HyperBrain Syllabus

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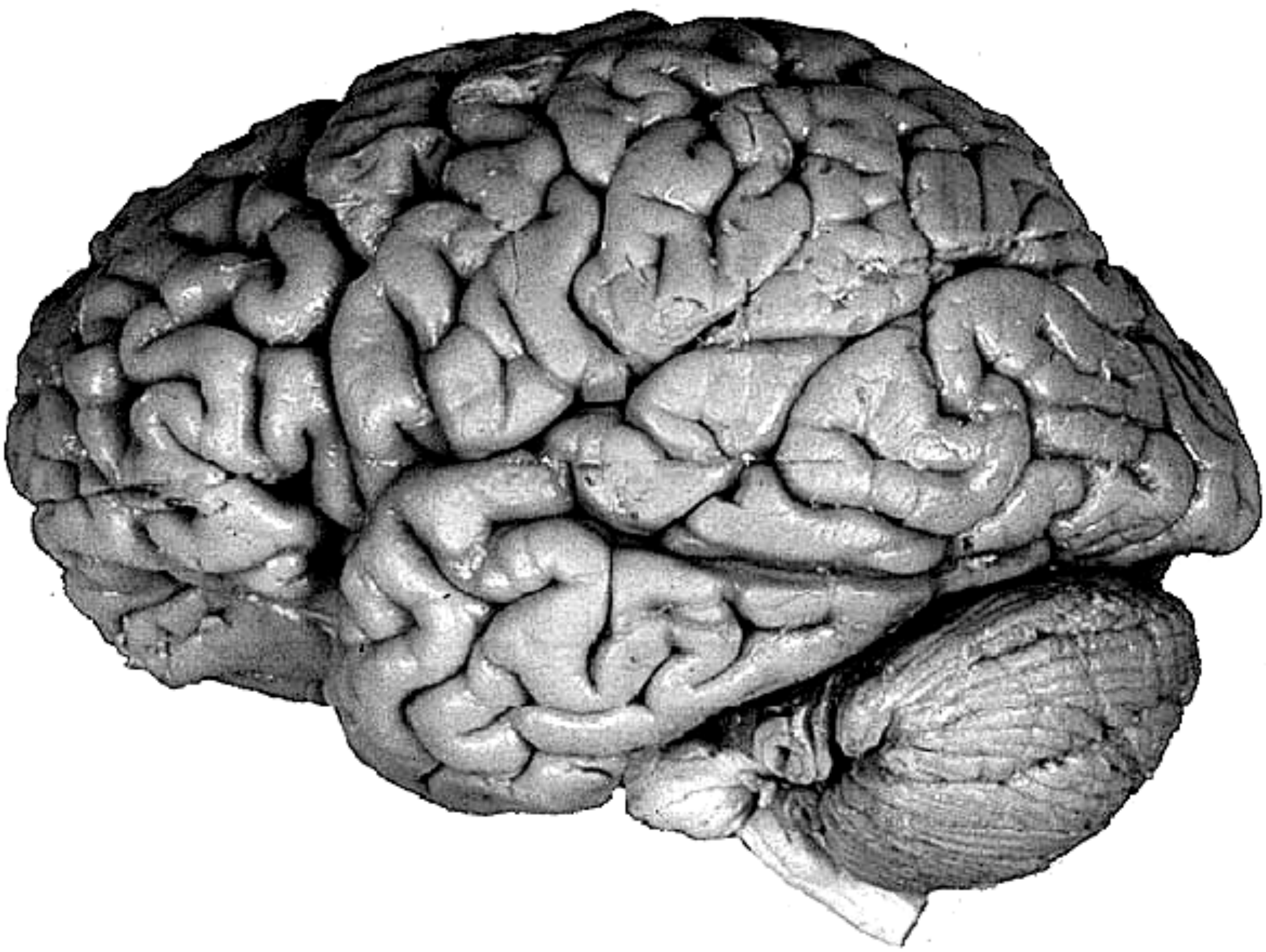

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2010 Edition

Contents

HyperBrain Instructions

To get to the HyperBrain web site, just type "hyperbrain" into Google, and click on the first result (http://library.med.utah.edu/kw/hyperbrain/), and then bookmark this site.

On the Home page, click on "User Guide" and follow the instructions there.

You are expected to do all of the HyperBrain chapters, not just those with a corresponding lab. HyperBrain chapters without a corresponding lab should be done the evening of the corresponding lecture to reinforce your learning in class.

This **HyperBrain Syllabus (pdf)** is for use with **HyperBrain on the web**. This is the same text that is on the web. It is provided so you can print it, annotate it, bring it to lab, and use it for review according to your needs.

> This HyperBrain Syllabus (pdf) also includes a one-page Review of Terms, at the end of each chapter, that is not included in HyperBrain on the web.

How to use HyperBrain

1. **Complete the corresponding HyperBrain chapter(s) on the web BEFORE lab.**

   Otherwise, lab will be a low-yield experience: You will have only about 45 minutes to review the structures and 3D relationships on actual brains, and to review the material with your lab preceptor. Many images on the practical exams are HyperBrain web images.

2. **For each chapter:**

   a. **Read the text**, clicking on **all numbered links** and **all figures**. Also, click on **all glossary terms to see additional images of the anatomy, but do not read the glossary definitions unless you need to.**

   b. **Complete the Syllabus Quiz**, linked at the end of the chapter.

   c. **Click on the Pathway Quiz and movies** for additional ways to learn the information.

We hope you find HyperBrain useful and enjoyable. Your suggestions are welcome.

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Suzanne S. Stensaas, Ph.D. provided photograph revisions 2004 – 2010

1. The Cranial Nerves and the Circle Of Willis

Revised 2007

The objectives of this chapter are to identify:

1. The structural divisions of the central nervous system (CNS).
2. The cranial nerve roots associated with each brain stem division.
3. The connective tissue wrappings, or the meninges, of the brain and spinal cord.
4. The major arteries, veins and dural sinuses.

I. Regions of the CNS

The neural tube finally consists of six divisions. Although each division has a characteristic appearance, both macroscopically and microscopically, it does not constitute a separate and independent functional unit. The central nervous system does not consist merely of a series of transