory) <---> temporal cortex
LGB — lateral geniculate (body) nucleus (vision) <---> occipital cortex

Association Nuclei (and Association Cortex)

These nuclei are reciprocally connected to association areas of the cerebral cortex.

DM — dorsomedial nucleus <---> prefrontal cortex
AN — anterior nucleus <---> limbic lobe
Pul — pulvinar <---> visual cortex
LP — lateral posterior <---> parietal lobe
LD — lateral dorsal <---> parietal lobe

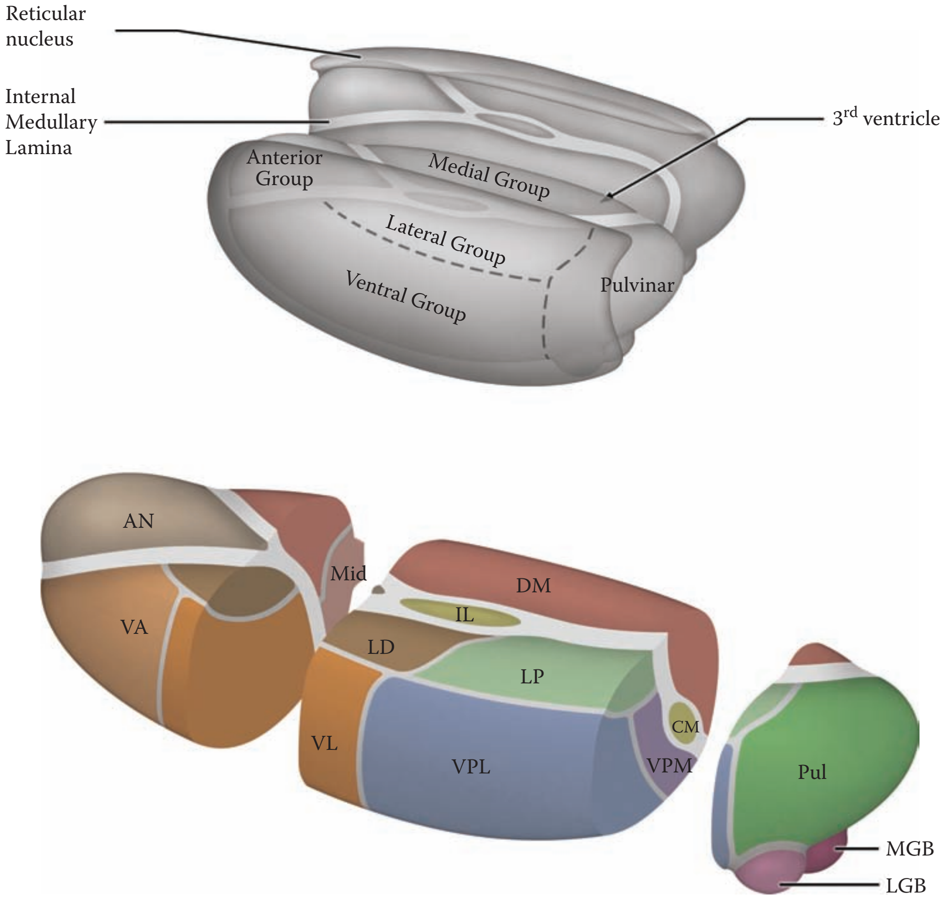
Nonspecific Nuclei (to Widespread Areas of the Cerebral Cortex)

IL — intralaminar
CM — centromedian
Ret — reticular

ADDITIONAL DETAIL

For schematic purposes, this presentation of the thalamic nuclei, which is similar to that shown in a number of textbooks, is quite usable. Histological sections through the thalamus are challenging and beyond the scope of an introductory course.

Note to the Learner: The thalamus is being introduced at this point because it is involved throughout the study of the brain. The learner should learn the names and understand the general organization of the various nuclei at this point. It is advised to consult this diagram, as the cerebral cortex is described in the following illustrations. Each of the specific relay nuclei involved in one of the pathways will be introduced again with the functional systems (in Section B) and, at that point, the student should return to this illustration. A summary diagram showing the thalamus and the cortex with the detailed connections will be presented in Section C (see Figure 63). Various nuclei are also involved with the limbic system (see Section D).



AN = Anterior nuclei

LD = Lateral dorsal
LP = Lateral posterior
Pul = Pulvinar

DM = Dorsomedial
Mid = Midline

LGB = Lateral geniculate body
MGB = Medial geniculate body

VA = Ventral anterior
VL = Ventral lateral
VPL = Ventral posterolateral
VPM = Ventral posteromedial

IL = Intralaminar
CM = Centromedian

FIGURE 12: **Thalamus 2** — Nuclei

FIGURE 13
CEREBRAL HEMISPHERES 1

CEREBRAL CORTEX: DORSAL (PHOTOGRAPHIC) VIEW

When people talk about “the brain,” they are generally referring to the cerebral hemispheres, also called the cerebrum. The brain of higher apes and humans is dominated by the cerebral hemispheres. The outer layer, the **cerebral cortex**, with its billions of neurons and its vast interconnections, is responsible for sensory perception, movement, language, thinking, memory, consciousness, and certain aspects of emotion. In short, we need the intact cerebral hemispheres to adapt to our ever-changing external environment.

The neurons of the cerebral cortex are organized in layers and generally there are six layers; this highly evolved cortex is called **neocortex**. Neurons in each of the layers differ in their functional contribution to cortical “processing.” In formalin-fixed material, the cortex (which includes neurons, dendrites, and synapses) takes on a grayish appearance and is often referred to as the gray matter (see Figure 27 and Figure 29).

The cerebral hemispheres occupy the interior of the skull, the cranial cavity. The brain in this photograph is seen from above and from the side — one hemisphere has the meninges removed and the other is still covered with dura, the thick outer meningeal layer. The dural layer has additional folds within the skull that subdivide the cranial cavity and likely serve to keep the brain in place. The two major dural sheaths are the falx cerebri (between the hemispheres in the sagittal plane, see Figure 16) and the tentorium cerebelli (in the transverse plane between the occipital lobe and the cerebellum, see Figure 17 and Figure 30). Inside the dural layer are large channels, called venous sinuses, which convey blood from the surface of the hemispheres and return the blood to the heart via the internal jugular vein. The **superior sagittal sinus**, which is located at the upper edge of the interhemispheric fissure, is one of the major venous sinuses (see Figure 21). The **subarachnoid space**, between the arachnoid and pia, is filled with CSF (see Figure 21). Therefore, the brain is actually “floating” inside the skull.

The surface of the hemispheres in humans and some other species is thrown into irregular folds. These ridges are called **gyri** (singular **gyrus**), and the intervening crevices are called **sulci** (singular **sulcus**). This arrangement allows for a greater surface area to be accommodated within the same space (i.e., inside the skull). A very deep sulcus is called a **fissure**; two of these are indicated, the central fissure and the parieto -occipital fissure. These tend to be constant in all human brains.

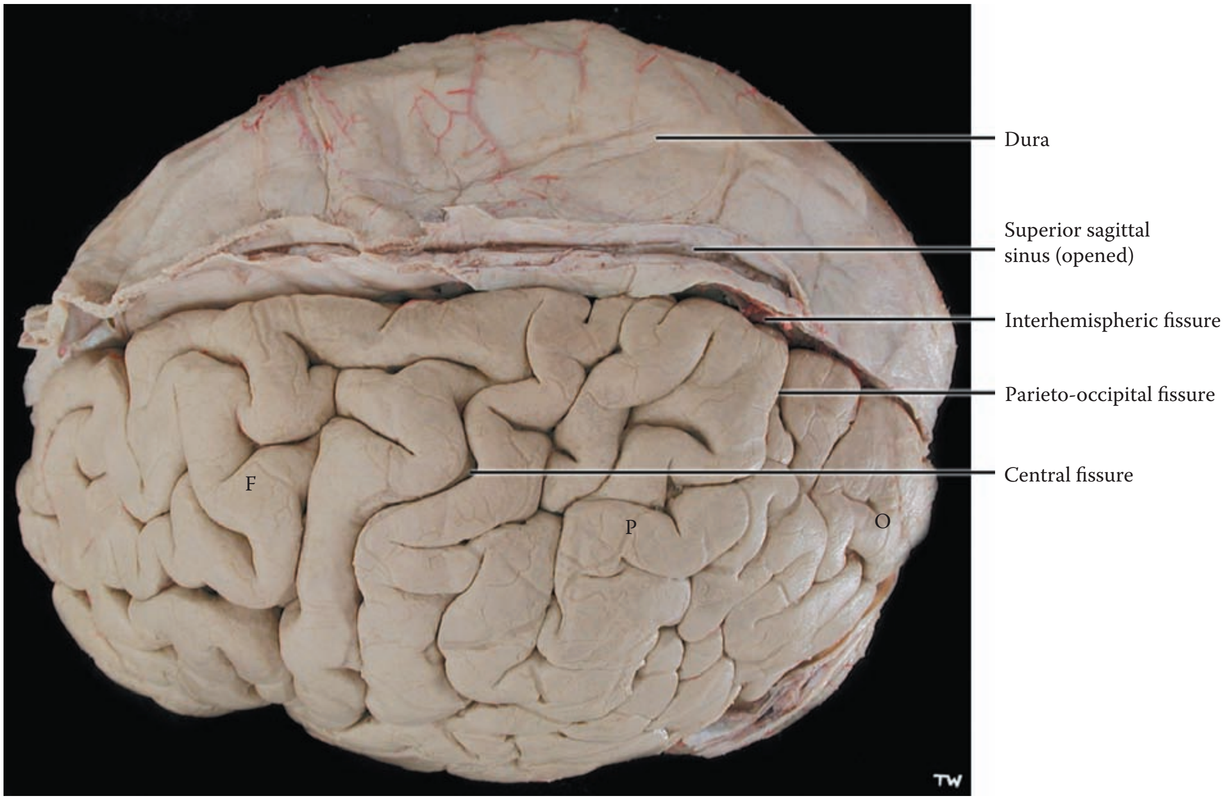
Different parts of the cortex have different functions. Some parts have a predominantly motor function, whereas other parts are receiving areas for one of the major sensory systems. Most of the cerebral cortex in humans has an “**association** function,” a term that can perhaps be explained functionally as interrelating the various activities in the different parts of the brain.

The basic division of each of the hemispheres is into **four lobes**: frontal, parietal, temporal, and occipital. Two prominent fissures allow this subdivision to be made — the central fissure and the lateral fissure. The **central fissure** divides the area anteriorly, the frontal lobe, from the area posteriorly, the parietal lobe. The parietal lobe extends posteriorly to the parieto-occipital fissure (see Figure 17). The brain area behind that fissure is the occipital lobe. The temporal lobe and the lateral fissure cannot be seen on this view of the brain (see next illustration).

The surface of the cerebral hemispheres can be visualized from a number of other directions — from the side (the dorsolateral view, see Figure 14), and from below (inferior view, see Figure 15A and Figure 15B); in addition, after dividing the two hemispheres along the interhemispheric fissure (in the midline), the hemispheres are seen to have a medial surface as well (see Figure 17).

CLINICAL ASPECT

Intracranial bleeds can occur between the skull and the dura (called epidural, usually arterial), between the dura and arachnoid (called subdural, usually venous), into the CSF space (called subarachnoid, usually arterial), or into the substance of the brain (brain hemorrhage). Since the brain is enclosed is a rigid box, the skull, any abnormal bleeding inside the head may lead to an increase in intracranial pressure (discussed with the Introduction to Section C).



F = Frontal lobe
P = Parietal lobe
O = Occipital lobe

FIGURE 13: **Cerebral Hemispheres 1** — Dorsal View (photograph)

FIGURE 14A
CEREBRAL HEMISPHERES 2

CEREBRAL CORTEX: DORSOLATERAL (PHOTOGRAPHIC) VIEW

This is a photographic image of the same brain as shown in the previous illustration, tilted slightly, to show the dorsolateral aspect of the hemispheres. The edge of the other hemisphere (with meninges) is still in view. It is now possible to identify the sulci and fissures with more certainty. The **central fissure** (often called the fissure of Rolando) is seen more completely, dividing the frontal lobe anteriorly from the parietal lobe posteriorly. The deep **lateral fissure** is clearly visible (see below).

Some cortical areas are functionally directly connected with either a sensory or motor system; these are known as the **primary areas**. The gyrus in front of the central fissure is called the **precentral** gyrus, also called area 4, and it is the primary **motor** area, specialized for the control of voluntary movements (see Figure 53 and Figure 60). The area in front of this gyrus is called the **(lateral) premotor area**, also called area 6, which is likewise involved with voluntary motor actions (see also Figure 53 and Figure 60). An area in the frontal lobe (outlined) has a motor function in regards to eye movements; this is called the **frontal eye field** (area 8). The gyrus behind the central fissure is the **postcentral gyrus**, including areas 1, 2 and 3 (see Figure 36 and Figure 60), and it has a **somatosensory** function for information from the skin (and joints). (Other sensory primary areas will be identified at the appropriate time.)

The remaining cortical areas that are not directly linked to either a sensory or motor function are called **association** cortex. The most anterior parts of the frontal lobe are the newest in evolution and are known as the **prefrontal cortex** (in front of the frontal eye fields previously mentioned). This broad cortical area seems to be the chief "executive" part of the brain. The **parietal areas** are connected to sensory inputs and have a major role in integrating sensory information from the various modalities. In the parietal lobe, there are two special gyri, the **supramarginal** and **angular** gyri; these areas, particularly on the nondominant side, seem to be involved in visuospatial activities.

Some cortical functions are not equally divided between the two hemispheres. One hemisphere is therefore said to be dominant for that function. This is the case for **language** ability, which, in most people, is located in the left hemisphere. This photograph of the left hemisphere shows the two language areas: **Broca's** area for the motor aspects of speech and **Wernicke's** area for the comprehension of written and spoken language (near the auditory area).

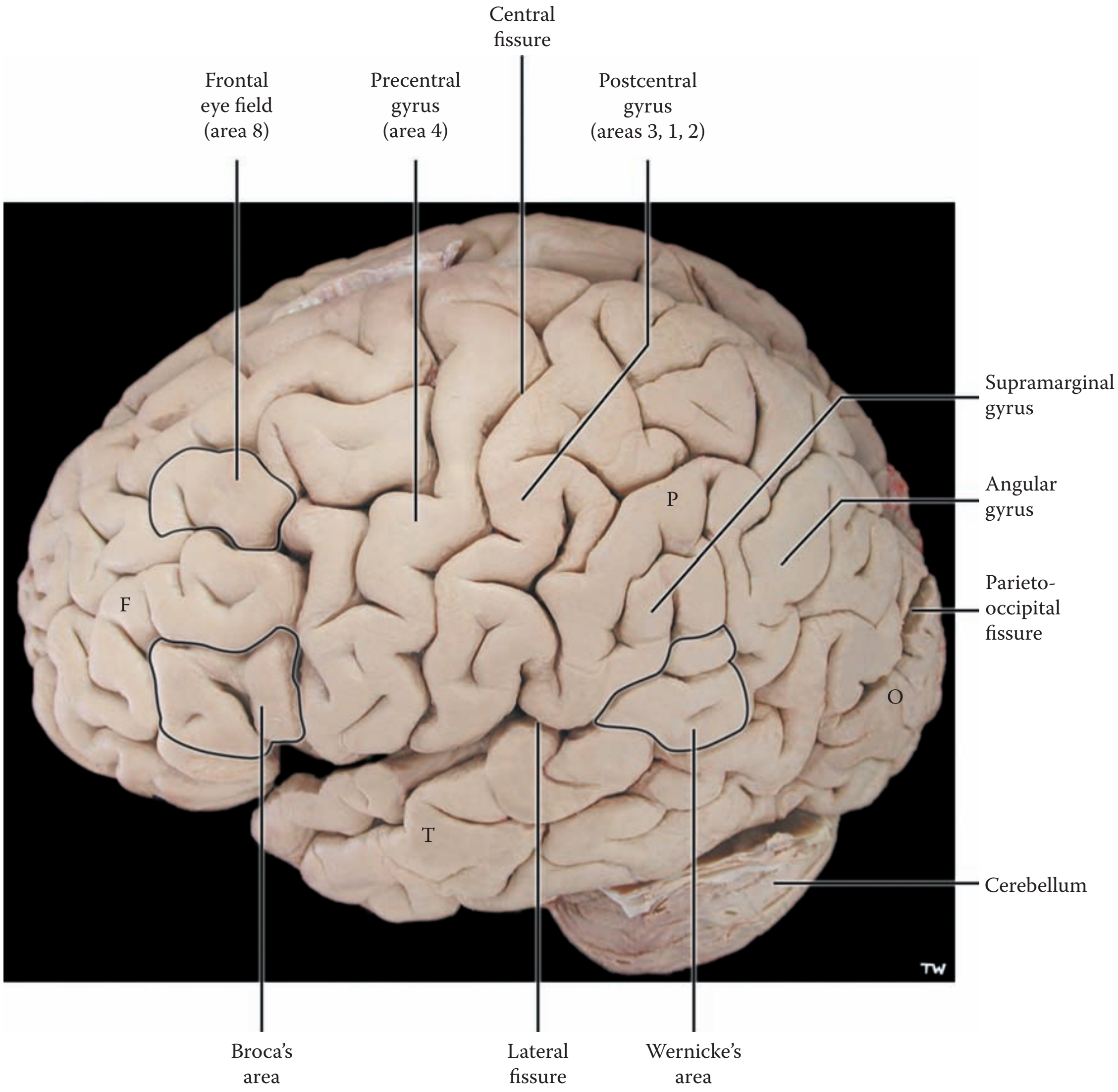
The lateral fissure (also known as the fissure of Sylvius) divides the temporal lobe below from the frontal and parietal lobes above. Extending the line of the lateral fissure posteriorly continues the demarcation between the temporal and parietal lobes. The **temporal lobe** seen on this view is a large area of association cortex whose function is still being defined, other than the portions involved with the auditory system (see Figure 38 and Figure 39) and language (on the dominant side). Other portions of the temporal lobe include the inferior parts (to be discussed with the following illustrations) and the medial portion, which is part of the limbic system (see Section D).

The location of the parieto-occipital fissure is indicated on this photograph (see also previous illustration). This fissure, which separates the parietal lobe from the occipital lobe, is best seen when the medial aspect of the brain is visualized after dividing the hemispheres (see Figure 17). The occipital lobe is concerned with the processing of visual information.

The cerebellum lies below the occipital lobe, with the large dural sheath, the tentorium cerebelli (not labeled, see Figure 17) separating these parts of the brain.

CLINICAL ASPECTS

It is most important to delineate anatomically the functional areas of the cortex. This forms the basis for understanding the clinical implications of damage (called lesions) to the various parts of the brain. Clinicians are now being assisted in their tasks by modern imaging techniques, including CT (see Figure 28A) and MRI (see Figure 28B).



F = Frontal lobe
P = Parietal lobe
T = Temporal lobe
O = Occipital lobe (areas 18, 19)

FIGURE 14A: Cerebral Hemispheres 2 — Dorsolateral View (photograph)

FIGURE 14B
CEREBRAL HEMISPHERES 3

THE INSULA

The lateral fissure has been "opened" to reveal some buried cortical tissue; this area is called the **insula**. The function of this cortical area has been somewhat in doubt over the years. It seems that this is the area responsible for receiving taste sensations, relayed from the brainstem (see Figure 8B and Figure 67A). Sensations from our internal organs may reach the cortical level in this area.

The specialized cortical gyri for hearing (audition) are also to be found within the lateral fissure, but they are part of the upper surface of the superior temporal gyrus (as shown in Figure 38 and Figure 39).

It should be noted that the lateral fissure has within it a large number of blood vessels, which have been removed —branches of the middle cerebral artery (discussed with Figure 58). Branches to the interior of the brain, the striate arteries, are given off in the lateral fissure (see Figure 62). The insular cortex can be recognized on a horizontal section of the brain (see Figure 27) and also on coronal views of the brain (see Figure 29), as well as with brain imaging (CT and MRI).

CLINICAL ASPECT

A closed head injury that affects the brain is one of the most serious forms of accidents. The general term for this is a **concussion**, a bruising of the brain. There are various degrees of concussion depending upon the severity of the trauma. The effects vary from mild headache to unconsciousness and may include some memory loss, usually temporary. Everything possible should be done to avoid a brain injury, particularly when participating in sport activities. Proper headgear in the form of a helmet should be worn by children and adults while cycling, skiing, snowboarding, and skating (winter and inline). Closed head injuries occur most frequently with motor vehicle accidents, and the use of seatbelts and proper seats for children reduces the risk.

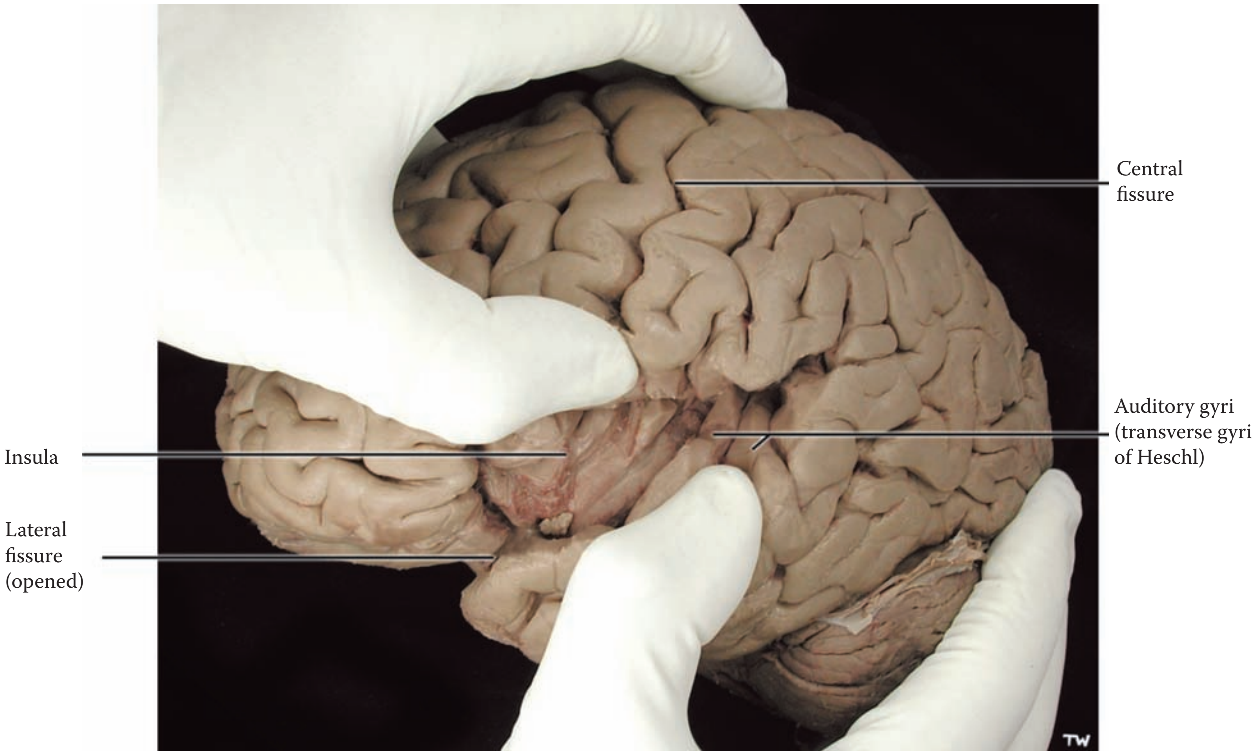


FIGURE 14B: **Cerebral Hemispheres 3** — The Insula (photograph)

FIGURE 15A
CEREBRAL HEMISPHERES 4

CEREBRAL CORTEX: INFERIOR (PHOTOGRAPHIC) VIEW WITH BRAINSTEM

This is a photographic view of the same brain seen from below, the inferior view, a view that includes the brainstem and the cerebellum. The medulla and pons, parts of the brainstem can be identified (see Figure 6 and Figure 7), but the midbrain is mostly hidden from view. The cranial nerves are still attached to the brainstem, and some of the arteries to the brain are also present.

The frontal lobe occupies the anterior cranial fossa of the skull. The inferior surface of the frontal lobe extends from the frontal pole to the anterior tip of the temporal lobe (and the beginning of the lateral fissure). These gyri rest on the roof of the orbit and are sometimes referred to as the **orbital gyri**. This is association cortex and these gyri have strong connections with the limbic system (discussed in Section D).

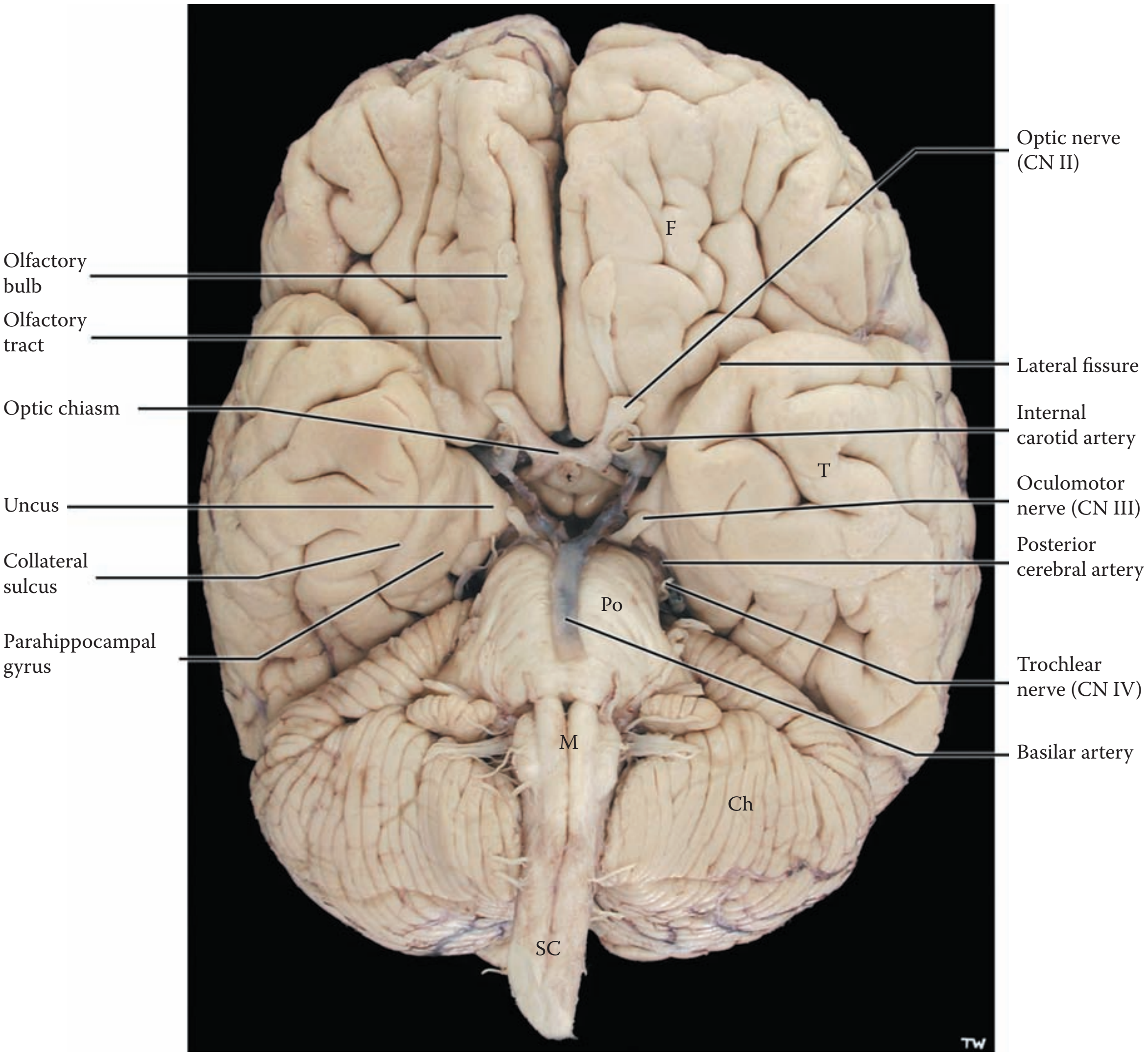
The next area is the inferior surface of the **temporal lobe**. This lobe occupies the middle cranial fossa of the skull. The temporal lobe extends medially toward the midbrain and ends in a blunt knob of tissue known as the **uncus**. Moving laterally from the uncus, the first sulcus visible is the collateral sulcus/fissure (seen clearly on the left side of this photograph). The **parahippocampal gyrus** is the gyurus medial to this sulcus; it is an extremely important gyrus of the limbic system (discussed with Figure 74). It should be noted that the uncus is the most medial protrusion of this gyrus. (The clinical significance of the uncus and uncal herniation will be discussed with the next illustration.)

The olfactory tract and optic nerve (and chiasm) are seen on this view. Both are, in fact, CNS pathways and are not peripheral cranial nerves, even though they are routinely called CN I and CN II. The olfactory bulb is the site of termination of the olfactory nerve filaments from the nose; these filaments are, in fact, the peripheral nerve CN I (see Figure 79). Olfactory information is then carried in the olfactory tract to various cortical and subcortical areas of the temporal lobe (discussed with Figure 79). The optic nerves (CN II) exit from the orbit and continue to the optic chiasm, where there is a partial crossing of visual fibers, which then continue as the optic tract (see Figure 41A). Posterior to the chiasm is the area of the hypothalamus, part of the diencephalon, including the pituitary stalk and the mammillary bodies, which will be seen more clearly in the next illustration.

The brainstem and cerebellum occupy the posterior part of this brain from this inferior perspective. These structures occupy the posterior cranial fossa of the skull. In fact, the cerebellum obscures the visualization of the occipital lobe (which is shown in the next photograph, after removing most of the brainstem and cerebellum). Various cranial nerves can be identified as seen previously (see Figure 7). The oculomotor nerve, CN III, should be noted as it exits from the midbrain; the slender trochlear nerve (CN IV) can also be seen.

Part of the arterial system is also seen in this brain specimen (the arterial supply is discussed with Figure 58–Figure 62). The initial part, vertebral arteries and the formation of the basilar artery, are missing, as are the three pairs of cerebellar arteries. The basilar artery, which is situated in front of the pons, ends by dividing into the posterior cerebral arteries to supply the occipital regions of the brain. The cut end of the internal carotid artery is seen, but the remainder of the arterial circle of Willis is not dissected on this specimen (see Figure 58); the arterial supply to the cerebral hemispheres will be fully described in Section C (see Figure 60 and Figure 61).

Note to the Learner: The specimen of the brainstem and diencephalon shown in Figure 7 was created by dissecting these parts of the brain free of the hemispheres. This has been done by cutting the fibers going to and from the thalamus, as well as all the fibers ascending to and descending from the cerebral cortex (called projection fibers, discussed with Figure 16). The diagrams of such a specimen are shown in Figure 6, Figure 8A, and Figure 8B.



F = Frontal lobe
T = Temporal lobe
Po = Pons
M = Medulla
SC = Spinal cord
Ch = Cerebellar hemisphere

FIGURE 15A: **Cerebral Hemispheres 4** — Inferior View with Brainstem (photograph)

FIGURE 15B
CEREBRAL HEMISPHERES 5

INFERIOR SURFACE: INFERIOR (PHOTOGRAPHIC) VIEW WITH MIDBRAIN

This is another brain specimen showing the inferior surface of the brain, in which the brainstem has been sectioned through at the level of the midbrain, removing most of the brainstem and the attached cerebellum. The cut surface of the midbrain is exposed, showing a linear area of brain tissue, which is black in coloration; this elongated cluster of cells is the nucleus of the midbrain called the **substantia nigra**, and consists of neurons with pigment inside the cells (discussed with Figure 65). The functional role of the substantia nigra is discussed with the basal ganglia (see Figure 24 and Figure 52).

This dissection reveals the inferior surface of both the temporal and the occipital lobes. It is not possible to define the boundary between these two lobes on this view. Some of these inferior gyri are involved with the processing of visual information, including color, as well as facial recognition. The parahippocampal gyri should be noted on both sides, with the collateral sulcus demarcating the lateral border of this gyrus (seen in the previous illustration; discussed with Figure 72A and Figure 72B).

The optic nerves (cut) lead to the optic chiasm, and the regrouped visual pathway continues, now called the optic tract (see Figure 41A and Figure 41C). Behind the optic chiasm are the median eminence and then the mammillary (nuclei) bodies, both of which belong to the hypothalamus. The **median eminence** (not labeled) is an elevation of tissue that contains some hypothalamic nuclei. The **pituitary stalk**, identified on the previous illustration, is attached to the median eminence, and this stalk connects the hypothalamus to the pituitary gland. Behind this are the paired **mammillary bodies**, two nuclei of the hypothalamus (which will be discussed with the limbic system, see Figure 78A).

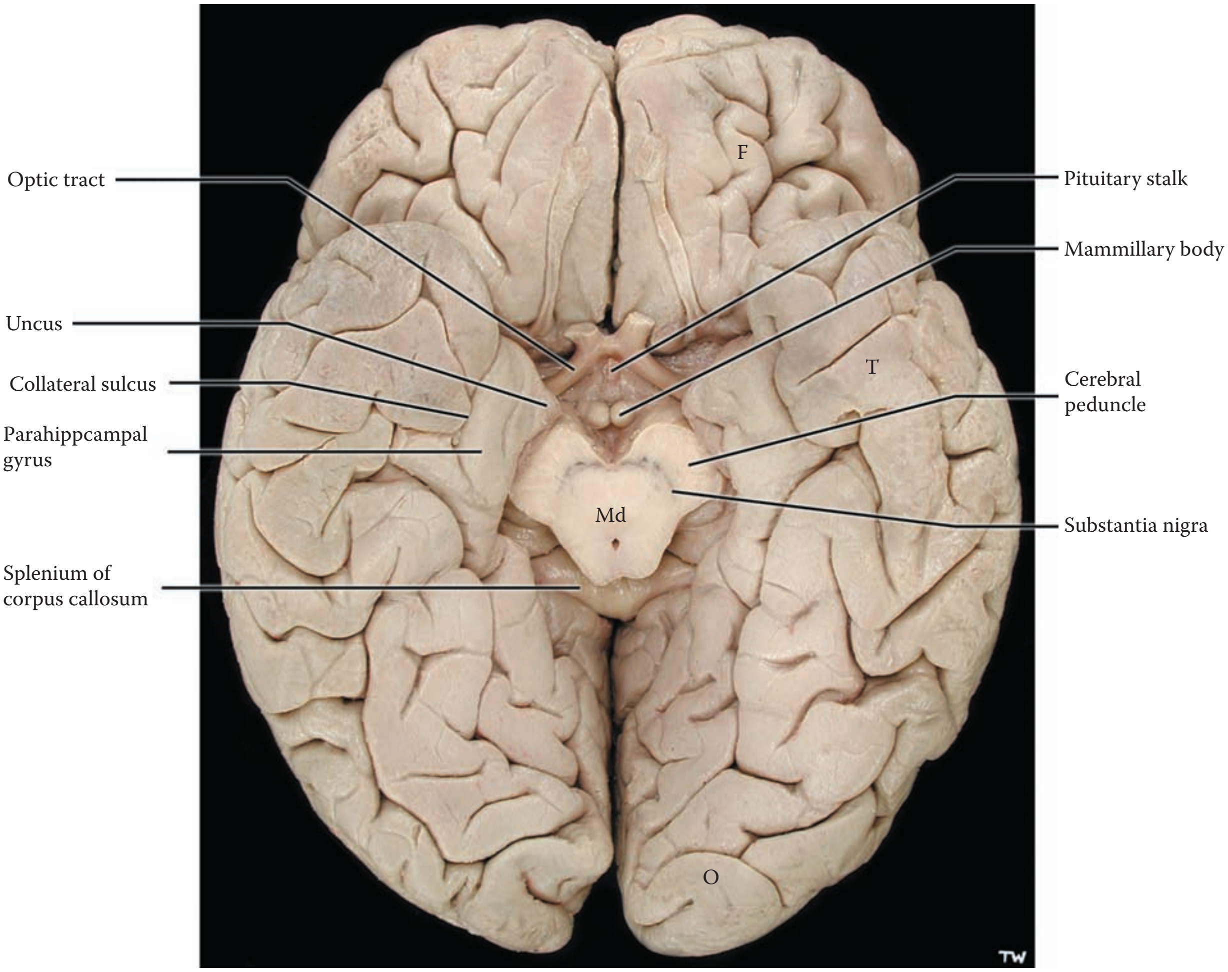
Also visible on this specimen is the posterior thickened end of the corpus callosum (discussed with the next illustration) called the splenium (see Figure 17 and Figure 19A).

A thick sheath of dura separates the occipital lobe from the cerebellum below — the **tentorium cerebelli** (as it covers over the cerebellum). The cut edge of the tentorium can be seen in Figure 17, and its location is seen in Figure 18, above the cerebellum. The tentorium divides the cranial cavity into an area above it, the supratentorial space, a term that is used often by clinicians to indicate a problem in any of the lobes of the brain. The area below the tentorium, the infratentorial space, corresponds to the posterior cranial fossa. The tentorial sheath of dura, the tentorium cerebelli, splits around the brainstem at the level of the midbrain; this split in the tentorium is called the **tentorial notch** (hiatus).

CLINICAL ASPECT

The uncus has been clearly identified in the specimens, with its blunted tip pointed medially. The uncus is in fact positioned just above the free edge of the tentorium cerebelli. Should the volume of brain tissue increase above the tentorium, due to brain swelling, hemorrhage, or a tumor, accompanied by an increase in intracranial pressure (ICP), the hemispheres would be forced out of their supratentorial space. The only avenue to be displaced is in a downward direction, through the tentorial notch, and the uncus becomes the leading edge of this pathological event. The whole process is clinically referred to as "**uncal herniation**."

Since the edges of the tentorium cerebelli are very rigid, the extra tissue in this small area causes a compression of the brain matter, leading to compression of the brainstem; this is followed by a progressive loss of consciousness. CN III is usually compressed as well, damaging it, and causing a fixed and dilated pupil on that side, an ominous sign in any lesion of the brain. This is a medical emergency! Continued herniation will lead to further compression of the brainstem and a loss of vital functions, followed by rapid death.



F = Frontal lobe
T = Temporal lobe
O = Occipital lobe
Md = Midbrain (cut)

FIGURE 15B: **Cerebral Hemispheres 5** — Inferior View with Midbrain (photograph)

FIGURE 16
CEREBRAL HEMISPHERES 6

CORPUS CALLOSUM: SUPERIOR (PHOTOGRAPHIC) VIEW

In this photograph, the brain is again being viewed from directly above (see Figure 13), with the interhemispheric fissure opened. The dural fold between the hemispheres, the falx cerebri, has been removed from the interhemispheric fissure. This thick sheath of dura keeps the two halves of the hemispheres in place within the cranial cavity. A whitish structure is seen in the depths of the fissure — the **corpus callosum**.

One of the other major features of the cerebral cortex is the vast number of neurons that are devoted to communicating with other neurons of the cortex. These interneurons are essential for the processing and elaboration of information, whether generated in the external world or internally by our "thoughts." This intercommunicating network is reflected in the enormous number of interconnections between cortical areas. These interconnecting axons are located within the depths of the hemispheres. They have a white coloration after fixation in formalin, and these regions are called the **white matter** (see Figure 27 and Figure 29).

The white matter bundles within the hemispheres are of three kinds:

- **Commissural** bundles — connecting cortical areas across the midline
- **Association** bundles — interconnecting the cortical areas on the same side
- **Projection** fibers — connecting the cerebral cortex with subcortical structures, including the basal ganglia, thalamus, brainstem, and spinal cord

All such connections are bidirectional, including the projection fibers.

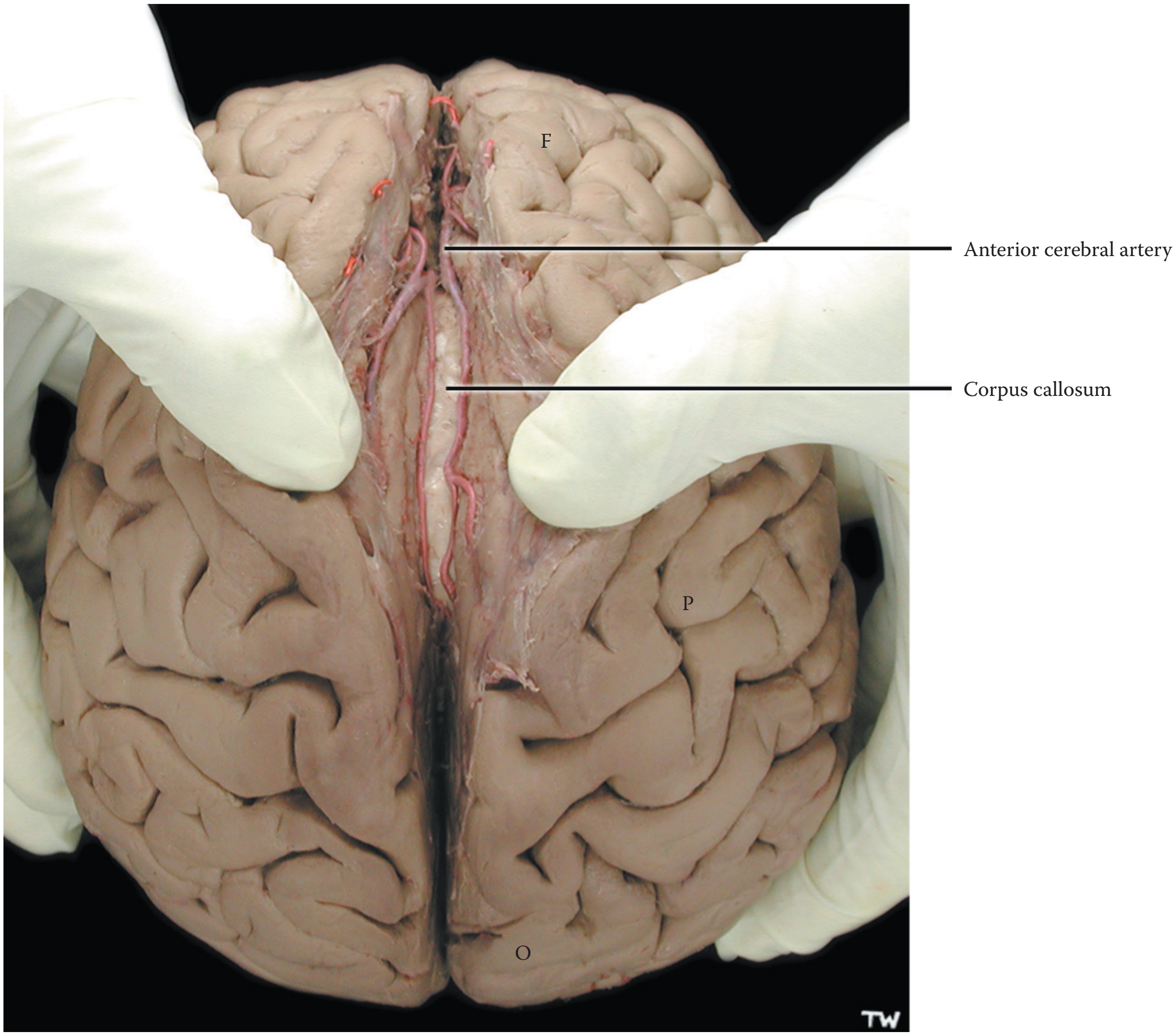
The corpus callosum is the largest of the commissural bundles, as well as the latest in evolution. This is the anatomic structure required for each hemisphere to be kept informed of the activity of the other hemisphere. The axons connect to and from the lower layers of the cerebral cortex, and in most cases the connections are between homologous areas and are reciprocal. If the brain is sectioned in the sagittal plane along the interhemispheric fissure, the medial aspect of the brain will be revealed (see next illustration). The corpus callosum will be divided in the process. The fibers of the corpus callosum can be followed from the midline to the cortex (see Figure 19A).

It is difficult on this view to appreciate the depth of the corpus callosum within the interhemispheric fissure. In fact, there is a considerable amount of cortical tissue on the medial surface of the hemispheres, as represented by the frontal, parietal, and occipital lobes (see the next illustration).

In this specimen, the blood vessels supplying the medial aspect of the hemispheres are present. These vessels are the pericallosal arteries, a continuation of the anterior cerebral arteries (to be fully described with Figure 58 and Figure 61; see also Figure 70B). It should also be noted that the cerebral ventricles are located below (i.e., inferior to) the corpus callosum (see Figure 17 and Figure 19A).

The other white matter bundles, the association and projection fibers, will be discussed with other photographic views of the brain (see Figure 19A and Figure 19B). The anterior commissure is an older and smaller commissure connecting the anterior portions of the temporal lobe and limbic structures (see Figure 70A).

The clinical aspect of the corpus callosum is discussed with Figure 19A.



F = Frontal lobe
P = Parietal lobe
O = Occipital lobe

FIGURE 16: **Cerebral Hemispheres 6** — Superior View (photograph)

FIGURE 17
CEREBRAL HEMISPHERES 7

CEREBRAL HEMISPHERES: MEDIAL (PHOTOGRAPHIC) VIEW

This view of the brain sectioned in the midline (midsagittal plane) is probably the most important view for understanding the gross anatomy of the hemispheres, the diencephalon, the brainstem, and the ventricles. The section has divided the corpus callosum, gone in between the thalamus of each hemisphere (through the third ventricle), and passed through all parts of the brainstem.

The medial aspects of the lobes of the brain are now in view. The central fissure does extend onto this part of the brain (although not as deep as on the dorsolateral surface). The medial surface of the frontal lobe is situated anterior to the fissure; the inferior gyri of the frontal lobe sit on the bone that separates the anterior cranial fossa from the orbits (see Figure 15A and Figure 15B). The parietal lobe lies between the central fissure and the deep **parieto-occipital fissure**. The **occipital lobe** is now visible, posterior to this fissure. The main fissure that divides this lobe is the calcarine fissure (see Figure 41B); the primary visual area, commonly called **area 17** is situated along its banks (see Figure 41A and Figure 41B).

The corpus callosum in this specimen has the expected “white matter” appearance. Inside each cerebral hemisphere is a space filled with CSF, the lateral ventricle (see Figure 20A and Figure 20B). The **septum pellucidum**, a membranous septum that divides the anterior portions of the lateral ventricles of one hemisphere from that of the other side, has been torn during dissection, revealing the lateral ventricle of one hemisphere behind it (see Figure OL and Figure 28A). The fornix, a fiber tract of the limbic system, is located in the free lower edge of the septum. Above the corpus callosum is the **cingulate gyrus,** an important gyrus of the limbic system (see Figure 70A).

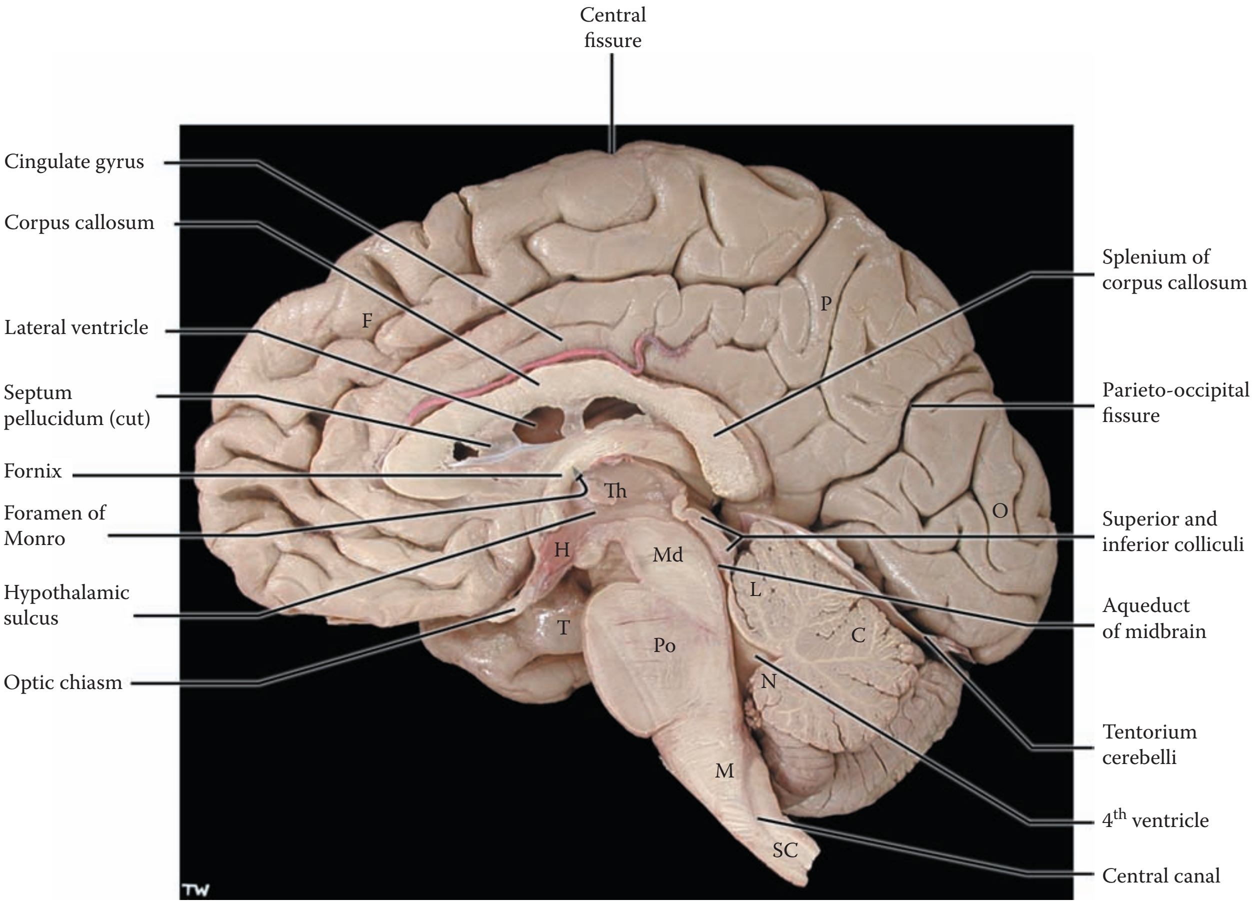
The sagittal section goes through the midline third ventricle (see Figure OA, Figure 9A, Figure 20A, and Figure 20B), thereby revealing the diencephalic region. (This region is shown at a higher magnification in Figure 41B). On this medial view, the thalamic portion of the diencephalon is separated from the hypothalamic part by a groove, the **hypothalamic sulcus**. This sulcus starts at the foramen of Monro (the interventricular foramen, discussed with the ventricles, see Figure 20A and Figure 20B) and ends at the aqueduct of the midbrain. The optic chiasm is found at the anterior aspect of the hypothalamus, and behind it is the mammillary body (see Figure 15B).

The three parts of the brainstem can be distinguished on this view — the midbrain, the pons with its bulge anteriorly, and the medulla (refer to the ventral views shown in Figure 6 and Figure 7). Through the midbrain is a narrow channel for CSF, the aqueduct of the midbrain (see Figure 20A and Figure 20B). The midbrain (behind the aqueduct) includes the superior and inferior colliculi, referred to as the tectum (see Figure 9A, Figure 10, and Figure 18).

The aqueduct connects the third ventricle with the fourth ventricle, a space with CSF that separates the pons and medulla from the cerebellum (see Figure 20A and Figure 20B). CSF escapes from the ventricular system at the bottom of the fourth ventricle through the foramen of Magendie (see Figure 21), and the ventricular system continues as the narrow central canal of the spinal cord (see Figure 4).

The cerebellum lies behind (or above) the fourth ventricle. It has been sectioned through its midline portion, the **vermis** (see Figure 54). Although it is not necessary to name all of its various parts, it is useful to know two of them — the lingula and the nodulus. (The reason for this will become evident when describing the cerebellum, see Figure 54). The tonsil of the cerebellum can also be seen in this view (not labeled, see Figure 9B and Figure 56).

The cut edge of the tentorium cerebelli, the other main fold of the dura, is seen separating the cerebellum from the occipital lobe. One of the dural venous sinuses, the straight sinus, runs in the midline of the tentorium (see next illustration). This view clarifies the separation of the supratentorial space, namely the cerebral hemispheres, from the infratentorial space, the brainstem, and the cerebellum in the posterior cranial fossa.



F = Frontal lobe
P = Parietal lobe
T = Temporal lobe
O = Occipital lobe

Th = Thalamus
H = Hypothalamus

Md = Midbrain
Po = Pons
M = Medulla
SC = Spinal cord

C = Cerebellum
L = Lingula
N = Nodulus

FIGURE 17: **Cerebral Hemispheres 7** — Medial View (photograph)

FIGURE 18
CEREBRAL HEMISPHERES 8

MRI: T1 SAGITTAL VIEW (RADIOGRAPH)

This radiological image, obtained by magnetic resonance imaging (**MRI**), shows the brain as clearly as the actual brain itself (review the NOTE on radiologic imaging with Figure 3). This is the way the brain will be seen in the clinical setting. The view presented is called a **T1-weighted** image. Note that the CSF is dark in this image, including the ventricles, the subarachnoid space, and cisterns (see Figure 21). The bones (tables) of the skull are visible as a dark space, while the bone marrow, including its replacement by fatty tissue, and layers of soft tissue (and fatty tissue) of the scalp are well demarcated (white). The superior sagittal sinus can also be seen (see Figure 13 and Figure 21).

The various structures of the brain can easily be identified by comparing this view with the photographic view of the brain shown in the previous illustration, including the lobes of the brain. The corpus callosum can be easily identified, with the cingulate gyrus just above it and the lateral ventricle just below it (see also Figure 30). Various fissures (e.g., parieto-occipital, calcarine) can also be identified along with some cortical gyri (e.g., area 17, see Figure 41B). The space below the occipital lobe is occupied by the tentorium cerebelli (discussed with Figure 15B); the straight sinus, one of the dural venous sinuses, runs in the midline of the tentorium (see Figure 21).

The thalamus (the diencephalon) is seen below the lateral ventricle, and the tract immediately above it is the fornix (see Figure 70A). The structure labeled septum pellucidum separates the lateral ventricles of the hemispheres from each other (shown clearly in Figure 28A and Figure 30). The pineal is visible on this radiograph at the posterior end of the thalamus (just below the splenium of the corpus callosum); the pineal gland is cystic in this case, making it easy to identify. The pituitary gland is situated within the pituitary bony fossa, the sella turcica (see Figure 21).

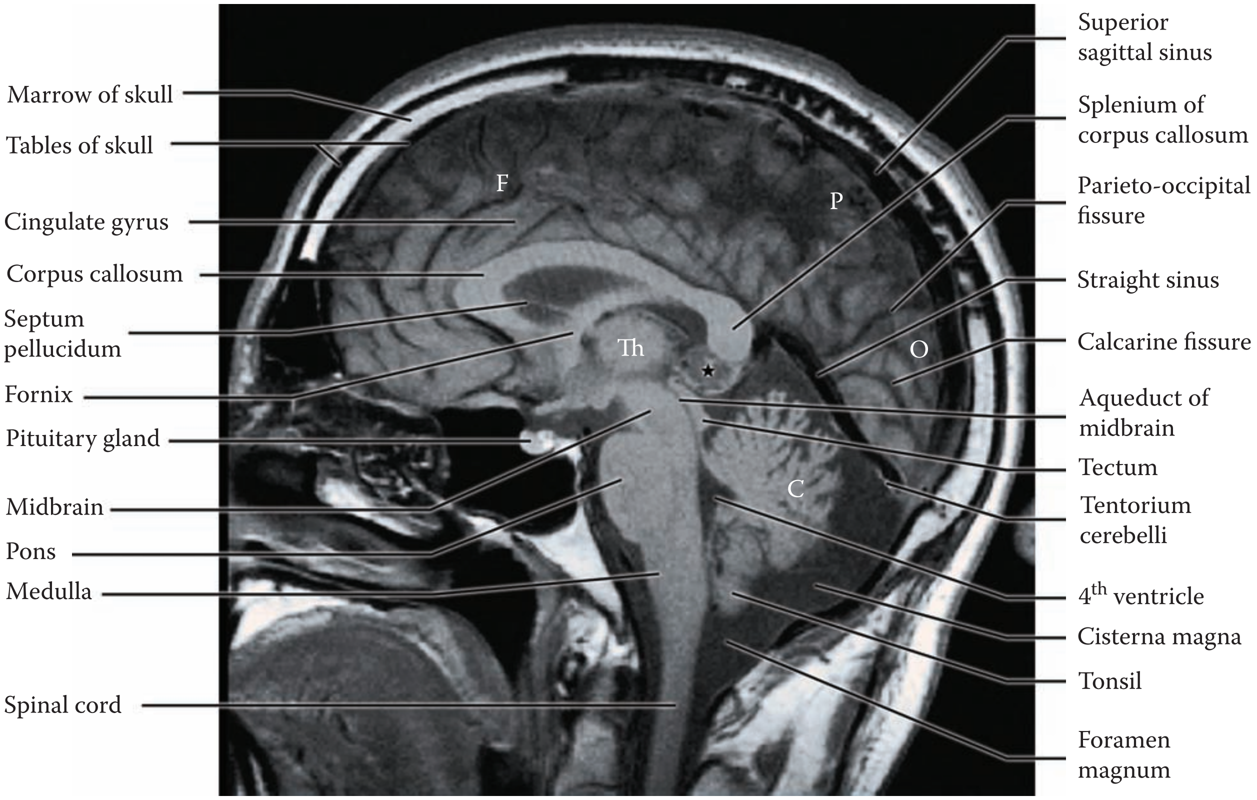
Below the thalamus is the brainstem — its three parts, midbrain, pons, and medulla, can be identified. The tectum (with its four colliculi) is seen behind the aqueduct of the midbrain (see Figure 21). Posterior to the tectum is a CSF cistern (see Figure 28A, the guadrigeminal cistern). The fourth ventricle separates the cerebellum from the pons and medulla. The medulla ends at the foramen magnum and becomes the spinal cord.

The cerebellar folia are quite distinct on this image. The location of the cerebellar tonsil(s) should be noted, adjacent to the medulla and immediately above the foramen magnum, the “opening” at the base of the skull (see discussion on tonsillar herniation with Figure 9). The location of the cerebello-medullary cistern, the **cisterna magna**, behind the medulla and just above the foramen magnum is easily seen (see Figure 3 and Figure 21).

The remaining structures are those of the nose and mouth, which are not within our subject matter in this atlas.

CLINICAL ASPECT

This is a most important view for viewing the brain in the clinical setting. Abnormalities of structures, particularly in the posterior cranial fossa, can be easily visualized. Displacement of the brainstem into the foramen magnum because of a developmental disorder, known as an **Arnold-Chiari malformation**, will cause symptoms related to compression of the medulla at that level; in addition, there may be blockage of the CSF flow causing hydrocephalus (see Figure 21).



F = Frontal lobe
P = Parietal lobe
O = Occipital lobe

Th = Thalamus

C = Cerebellum

★ = Pineal cyst

FIGURE 18: **Cerebral Hemispheres 8** — MRI: Sagittal View (radiograph)

FIGURE 19A
CEREBRAL HEMISPHERES 9

WHITE MATTER: MEDIAL DISSECTED VIEW — CORPUS CALLOSUM (PHOTOGRAPH)

The structures that are found within the depths of the cerebral hemispheres include the white matter, the cerebral ventricles, and the basal ganglia (see Figure OA and Figure OL). The white matter consists of the myelinated axonal fibers connecting brain regions. In the spinal cord these were called tracts; in the hemispheres these bundles are classified in the following way (also discussed with Figure 16) — association bundles, projections fibers, and commissural connections.

The dissection of this specimen needs some explanation. The brain is again seen from the medial view. (Its anterior aspect is on the left side of this photograph.) Cortical tissue has been removed from a brain (such as the one shown in Figure 17), using blunt dissection techniques. If done successfully, the fibers of the corpus callosum can be followed, as well as other white matter bundles (see Figure 19B). These fibers intermingle with other fiber bundles that make up the mass of white matter in the depth of the hemisphere.

The corpus callosum is the massive commissure of the forebrain, connecting homologous regions of the two hemispheres of the cortex across the midline (see also Figure 16). This dissection shows the white matter of the corpus callosum, followed to the cortex. In the midline, the thickened anterior aspect of the corpus callosum is called the genu, and the thickened posterior portion is the splenium (neither has been labeled).

If one looks closely, looping U-shaped bundles of fibers can be seen connecting adjacent gyri; these are part of the local association fibers.

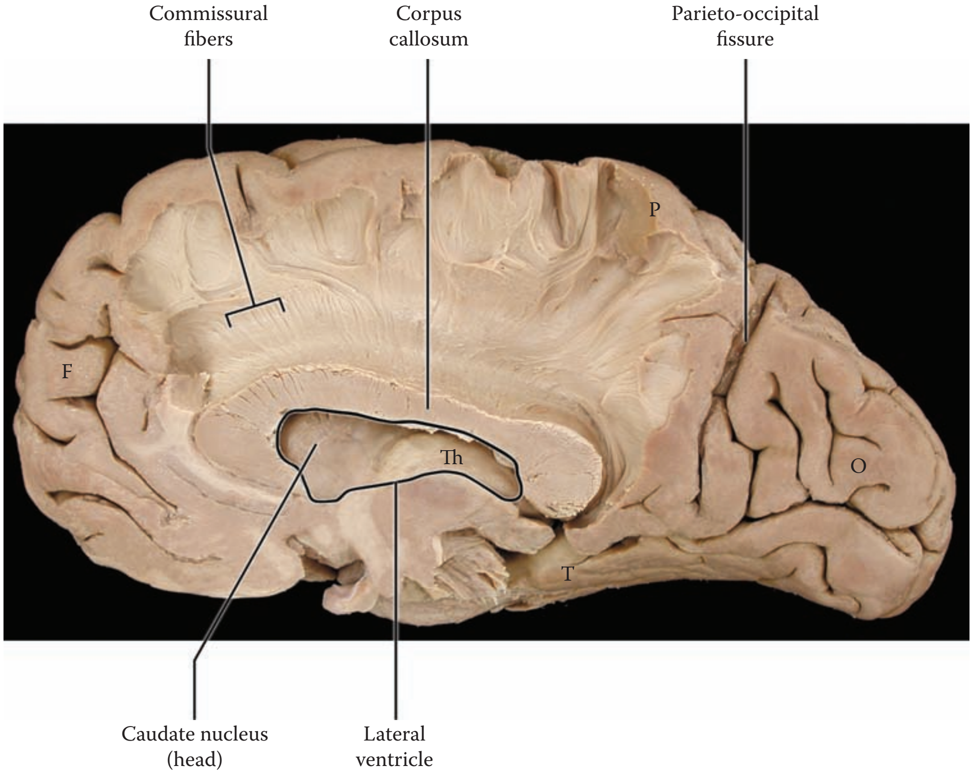
The lateral ventricle is situated under the corpus callosum, while the diencephalon (the thalamus) is below the ventricle. Inside the anterior horn of the ventricle (see Figure 20A) there is a bulge that is formed by the head of the caudate nucleus; the caudate bulge is also seen on horizontal views of the brain (see Figure 27 and Figure 28A).

CLINICAL ASPECT

Although the connections of the corpus callosum are well described, its function under normal conditions is hard to discern. In rare cases, persons are born without a corpus callosum, a condition called agenesis of the corpus callosum, and these individuals as children and adults usually cannot be distinguished from normal individuals, unless specific testing is done.

The corpus callosum has been sectioned surgically in certain individuals with intractable epilepsy, that is, epilepsy which has not been controllable using anti-convulsant medication. The idea behind this surgery is to stop the spread of the abnormal discharges from one hemisphere to the other. Generally, the surgery has been helpful in well-selected cases, and there is apparently no noticeable change in the person, nor in his or her level of brain function.

Studies done in these individuals have helped to clarify the role of the corpus callosum in normal brain function. Under laboratory conditions, it has been possible to demonstrate in these individuals how the two hemispheres of the brain function independently, after the sectioning of the corpus callosum. These studies show how each hemisphere responds differently to various stimuli, and the consequences in behavior of the fact that information is not getting transferred from one hemisphere to the other hemisphere.



F = Frontal lobe
P = Parietal lobe
T = Temporal lobe
O = Occipital lobe

Th = Thalamus (cut)

FIGURE 19A: **Cerebral Hemispheres 9** — Medial Dissected View: Corpus Callosum (photograph)

FIGURE 19B
CEREBRAL HEMISPHERES 10

WHITE MATTER: LATERAL DISSECTED VIEW — ASSOCIATION BUNDLES (PHOTOGRAPH)

The dorsolateral aspect of the brain is being viewed in this photograph (see Figure 14A). The lateral fissure has been opened, with the temporal lobe below; deep within the lateral fissure is the insula (see Figure 14B and Figure 39).

Under the cerebral cortex is the white matter of the brain. It is possible to dissect various fiber bundles (not easily) using a blunt instrument (e.g., a wooden tongue depressor). Some of these, functionally, are the association bundles, fibers that interconnect different parts of the cerebral cortex on the same side (classified with Figure 16).

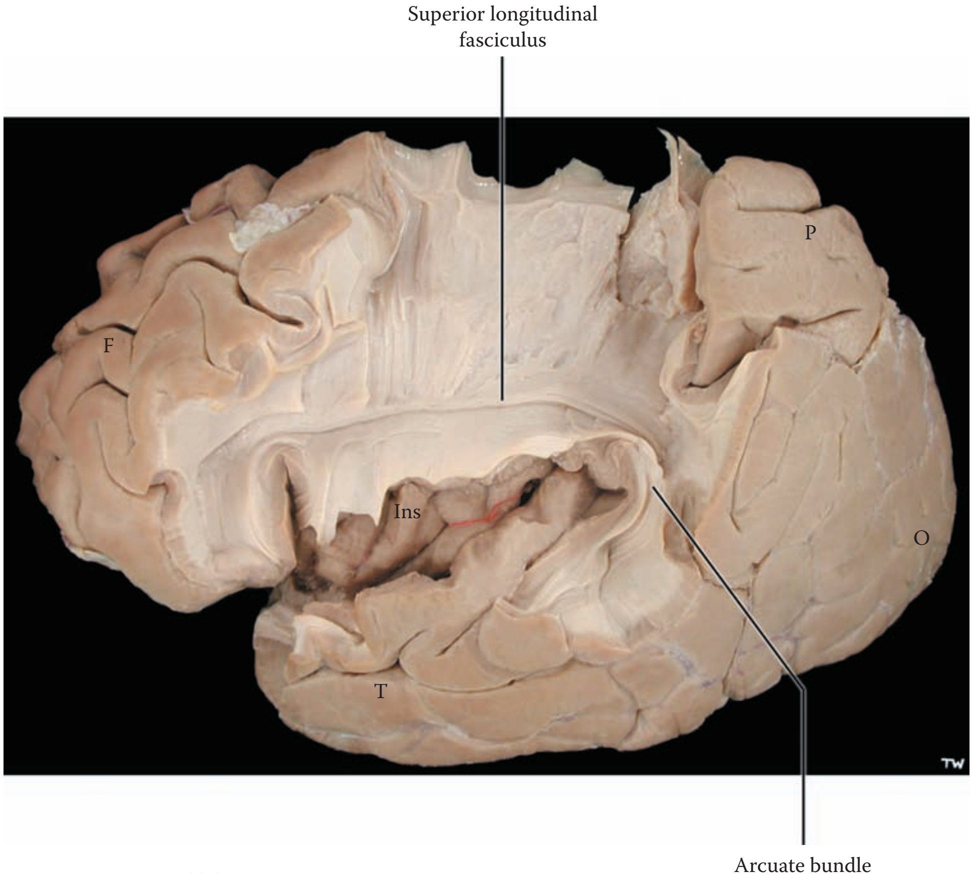
This specimen has been dissected to show two of the association bundles within the hemispheres. The **superior longitudinal fasciculus** (fasciculus is another term for a bundle of axons) interconnects the posterior parts of the hemisphere (e.g., the parietal lobe) with the frontal lobe. There are other association bundles present in the hemispheres connecting the various portions of the cerebral cortex. The various names of these association bundles usually are not of much importance in a general introduction to the CNS and only will be mentioned if need be. Shorter association fibers are found between adjacent gyri (see previous illustration).

These association bundles are extremely important in informing different brain regions of ongoing neuronal processing, allowing for integration of our activities (for example sensory with motor and limbic). One of the major functions of these association bundles in the human brain seems to be bringing information to the frontal lobes, especially to the prefrontal cortex, which acts as the "executive director" of brain activity (see Figure 14A).

One of the most important association bundles, the **arcuate bundle**, connects the two language areas. It connects Broca's area anteriorly with Wernicke's area in the superior aspect of the temporal lobe, in the dominant (left) language hemisphere (see Figure 14A).

Clinical Aspect

Damage to the arcuate bundle due to a lesion, such as an infarct or tumor, in that region leads to a specific disruption of language, called conduction aphasia. **Aphasia** is a general term for a disruption or disorder of language. In conduction aphasia, the person has normal comprehension (intact Wernicke's area) and fluent speech (intact Broca's area). The only language deficit seems to be an inability to repeat what has been heard. This is usually tested by asking the patient to repeat single words or phrases whose meaning cannot be readily understood (e.g., the phrase "no ifs, ands, or buts"). There is some uncertainty whether this is in fact the only deficit, since isolated lesions of the arcuate bundle have not yet been described.



F = Frontal lobe
P = Parietal lobe
T = Temporal lobe
O = Occipital lobe

Ins = Insula

FIGURE 19B: **Cerebral Hemispheres 10** — Lateral Dissected View: Association Bundles (photograph)

FIGURE 20A
VENTRICLES 1

VENTRICLES: LATERAL VIEW

The ventricles are cavities within the brain filled with **CSF**. The formation, circulation, and locations of the CSF will be explained with Figure 21.

The ventricles of the brain are the spaces within the brain that remain from the original neural tube, the tube that was present during development. The cells of the nervous system, both neurons and glia, originated from a germinal matrix that was located adjacent to the lining of this tube. The cells multiply and migrate away from the walls of the neural tube, forming the nuclei and cerebral cortex. As the nervous system develops, the mass of tissue grows and the size of the tube diminishes, leaving various spaces in different parts of the nervous system (see Figure OA and Figure OL).

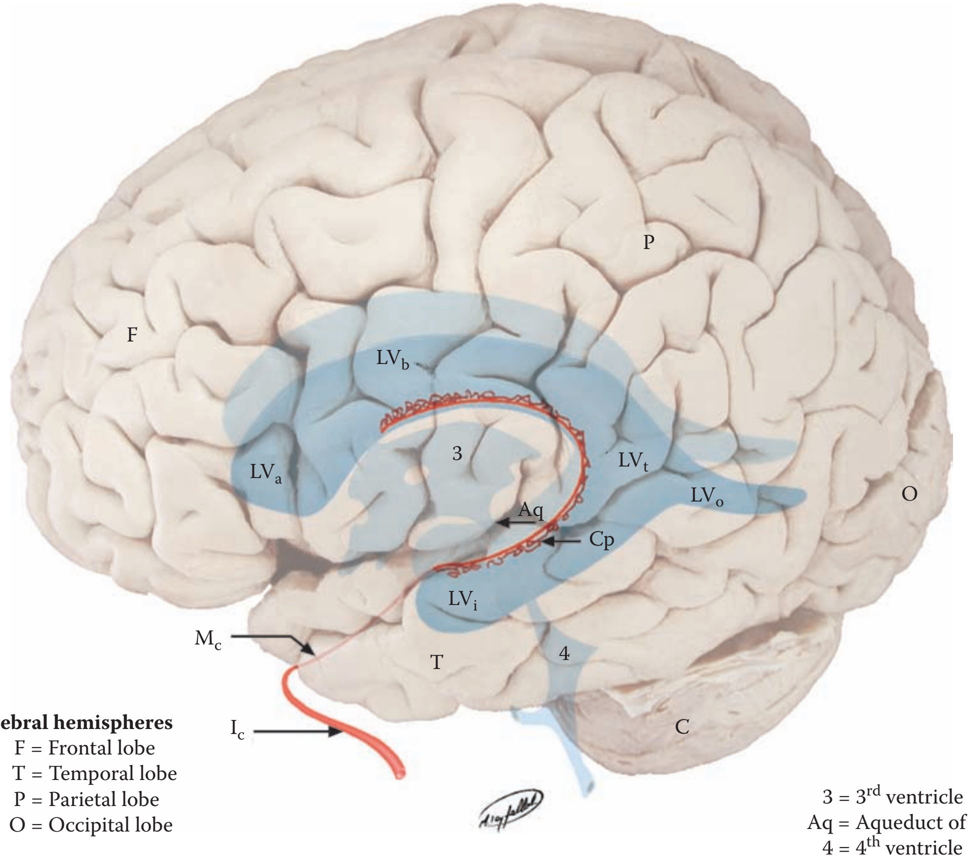
The parts of the tube that remain in the hemispheres are called the cerebral ventricles, also called the **lateral ventricles**. The lateral ventricle of the hemispheres, shown here from the lateral perspective, is shaped like the letter C (in reverse); it curves posteriorly and then enters into the temporal lobe. Its various parts are: the **anterior horn**, which lies deep to the frontal lobes; the central portion, or **body**, which lies deep to the parietal lobes; the **atrium** or **trigone**, where it widens and curves and then enters into the temporal lobe as the **inferior horn**. In addition, there may be an extension into the occipital lobes, the **occipital** or posterior horn, and its size varies. These lateral ventricles are also called ventricles **I and II** (assigned arbitrarily).

Each lateral ventricle is connected to the midline third ventricle by an opening, the **foramen of Monro** (interventricular foramen — seen in the medial view of the brain, Figure 17 and Figure 41B; also Figure 20B and Figure 21). The **third ventricle** is a narrow slit-like ventricle between the thalamus on either side and could also be called the ventricle of the diencephalon (see Figure 9B). Sectioning through the brain in the midline (as in Figure 17) passes through the third ventricle. Note that the “hole” in the middle of the third ventricle represents the interthalamic adhesion, linking the two thalami across the midline (see Figure 6; discussed with Figure 11; see also Figure 41B).

The ventricular system then narrows considerably as it goes through the midbrain and is now called the **aqueduct of the midbrain**, the cerebral aqueduct, or the aqueduct of Sylvius (see Figure 17, Figure 18, and Figure 20B; also Figure 41B and Figure 65). In the hindbrain region, the area consisting of pons, medulla, and cerebellum, the ventricle widens again to form the **fourth ventricle** (see Figure 17, Figure 20B, and Figure 66). The channel continues within the CNS and becomes the very narrow **central canal** of the spinal cord (see Figure 17, Figure 20B, Figure 21, and Figure 69).

Specialized tissue, the **choroid plexus,** the tissue responsible for the formation of the CSF, is located within the ventricles. It is made up of the lining cells of the ventricles, the ependyma, and pia with blood vessels (discussed with Figure 21). This diagram shows the choroid plexus in the body and inferior horn of the lateral ventricle; the tissue forms large invaginations into the ventricles in each of these locations (see Figure 27 and Figure 74 for a photographic view of the choroid plexus). The blood vessel supplying this choroid plexus comes from the middle cerebral artery (shown here schematically; see Figure 58). Choroid plexus is also found in the roof of the third ventricle and in the lower half of the roof of the fourth ventricle (see Figure 21).

CSF flows through the ventricular system, from the lateral ventricles, through the interventricular foramina into the third ventricle, then through the narrow aqueduct and into the fourth ventricle (see Figure 21). At the bottom of the fourth ventricle, CSF flows out of the ventricular system via the major exit, the foramen of Magendie, in the midline, and enters the subarachnoid space. There are two additional exits of the CSF laterally from the fourth ventricle — the foramina of Luschka, which will be seen in another perspective (in the next illustration).



Cerebral hemispheres
F = Frontal lobe
T = Temporal lobe
P = Parietal lobe
O = Occipital lobe

Lateral ventricle
LV_a = Anterior horn
LV_b = Body
LV_t =Atrium (trigone)
LV_i = Inferior horn
LV_o = Occipital horn

Cp = Choroid plexus

3 = 3rd ventricle
Aq = Aqueduct of midbrain
4 = 4th ventricle

C = Cerebellum

Arteries
M_c = Middle cerebral
I_c = Internal carotid

FIGURE 20A: Ventricles 1 — Lateral View

FIGURE 20B
VENTRICLES 2

VENTRICLES: ANTERIOR VIEW

The ventricular system is viewed from the anterior perspective in this illustration. One can now see both lateral ventricles and the short interventricular foramen (of Monro) on both sides, connecting each lateral ventricle with the midline third ventricle (see Figure 28B and Figure 29). It is important to note that the thalamus (diencephalon) is found on either side of the third ventricle (see also Figure 9A).

CSF flows from the third ventricle into the aqueduct of the midbrain. This ventricular channel continues through the midbrain, and then CSF enters the fourth ventricle, which also straddles the midline. The ventricle widens into a diamond-shaped space, when seen from the anterior perspective. This ventricle separates the pons and medulla anteriorly from the cerebellum posteriorly. The lateral recesses carry CSF into the cisterna magna, the CSF cistern outside the brain (see Figure 21), through the **foramina of Luschka**, the lateral apertures, one on each side. The space then narrows again, becoming a narrow channel at the level of the lowermost medulla, which continues as the central canal of the spinal cord (see Figure 4).

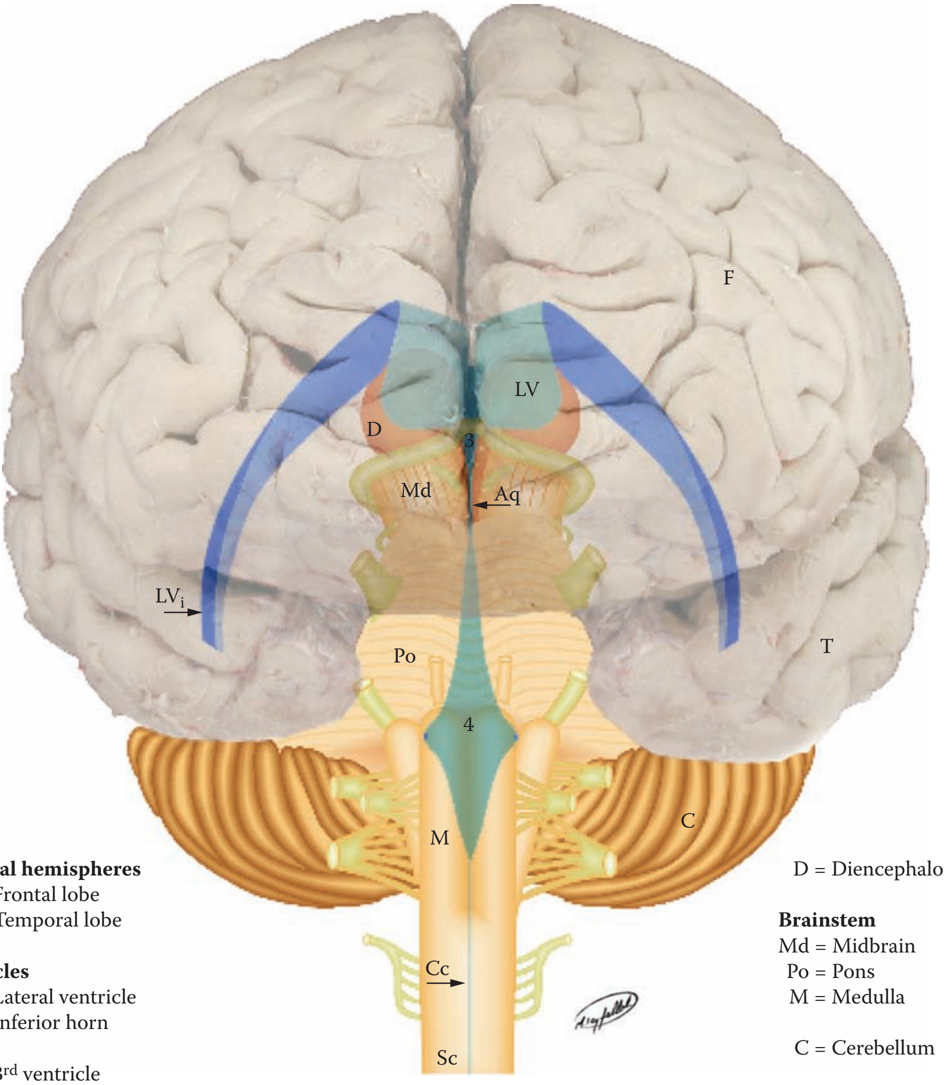
Sections of the brain in the coronal (frontal) axis, if done at the appropriate plane, will reveal the spaces of the lateral ventricles within the hemispheres (see Figure 29 and Figure 74). Likewise, sections of the brain in the horizontal axis, if done at the appropriate level, will show the ventricular spaces of the lateral and third ventricles (see Figure 27). These can also be visualized with radiographic imaging (CT and MRI, see Figure 28A, Figure 28B, and Figure 30).

CLINICAL ASPECT

It is quite apparent that the flow of CSF can be interrupted or blocked at various key points within the ventricular system. The most common site is the aqueduct of the midbrain, the cerebral aqueduct (of Sylvius). Most of the CSF is formed upstream, in the lateral (and third) ventricles. A blockage at the narrowest point, at the level of the aqueduct of the midbrain, will create a damming effect. In essence, this causes a marked enlargement of the ventricles, called **hydrocephalus**. The CSF flow can be blocked for a variety of reasons, such as developmentally, following meningitis, or by a tumor in the region. Enlarged ventricles can be seen with brain imaging (e.g., CT scan).

Hydrocephalus in infancy occurs not uncommonly, for unknown reasons. Since the sutures of the infant's skull are not yet fused, this leads to an enlargement of the head and may include the bulging of the anterior fontanelle. Clinical assessment of all infants should include measuring the size of the head and charting this in the same way one charts height and weight. Untreated hydrocephalus will eventually lead to a compression of the nervous tissue of the hemispheres and damage to the developing brain. Clinical treatment of this condition, after evaluation of the causative factor, includes shunting the CSF out of the ventricles into one of the body cavities.

In adults, hydrocephalus caused by a blockage of the CSF flow leads to an increase in intracranial pressure (discussed in the introduction to Section C). Since the sutures are fused, skull expansion is not possible. The cause in adults is usually a tumor, and in addition to the specific symptoms, the patient will most commonly complain of headache, often in the early morning.



Cerebral hemispheres
F = Frontal lobe
T = Temporal lobe

Ventricles
LV = Lateral ventricle
LV$_i$ = Inferior horn

3 = 3rd ventricle
Aq = Aqueduct of midbrain
4 = 4th ventricle

D = Diencephalon (thalamus)

Brainstem
Md = Midbrain
Po = Pons
M = Medulla

C = Cerebellum

Sc = Spinal cord

Cc = Central canal

FIGURE 20B: **Ventricles 2** — Anterior View

FIGURE 21
VENTRICLES 3

CSF CIRCULATION

This is a representation of the production, circulation, and reabsorption of CSF, the ventricles of the brain, and the subarachnoid spaces around the brain, enlargements of which are called cisterns.

The ventricles of the brain are lined with a layer of cells known as the ependyma. In certain loci within each of the ventricles, the ependymal cells and the pia meet, thus forming the **choroid plexus**, which invaginates into the ventricle. Functionally, the choroid plexus has a vascular layer, i.e., the pia, on the inside, and the ependymal layer on the ventricular side. CSF is actively secreted by the choroid plexus. The blood vessels of the choroid plexus are freely permeable, but there is a cellular barrier between the interior of the choroid plexus and the ventricular space — the **blood-CSF barrier** (B-CSF-B). The barrier consists of tight junctions between the ependymal cells that line the choroid plexus. CSF is actively secreted by the choroid plexus, and an enzyme is involved. The ionic and protein composition of CSF is different from that of serum.

Choroid plexus is found in the lateral ventricles (see Figure 20A), the roof of the third ventricle, and the lower half of the roof of the fourth ventricle. CSF produced in the lateral ventricles flows via the foramen of Monro (from each lateral ventricle) into the third ventricle, and then through the aqueduct of the midbrain into the fourth ventricle. CSF leaves the ventricular system from the fourth ventricle, as indicated schematically in the diagram. In the intact brain, this occurs via the medially placed foramen of Magendie and the two laterally placed foramina of Luschka (as described in the previous illustrations) and enters the enlargement of the subarchnoid space under the cerebellum, the cerebello-medullary cistern, the **cisterna magna.** The cisterna magna is found inside the skull, just above the foramen magnum (see Figure 18).

CSF flows through the subarachnoid space, between the pia and arachnoid. The CSF fills the enlargements of the subarachnoid spaces around the brainstem — the various cisterns (each of which has a separate name). The CSF then flows upward around the hemispheres of the brain and is found in all the gyri and fissures. CSF also flows in the subarachnoid space downward around the spinal cord to fill the lumbar cistern (see Figure 1, Figure 2C, and Figure 3).

This slow circulation is completed by the return of CSF to the venous system. The return is through the **arachnoid villi**, protrusions of arachnoid into the venous sinuses of the brain, particularly along the superior sagittal sinus (see Figure 18). These can sometimes be seen on the specimens as collections of villi, called **arachnoid granulations**, on the surface of the brain lateral to the interhemispheric fissure.

There is no real barrier between the intercellular tissue of the brain and the CSF through the ependyma lining the ventricles (at all sites other than the choroid plexus). Therefore, substances found in detectable amounts in the intercellular spaces of the brain may be found in the CSF.

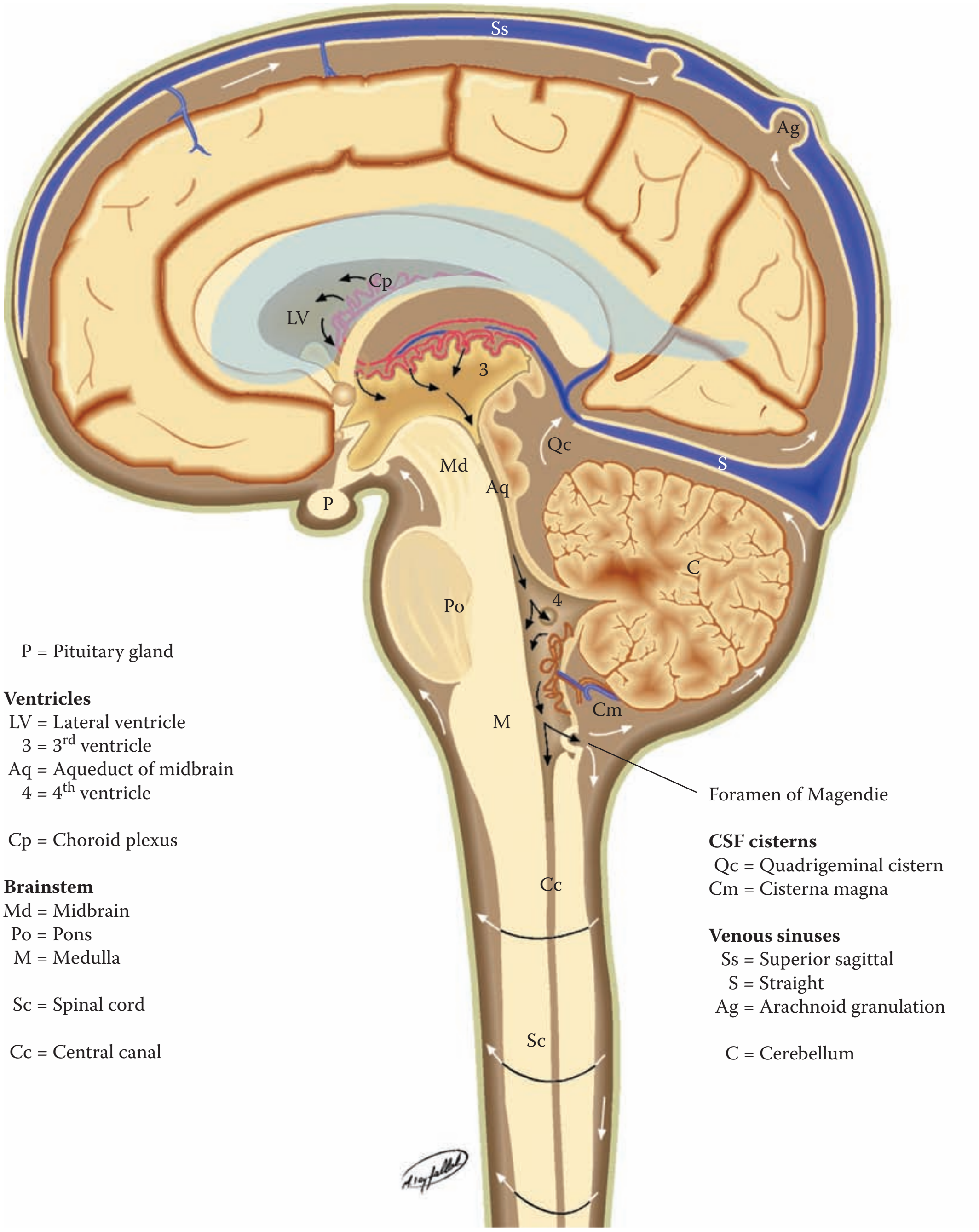
On the other hand, there is a real barrier, both structural and functional, between the blood vessels and the brain tissue. This is called the **blood-brain barrier** (**BBB**), and it is situated at the level of the brain capillaries where there are tight junctions between the endothelial cells. Only oxygen, carbon dioxide, glucose, and other (select) small molecules are normally able to cross the BBB.

CLINICAL ASPECT

The CSF flows down around the spinal cord and into the lumbar cistern. Sampling of CSF for clinical disease, including inflammation of the meninges (meningitis), is performed in the lumbar cistern (see Figure 1, Figure 2C, and Figure 3). The CSF is then analyzed, for cells, proteins, and other constituents to assist or confirm a diagnosis.

The major arteries of the circle of Willis travel through the subarachnoid space (see Figure 58). An aneurysm of these arteries that "bursts" (discussed with Figure 59A) will do so within the CSF space; this is called a subarachnoid hemorrhage.

Hydrocephalus has been discussed with the previous illustration.



P = Pituitary gland

Ventricles
LV = Lateral ventricle
3 = 3rd ventricle
Aq = Aqueduct of midbrain
4 = 4th ventricle

Cp = Choroid plexus

Brainstem
Md = Midbrain
Po = Pons
M = Medulla

Sc = Spinal cord

Cc = Central canal

CSF cisterns
Qc = Quadrigeminal cistern
Cm = Cisterna magna

Venous sinuses
Ss = Superior sagittal
S = Straight
Ag = Arachnoid granulation

C = Cerebellum

FIGURE 21: Ventricles 3 — CSF Circulation

FIGURE 22
BASAL GANGLIA 1

BASAL GANGLIA: ORIENTATION

There are large collections of gray matter within the hemispheres, belonging to the forebrain, in addition to the white matter and the ventricles already described. These neuronal groups are collectively called the **basal ganglia**. Oftentimes the term **striatum** is used for the basal ganglia, but this term is not always used with neuroanatomical precision. Our understanding of the functional role of the basal ganglia is derived largely from disease states affecting these neurons. In general, humans with lesions in the basal ganglia have some form of motor dysfunction, a **dyskinesia**, that is, a movement disorder. But, as will be discussed, these neurons have connections with both neocortical and limbic areas, and are definitely involved in other brain functions.

The description of the basal ganglia will be done in a series of illustrations. This diagram is for orientation and terminology; the following diagrams will discuss more anatomical details and the functional aspects. The details of the connections and the circuitry involving the basal ganglia will be described in Section C (see Figure 52 and Figure 53).

From the strictly anatomical point of view, the basal ganglia are collections of neurons located within the hemispheres. Traditionally, this would include the **caudate** nucleus, the **putamen**, the **globus pallidus**, and the amygdala (see Figure OA and Figure OL). The caudate and putamen are also called the **neostriatum**; histologically these are the same neurons but in the human brain they are partially separated from each other by projection fibers (see Figure 26). The putamen and globus pallidus are anatomically grouped together in the human brain and are called the **lentiform** or **lenticular nucleus** because of the lens-like configuration of the two nuclei, yet these are functionally distinct.

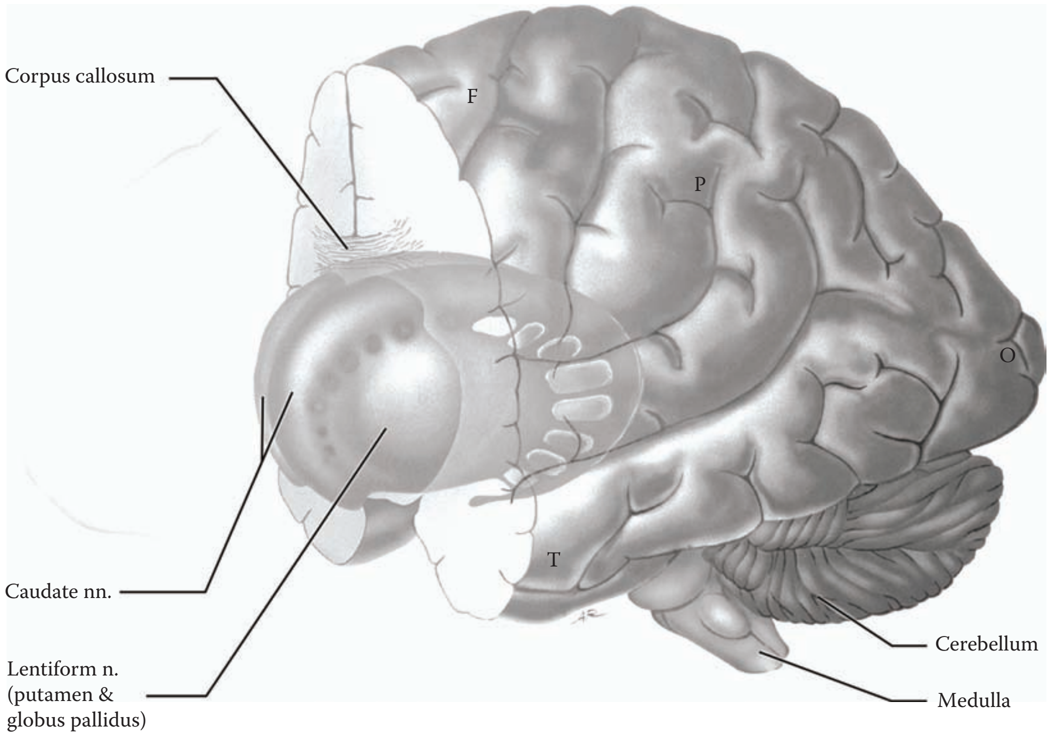
The development of the human brain includes the evolution of a temporal lobe and many structures "migrate" into this lobe, including the lateral ventricle. The caudate nucleus organization follows the curvature of the lateral ventricle into the temporal lobe (see Figure OL and Figure 25).

These basal ganglia are involved in the control of complex patterns of motor activity, such as skilled movements (e.g., writing). There are two aspects to this involvement. The first concerns the initiation of the movement. The second concerns the quality of the performance of the motor task. It seems that different parts of the basal ganglia are concerned with how rapidly a movement is to be performed and the magnitude of the movement. In addition, some of the structures that make up the basal ganglia are thought to influence cognitive aspects of motor control, helping to plan the sequence of tasks needed for purposeful activity. This is sometimes referred to as the selection of motor strategies.

Functionally, the basal ganglia system acts as a subloop of the motor system by altering cortical activity (to be fully discussed with Figure 52 and Figure 53). In general terms, the basal ganglia receive much of their input from the cortex, from the motor areas, and from wide areas of association cortex, as well as from other nuclei of the basal ganglia system. There are intricate connections between the various parts of the system (see Figure 52), involving different neurotransmitters; the output is directed via the thalamus mainly to premotor, supplementary motor, and frontal cortical areas (see Figure 53).

The amygdala, also called the amygdaloid nucleus, is classically one of the basal ganglia, because it is a subcortical collection of neurons (in the temporal lobe, anteriorly, see Figure OL and Figure 25). All the connections of the amygdala are with limbic structures, and so the discussion of this nucleus will be done in Section D (see Figure 75A and Figure 75B).

There are now known to be other subcortical nuclei in the forebrain, particularly in the basal forebrain region. These have not been grouped with the basal ganglia and will be described with the limbic system (in Section D).



F = Frontal lobe
P = Parietal lobe
T = Temporal lobe
O = Occipital lobe

FIGURE 22: **Basal Ganglia 1** — Orientation

FIGURE 23

BASAL GANGLIA 2

BASAL GANGLIA: NUCLEI — LATERAL VIEW

The basal ganglia, from the point of view of strict neuroanatomy, consist of three major nuclei in each of the hemispheres. (The reader is reminded that this illustration has been enlarged from the previous figure, and that these structures are located within the forebrain.)

- The **caudate**
- The **putamen**
- The **globus pallidus**

- The caudate nucleus is anatomically associated with the lateral ventricle and follows its curvature. It is described as having three portions (see Figure 25):
  - The head, located deep within the frontal lobe
  - The body, located deep in the parietal lobe
  - The tail, which goes in to the temporal lobe

The basal ganglia are shown in this illustration from the lateral perspective, as well as from above, allowing a view of the caudate nucleus of both sides. The various parts of the caudate nucleus are easily recognized — head, body, and tail. The head of the caudate nucleus is large and actually intrudes into the space of the anterior horn of the lateral ventricle (see Figure 27 and Figure 28A). The body of the caudate nucleus tapers and becomes considerably smaller and is found beside the body of the lateral ventricle (see Figure 29 and Figure 76). The tail follows the inferior horn of the lateral ventricle into the temporal lobe (see Figure 76). As the name implies, this is a slender extended group of neurons, even more difficult to identify in sections of the temporal lobe (see Figure 74).

The **lentiform** or lenticular nucleus, so named because it is lens-shaped, in fact is composed of two nuclei (see next illustration) — the **putamen** and the **globus pallidus**.

The lentiform nucleus is situated laterally and deep in the hemispheres, within the central white matter. Sections of the brain in the horizontal plane (see Figure 27) and in the coronal (frontal) plane (see Figure 29) show the location of the lentiform nucleus in the depths of the hemispheres, and this can be visualized with brain imaging (see Figure 28A and Figure 28B).

The lentiform (lenticular) nucleus is only a descriptive name, which means lens-shaped. The nucleus is in fact composed of two functionally distinct parts — the putamen laterally, and the globus pallidus medially (see Figure OA, Figure 27, and Figure 52). When viewing the basal ganglia from the lateral perspective, one sees only the putamen part (see Figure OL and Figure 73).

The caudate and the putamen contain the same types of neurons and have similar connections; often they are collectively called the **neostriatum**. Strands of neuronal tissue are often seen connecting the caudate nucleus with the putamen. A very distinct and important fiber bundle, the internal capsule, separates the head of the caudate nucleus from the lentiform nucleus (see next illustration). These fiber bundles "fill the spaces" in between the cellular strands.

ADDITIONAL DETAIL

The inferior or ventral portions of the putamen and globus pallidus are found at the level of the anterior commissure. Both have a limbic connection (discussed with Figure 80B). The amygdala, though part of the basal ganglia by definition, has its functional connections with the limbic system and will be discussed at that time (see Figure 75A and Figure 75B).

NOTE on terminology: Many of the names of structures in the neuroanatomical literature are based upon earlier understandings of the brain, with terminology that is often descriptive and borrowed from other languages. As we learn more about the connections and functions of brain areas, this terminology often seems awkward if not obsolete, yet it persists.

The term ganglia, in the strict use of the term, refers to a collection of neurons in the peripheral nervous system. Therefore, the anatomically correct name for the neurons in the forebrain should be the ***basal nuclei***. Few texts use this term. Most clinicians would be hard-pressed to change the name from basal ganglia to something else, so the traditional name remains.

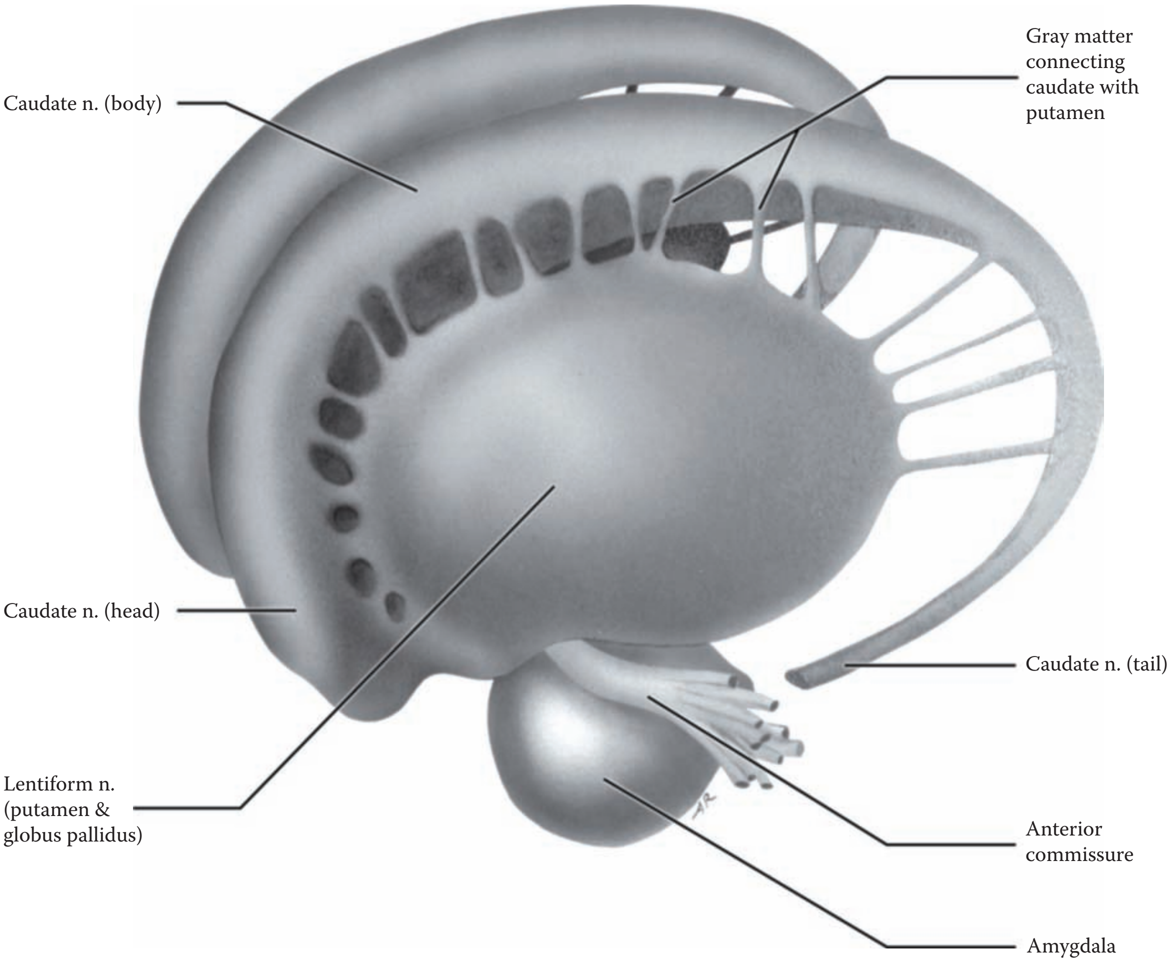


FIGURE 23: **Basal Ganglia 2** — Nuclei: Lateral View

FIGURE 24
BASAL GANGLIA 3

BASAL GANGLIA: NUCLEI — MEDIAL VIEW

This view has been obtained by removing all parts of the basal ganglia of one hemisphere, except the tail of the caudate and the amygdala. This exposes the caudate nucleus and the lentiform nucleus of the "distal" side; the lentiform nucleus is thus being visualized from a medial perspective.

The lentiform nucleus is now seen to be composed of its two portions, the putamen, laterally, and the globus pallidus, which is medially placed. In fact, the globus pallidus has two parts, an external (lateral) segment and an internal (medial) segment.

Functionally, the nuclei of the basal ganglia are organized in the following way. The input from the cerebral cortex and from other sources (thalamus, substantia nigra) is received by the caudate and putamen (see Figure 52). This information is relayed to the globus pallidus. It is composed of two segments, the medial and lateral segments, also known as internal and external segments, respectively. (These can also be seen in the horizontal section of the brain, see Figure 27). This subdivision of the globus pallidus is quite important functionally, as each of the segments has distinct connections. The globus pallidus, internal segment, is the major efferent nucleus of the basal ganglia (see Figure 53).

From the functional point of view, and based upon the complex pattern of interconnections, two other nuclei, which are not in the forebrain, should be included with the description of the basal ganglia — the **subthalamic nucleus** (part of the diencephalon), and the **substantia nigra** (located in the midbrain). The functional connections of these nuclei will be discussed as part of the motor systems (see Figure 52 and Figure 53).

A distinct collection of neurons is found in the ventral region of the basal ganglia — the **nucleus accumbens**. The nucleus accumbens is somewhat unique, in that it seems to consist of a mix of neurons from the basal ganglia and from the limbic structures in the region. This nucleus is involved with what is termed "reward" behavior and seems to be the part of the brain most implicated in drug addiction (discussed with the limbic system, see Figure 80B).

CLINICAL ASPECT

The functional role of this large collection of basal ganglia neurons is best illustrated by clinical conditions in which this system does not function properly. These disease entities manifest abnormal movements, such as chorea (jerky movements), athetosis (writhing movements), and tremors (rhythmic movements).

The most common condition that affects this functional system of neurons is **Parkinson's** disease. The person with this disease has difficulty initiating movements, the face takes on a mask-like appearance with loss of facial expressiveness, there is muscular rigidity, a slowing of movements (bradykinesia), and a tremor of the hands at rest, which goes away with purposeful movements (and in sleep). Some individuals with Parkinson's also develop cognitive and emotional problems, implicating these neurons in brain processes other than motor functions.

People with Parkinson's disease also develop **rigidity**. In rigidity, there is an increased resistance to passive movement of the limb, which involves both the flexors and extensors, and the response is not velocity dependent. There is no alteration of reflex responsiveness, nor is there clonus (discussed with Figure 49B). In this clinical state, the plantar response is normal (see Section B, Part III, Introduction).

The other major disease that affects the Basal Ganglia is **Huntington's Chorea**, an inherited degenerative condition. This disease, which starts in midlife, leads to severe motor dysfunction, as well as cognitive decline. The person whose name is most associated with this disease is Woody Guthrie, a legendary folk singer. There is now a genetic test for this disease that predicts whether the individual, with a family history of Huntington's, will develop the disease.

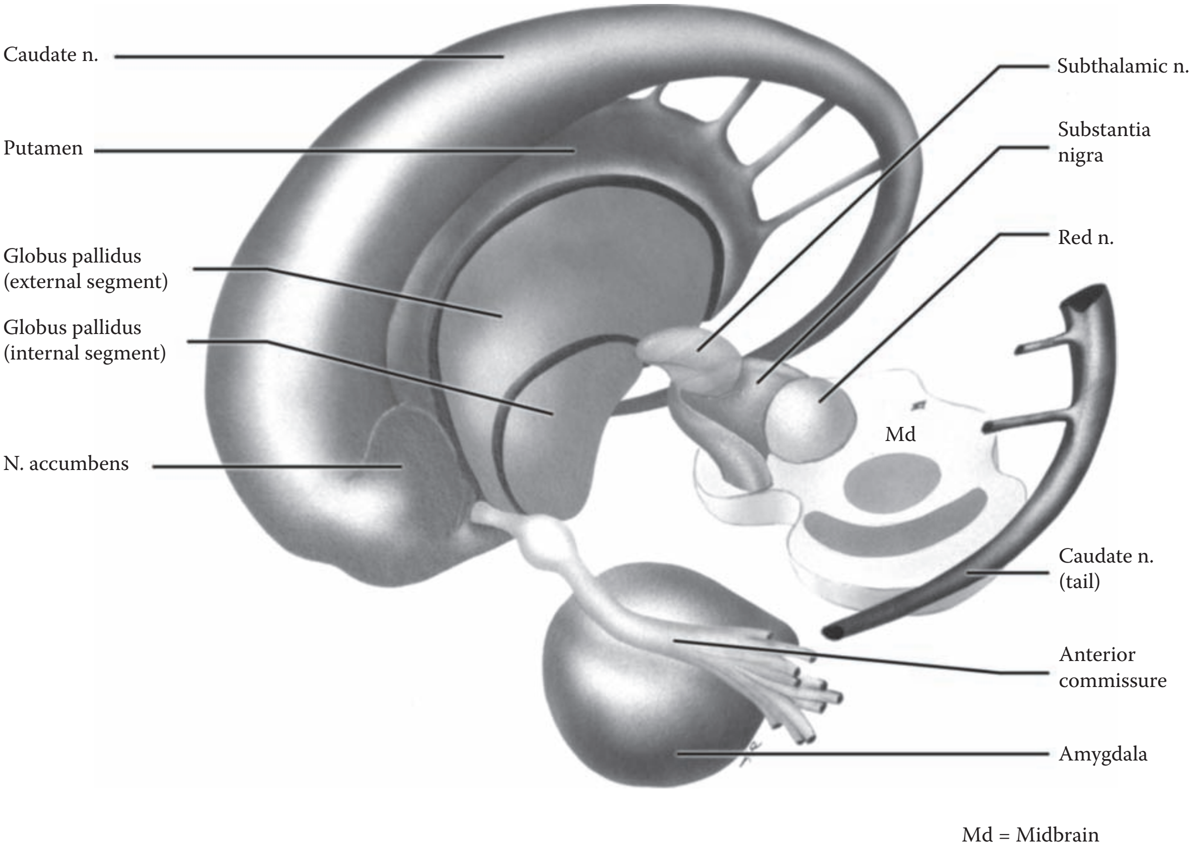


FIGURE 24: **Basal Ganglia 3** — Nuclei: Medial View

FIGURE 25
BASAL GANGLIA 4

BASAL GANGLIA AND VENTRICLES

In humans, the three nuclei of the basal ganglia have a complex and finite arrangement in the hemispheres of the brain. Visualization of their location is made easier by understanding their relationship with the cerebral ventricles (see Figure OA and Figure OL).

The lateral ventricles of the hemispheres are shown in this view, from the lateral perspective (as in Figure OL and Figure 20A). The way in which all three parts of the caudate nucleus, the head, body, and tail, are situated adjacent to the lateral ventricle can be clearly seen, with the tail following the ventricle into the temporal lobe (see Figure 22 and also Figure 76).

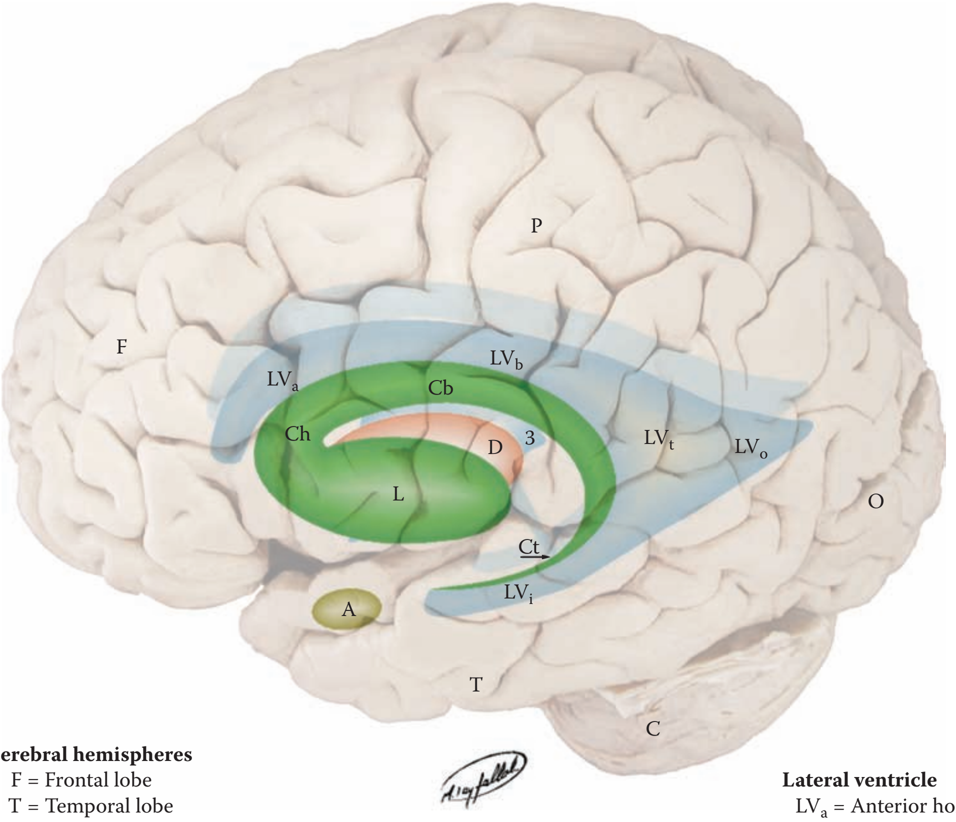
The various parts of the basal ganglia include the caudate nucleus, the lentiform nucleus, and also the amygdala. The lentiform nucleus, including putamen and globus pallidus, is located deep within the hemispheres, not adjacent to the ventricle. This “nucleus” is found lateral to the thalamus, which locates the lentiform nucleus as lateral to third ventricle in a horizontal section of the brain (see Figure 27). The lentiform nucleus, actually the putamen, is seen in a dissection of the brain from the lateral perspective (see Figure 73).

In this diagram one can see that the caudate and the lentiform nuclei are connected anteriorly. In addition, there are connecting strands of tissue between the caudate and putamen. (These connecting strands have been shown in the previous diagrams.) As fiber systems develop, namely the projection fibers, these nuclei become separated from each other, specifically by the anterior limb of the internal capsule (see next illustration).

Again, it should be noted that basal ganglia occupy a limited area in the depths of the hemispheres. Sections taken more anteriorly or more posteriorly (see Figure 74), or above the ventricles, will not have any parts of these basal ganglia.

In summary, both the caudate and the lentiform nuclei are found below the plane of the corpus callosum. The head of the caudate nucleus and the lentiform nucleus are found at the same plane as the thalamus, as well as the anterior horns of the lateral ventricles (see Figure 27). As will be seen, this is also the plane of the lateral fissure and the insula. These are important aspects of neuroanatomy to bear in mind when the brain is seen neuroradiologically with CT and MRI (see Figure 28A and Figure 28B).

From this lateral perspective, the third ventricle, occupying the midline, is almost completely hidden from view by the thalamus, which lies adjacent to this ventricle and forms its lateral boundaries (see Figure 9, Figure OA, Figure OL, and Figure 20B).



Cerebral hemispheres
F = Frontal lobe
T = Temporal lobe
P = Parietal lobe
O = Occipital lobe

Basal Ganglia
Ch = Caudate head
Cb = Caudate body
Ct = Caudate tail
L = Lenticular nucleus

A = Amygdala

Lateral ventricle
LV_a = Anterior horn
LV_b = Body
LV_t = Atrium (trigone)
LV_i = Inferior horn
LV_o = Occipital horn

3 = 3rd ventricle

D = Diencephalon (thalamus)

C = Cerebellum

FIGURE 25: **Basal Ganglia 4** — Nuclei and Ventricles

FIGURE 26
BASAL GANGLIA 5

INTERNAL CAPSULE: PROJECTION FIBERS

The white matter bundles that course between parts of the basal ganglia and the thalamus are collectively grouped together and called the **internal capsule**. These are projection fibers, axons going to and coming from the cerebral cortex. The internal capsule is defined as a group of fibers located at a specific plane within the cerebral hemispheres in a region that is situated between the head of the caudate, the lentiform, and the thalamus (see Figure OA, Figure OL, and Figure 25).

The internal capsule has three parts:

- **Anterior limb**. A group of fibers separates the two parts of the neostriatum from each other, the head of the caudate from the putamen. This fiber system carries axons that are coming down from the cortex, mostly to the pontine region, which are then relayed to the cerebellum (see Figure 55). Other fibers in the anterior limb relay from the thalamus to the cingulate gyrus (see Figure 77A) and to the prefrontal cortex (see Figure 77B).
- **Posterior limb**. The fiber system that runs between the thalamus (medially) and the lentiform nucleus (laterally) is the posterior limb of the internal capsule. The posterior limb carries three extremely important sets of fibers
  - Sensory information from thalamus to cortex, as well as the reciprocal connections from cortex to thalamus.
  - Most of the descending fibers to the brainstem (cortico-bulbar, see Figure 46) and spinal cord (cortico-spinal, see Figure 45).
  - In addition, there are fibers from other parts of the cortex that are destined for the cerebellum, after synapsing in the pontine nuclei (discussed with Figure 55).
- **The genu**. In a horizontal section, the internal capsule (of each side) is seen to be V-shaped (see Figure 27). Both the anterior limb and the posterior limb have been described — the bend of the "V" is called the genu, and it points medially (also seen with neuroradiological imaging, both CT, see Figure 28A, and MRI, see Figure 28B).

The internal capsule fibers are also seen from the medial perspective in a dissection in which the thalamus has been removed (see Figure 70B). The fibers of the internal capsule are also shown in a dissection of the brain from the lateral perspective, just medial to the lentiform nucleus (see Figure 73).

Below the level of the internal capsule is the midbrain. The descending fibers of the internal capsule continue into the midbrain and are next located in the structure called the cerebral peduncle of the midbrain (see Figure 6, Figure 7, Figure 45, and Figure 46; also seen in cross-sections of the brainstem in Figure 65).

In summary, at the level of the internal capsule, there are both the ascending fibers from thalamus to cortex, as well as descending fibers from widespread areas of the cerebral cortex to the thalamus, the brainstem and cerebellum, and the spinal cord. These ascending and descending fibers are all called projection fibers (discussed with Figure 16). This whole fiber system is sometimes likened to a funnel, with the top of the funnel being the cerebral cortex and the stem the cerebral peduncle. The base of the funnel, where the funnel narrows, would be the internal capsule. The main point is that the various fiber systems, both ascending and descending, are condensed together in the region of the internal capsule.

Note to the Learner: Many students have difficulty understanding the concept of the internal capsule, and where it is located. One way of thinking about it is to look at the projection fibers as a busy two-lane highway. The internal capsule represents one section of this pathway, where the roadway is narrowed.

CLINICAL ASPECT

The posterior limb of the internal capsule is a region that is apparently particularly vulnerable for small vascular bleeds. These small hemorrhages destroy the fibers in this region. Because of the high packing density of the axons in this region, a small lesion can cause extensive disruption of descending motor or ascending sensory pathways. This is one of the most common types of cerebrovascular accidents, commonly called a "stroke." (The details of the vascular supply to this region will be discussed with Figure 62.)

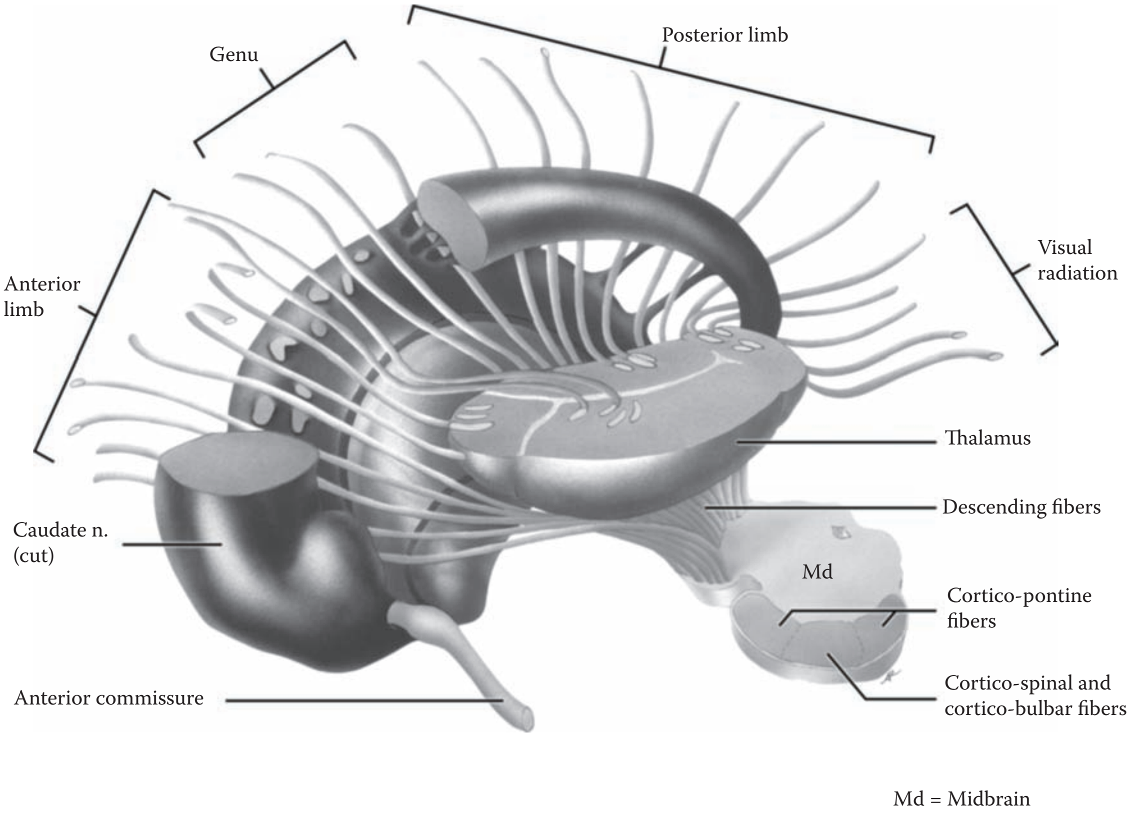


FIGURE 26: **Basal Ganglia 5** — Internal Capsule and Nuclei

FIGURE 27
BASAL GANGLIA 6

HORIZONTAL SECTION OF HEMISPHERES (PHOTOGRAPHIC VIEW)

In this photograph, the brain has been sectioned in the horizontal plane. From the dorsolateral view (the small figure on the upper left), the level of the section is just above the lateral fissure and at a slight angle downward from front to back. Using the medial view of the brain (the figure on the upper right), the plane of section goes through the anterior horn of the lateral ventricle, the thalamus and the occipital lobe.

This brain section exposes the white matter of the hemispheres, the basal ganglia, and parts of the ventricular system. Understanding this particular depiction of the brain is vital to the study of the forebrain. The structures seen in this view are also of immeasurable importance clinically, and this view is most commonly used in neuroimaging studies, both CT and MRI (shown in Figure 28A and Figure 28B).

The basal ganglia are present when the brain is sectioned at this level (see Figure 25). The head of the caudate nucleus protrudes into the anterior horn of the lateral ventricle (seen in the CT, Figure 28A). The lentiform nucleus, shaped somewhat like a lens, is demarcated by white matter. Since the putamen and caudate neurons are identical, therefore, the two nuclei have the same grayish coloration. The globus pallidus is functionally different and contains many more fibers, and therefore is lighter in color. Depending upon the level of the section, it is sometimes possible (in this case on both sides) to see the two subdivisions of the globus pallidus, the internal and external segments (see Figure 24).

The white matter medial to the lentiform nucleus is the internal capsule (see Figure 26 and Figure 73). It is divisible into an anterior limb and a posterior limb and genu. The **anterior limb** separates the lentiform nucleus from the head of the caudate nucleus. The **posterior limb** of the internal capsule separates the lentiform nucleus from the thalamus. Some strands of gray matter located within the internal capsule represent the strands of gray matter between the caudate and the putamen (as shown in Figure 23). The base of the "V" is called the **genu**.

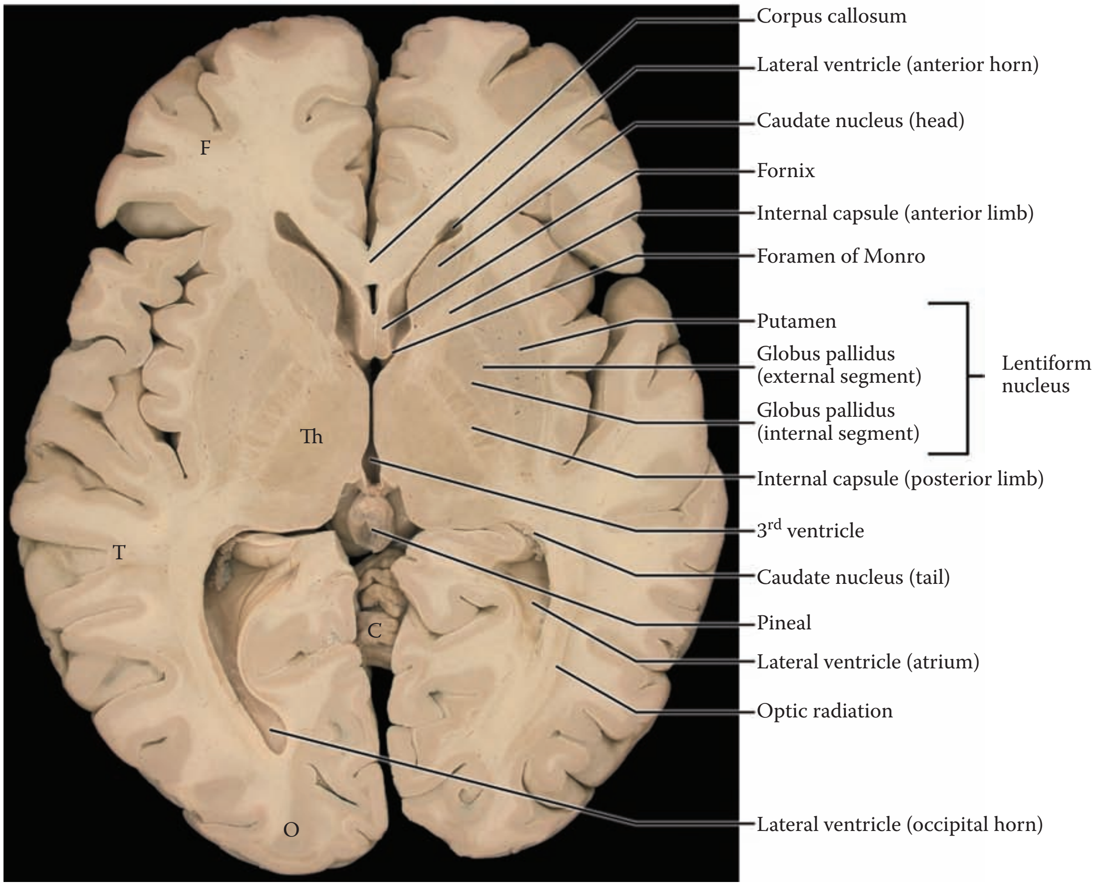
The anterior horn of the lateral ventricle is cut through its lowermost part and is seen in this photograph as a small cavity (see Figure 20A). The plane of the section has passed through the connection between the lateral ventricles and the third ventricle, the foramina of Monro (see Figure 20B). The section has also passed through the lateral ventricle as it curves into the temporal lobe to become the inferior horn of the lateral ventricle, the area called the atrium or trigone (better seen on the left side of this photograph; see Figure 20A and Figure 25). The choroid plexus of the lateral ventricle, which follows the inner curvature of the ventricle, is present on both sides (not labeled; see Figure 20A).

The section is somewhat asymmetrical in that the posterior horn of the lateral ventricle is fully present in the occipital lobe on the left side and not on the right side of the photograph. On the right side, a group of fibers is seen streaming toward the posterior pole, and these represent the visual fibers, called the optic radiation (discussed with Figure 41A and Figure 41B). The small size of the tail of the caudate nucleus alongside the lateral ventricle can be appreciated (see Figure 23 and Figure 25).

The third ventricle is situated between the thalamus of both sides (see Figure 9). The pineal is seen attached to the back end of the ventricle. A bit of the cerebellar vermis is visible posteriorly, behind the thalamus and between the occipital lobes.

CLINICAL ASPECT

This is the plane of view that would be used to look for small bleeds, called lacunes, in the posterior limb of the internal capsule (discussed with Figure 62). The major ascending sensory tracts and the descending motor tracts from the cerebral cortex are found in the posterior limb.



F = Frontal lobe
T = Temporal lobe
O = Occipital lobe

Th = Thalamus

C = Cerebellum (vermis)

FIGURE 27: **Basal Ganglia 6** — Horizontal Section (photograph)

FIGURE 28A
BASAL GANGLIA 7

HORIZONTAL VIEW: CT SCAN (RADIOGRAPH)

This radiological view of the brain is not in exactly the same horizontal plane as the anatomical specimen shown in the previous illustration. The radiological images of the brain are often done at a slight angle in order to minimize the exposure of the stuctures of the orbit, the retina and the lens, to the potential damaging effects of the x-rays used to generate a CT scan.

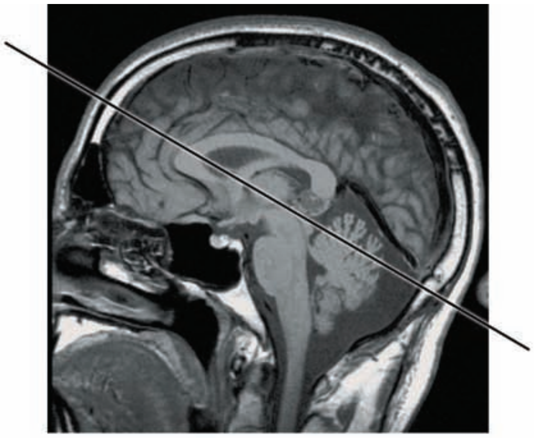
A CT image shows the skull bones (in white) and the relationship of the brain to the skull. A piece of the falx cerebri can also be seen. The outer cortical tissue is visible, with gyri and sulci, but not in as much detail as an MRI (shown in the next illustration). The structures seen in the interior of the brain include the white matter, and the ventricular spaces, the lateral ventricles with the septum pellucidum, and the third ventricle. Note that the CSF is dark (black). The cerebellum can be recognized, with its folia, but there is no sharp delineation between it and the cerebral hemispheres.

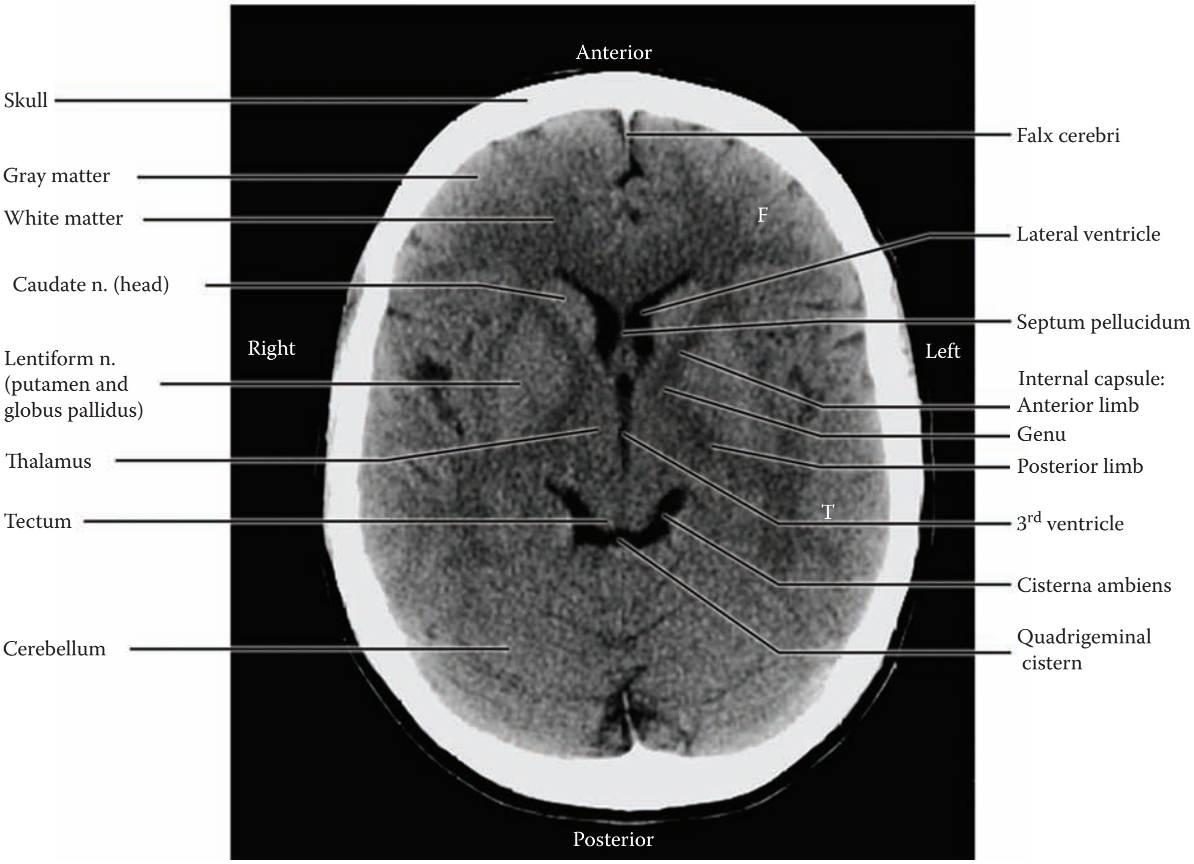
Although the basal ganglia and thalamus can be seen, there is little tissue definition. Note that the head of the caudate nucleus “protrudes” (bulges) into the anterior horn of the (lateral) ventricle (as in the previous brain section). The lentiform nucleus is identified and the internal capsule can be seen as well, with both the anterior and posterior limbs, and the genu.

The CSF cistern is seen behind the tectal plate (the colliculi; also known as the tectum or the quadrigeminal plate, see Figure 9A and Figure 10) — called the quadrigeminal plate cistern (seen also in the mid-sagittal views, Figure 17 and Figure 18, but not labeled); its “wings” are called the cisterna ambiens, a very important landmark for the neuroradiologist.

CLINICAL ASPECT

A regular CT can show an area of hemorrhage (blood has increased density), an area of decreased density (e.g., following an infarct), as well as changes in the size and shifting of the ventricles. This examination is invaluable in the assessment of a neurological patient in the acute stage of an illness or following a head injury and is most frequently used because the image can be captured in seconds. A CT can also be “enhanced” by injecting an iodinated compound into the blood circulation and noting whether it “escapes” into the brain tissue because of leakage in the BBB (discussed with Figure 21), for example, with tumors of the brain.





F = Frontal lobe
T = Temporal lobe

FIGURE 28A: **Basal Ganglia 7** — CT: Horizontal View (radiograph)

FIGURE 28B
BASAL GANGLIA 8

HORIZONTAL VIEW: T2 MRI (RADIOGRAPH)

This radiograph is a view of the brain taken in the same plane, horizontally, closer to the plane of the brain section (see Figure 27), but a little higher than the previous radiograph. Parameters of the MRI have been adjusted to generate a **T2**-weighted image (see explanation with Figure 3). In this view, the CSF of the ventricles is white, while the bones of the skull are dark.

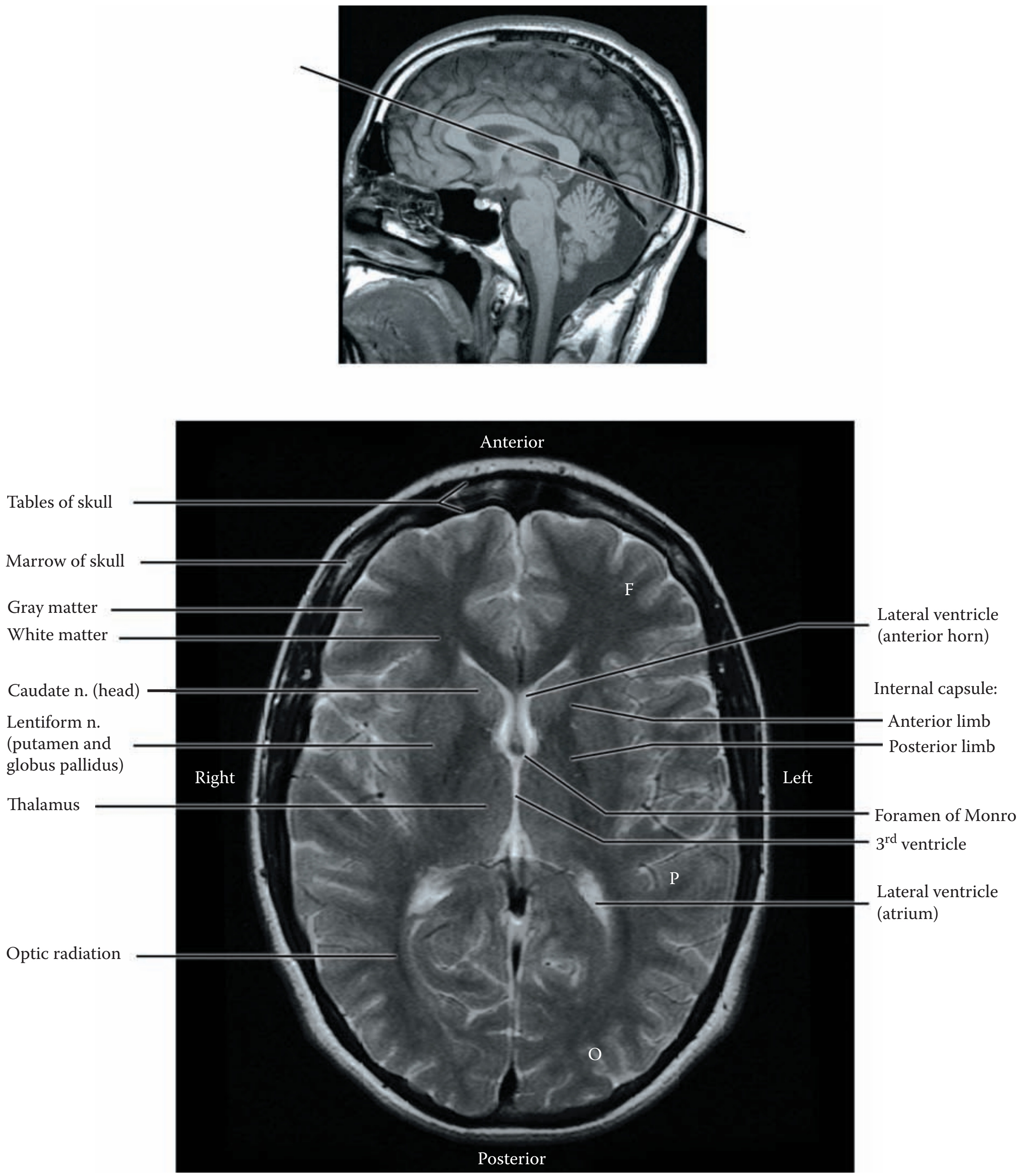
This MRI shows the brain as if it were an anatomical specimen (compare with the previous illustration) — there is a good differentiation between the gray matter and the white matter. There is a clear visualization of the basal ganglia and its subdivisions (head of the caudate, lentiform nucleus), as well as the thalamus. (**Note**: The line separating the putamen from the globus pallidus can "almost" be seen on the right side of the photograph.) In addition, the area of the internal capsule is also clearly seen.

The anterior horns of the lateral ventricle are present, and the section has passed through the formina of Monro (see Figure 20A, Figure 20B, and Figure 21). The lateral ventricle posteriorly is cut at the level of its widening, the atrium or trigone, as it curves into the temporal lobe (see Figure 20A). The third ventricle is in the midline, between the thalami (see Figure 6, Figure 7, and Figure 9A).

The linear marking in the white matter behind the atrium likely represents the optic radiation, from the lateral geniculate to the calcarine cortex (see Figure 41A and Figure 41C).

CLINICAL ASPECT

The MRI has proved to be invaluable in assessing lesions of the CNS — infarcts, tumors, plaques of multiple sclerosis, and numerous other lesions. An MRI can also be enhanced with intravenous gadolinium, which escapes with the blood when there is a breakdown of the BBB, and helps in the evaluation of pathology, such as tumors.



F = Frontal lobe
P = Parietal lobe
O = Occipital lobe

FIGURE 28B: **Basal Ganglia 8** — MRI: Horizontal View (radiograph)

FIGURE 29
BASAL GANGLIA 9

CORONAL SECTION OF HEMISPHERES (PHOTOGRAPHIC VIEW)

This photographic view of the brain is sectioned in the coronal plane and shows the internal aspect of the hemispheres. On the dorsolateral view (small figure, upper left) the plane of section goes through both the frontal and the temporal lobes and would include the region of the basal ganglia. From the medial perspective (the figure on the upper right), the section includes the body of the lateral ventricles with the corpus callosum above, the anterior portion of the thalamus, and the third ventricle; the edge of the section also passes through the hypothalamus, the mammillary nucleus, and includes the optic tracts. The section passes in front of the anterior part of the midbrain, the cerebral peduncles, and the front tip of the pons.

The cerebral cortex, the gray matter, lies on the external aspect of the hemispheres and follows its outline into the sulci in between, wherever there is a surface. The deep interhemispheric fissure is seen between the two hemispheres, above the corpus callosum (not labeled, see Figure 16 and Figure 17). The lateral fissure is also present, well seen on the left side of the photograph (also not labeled), with the insula within the depths of this fissure (see Figure 14B and Figure 39).

The white matter is seen internally; it is not possible to separate out the various fiber systems of the white matter (see Figure 19A and Figure 19B). Below the corpus callosum are the two spaces, the cavities of the lateral ventricle, represented at this plane by the body of the ventricles (see Figure 20B, Figure 25, and Figure 76). The small gray matter on the side of the lateral ventricle is the body of the caudate nucleus (see Figure 23, Figure 25, Figure 27, and Figure 76). Because the section was not cut symmetrically, the inferior horn of the lateral ventricle is found only on the right side of this photograph, in the temporal lobe.

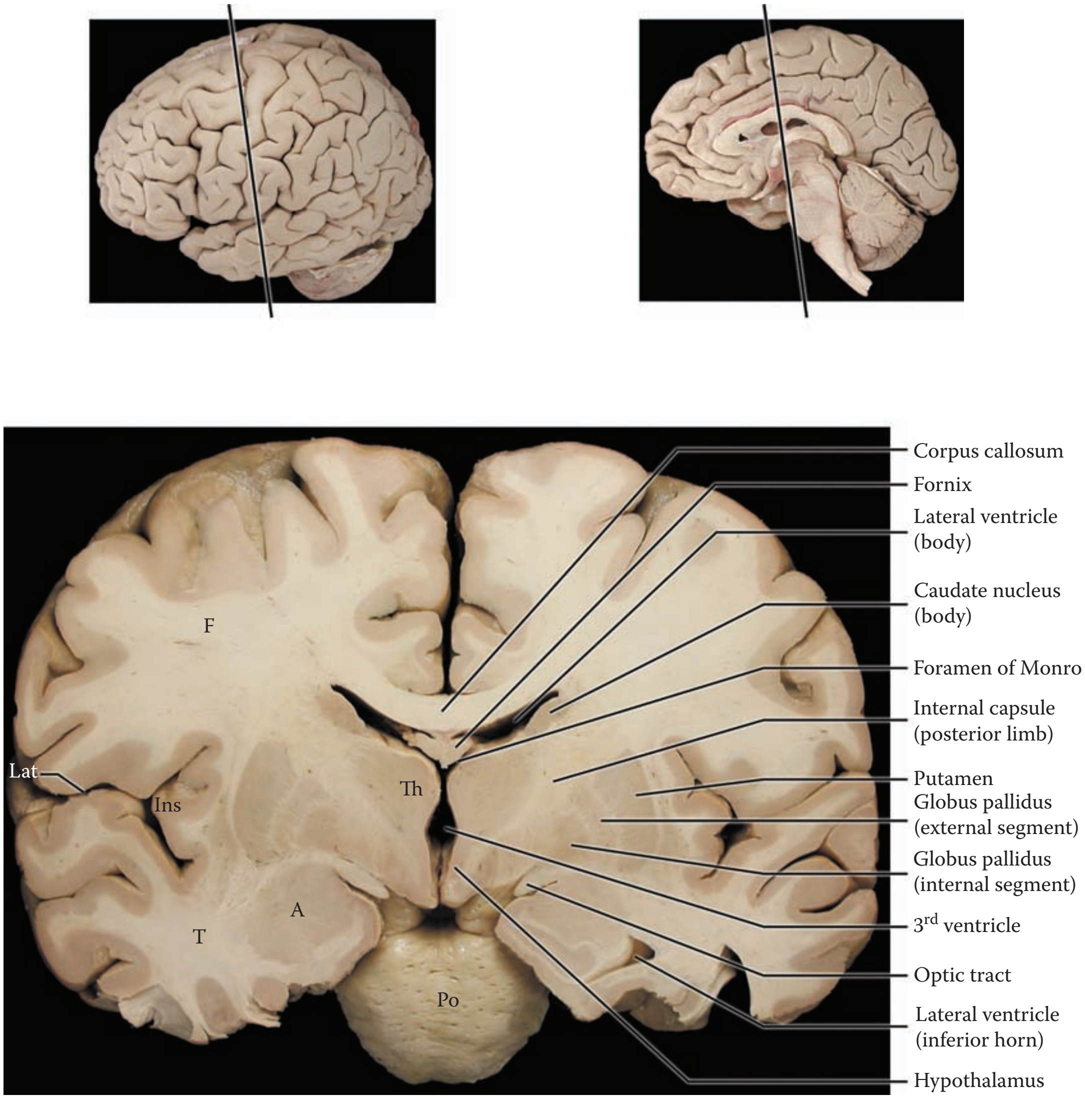
The brain is sectioned in the coronal plane through the diencephalic region. The gray matter on either side of the third ventricle is the thalamus (see Figure 11). Lateral to this is a band of white matter, which by definition is part of the internal capsule, with the lentiform nucleus on its lateral side. In order to identify which part this is, the learner should refer to the section in the horizontal plane (see Figure 26 and Figure 27); the portion between the thalamus and lentiform nucleus is the posterior limb.

The parts of the lentifrom nucleus seen in this view include the putamen as well as the two portions of the globus pallidus, the external and internal segments. Since the brain has not been sectioned symmetrically, the two portions are more easily identified on the right side of the photograph. The claustrum has also been labeled (see below). The structures noted in this section should be compared with a similar (coronal) view of the brain taken more posteriorly (see Figure 74).

The gray matter within the temporal lobe, best seen on the left side of the photograph, is the amygdala (see Figure OL, Figure 25, and Figure 75A). It is easy to understand why this nucleus is considered one of the basal ganglia, by definition. Its function, as well as that of the fornix, will be explained with the limbic system section of this atlas (Section D).

Additional Detail

Lateral to the lentiform nucleus is another thin strip of gray matter, the claustrum. The functional contribution of this small strip of tissue is not really known. The claustrum is also seen in the horizontal section (see Figure 27). Lateral to this is the cortex of the insula, inside the lateral fissure (see Figure 14B and Figure 39).



F = Frontal lobe
T = Temporal lobe

Lat = Lateral fissure
Ins = Insula

Th = Thalamus

A = Amygdala

Po = Pons

FIGURE 29: **Basal Ganglia 9** — Coronal Section (photograph)

FIGURE 30
BASAL GANGLIA 10

CORONAL VIEW: MRI (RADIOGRAPH)

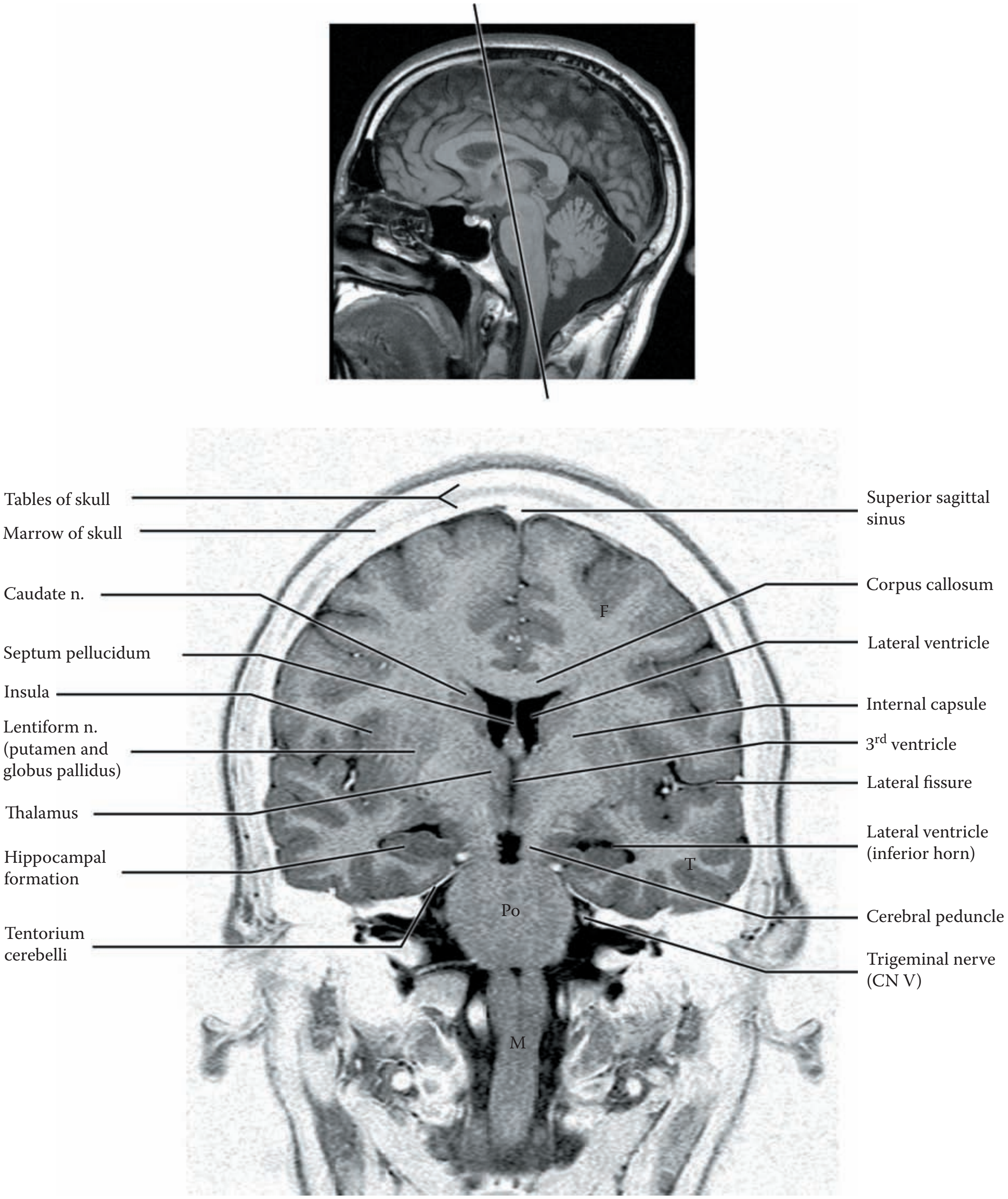
This is a view of the brain similar to the previous brain section, in the coronal plane. The T2 MRI has been adjusted on the viewing screen to invert the displayed image (sometimes called an inverted video view). The distinction between the gray matter and the white matter is enhanced with this view; the CSF is dark. Note that the tables of the skull are now white, and the bone marrow is dark. The superior sagittal sinus is seen in the midline, at the top of the falx cerebri (bright).

The cortex and white matter can be easily differentiated. The corpus callosum is seen crossing the midline. The caudate nucleus is diminishing in size, from the head (anteriorly) to the body (posteriorly — compare with another coronal section of the brain, see Figure 74). The lentiform nucleus is still present and the thalamus can be seen adjacent to the third ventricle.

By definition, the section has passed through the posterior limb of the internal capsule (see Figure 26). Its fibers are seen as continuing to become the cerebral peduncle (see Figure 6 and Figure 7). The plane of section includes the lateral fissure, and the insula (see Figure 17B). The temporal lobe includes the hippocampal formation and the inferior horn of the lateral ventricle (see Figure 20A, Figure 20B, and Figure 74).

The lateral ventricle is seen, divided by the septum pellucidum into one for each hemisphere (see also Figure 62). Again, the plane of section has passed through the foramina of Monro, connecting to the third ventricle, which is situated between the thalamus on either side.

This view also includes the brainstem — the midbrain (the cerebral peduncles), the pons (the ventral portion), and the medulla. The trigeminal nerve has been identified at the midpontine level. The tentorium cerebelli can now be clearly seen (see Figure 17 and Figure 41B), with its opening (also called incisura) at the level of the midbrain (discussed with uncal herniation, see Figure 15B).



F = Frontal lobe
T = Temporal lobe
Po = Pons
M = Medulla

FIGURE 30: **Basal Ganglia 10** — MRI: Coronal View (radiograph)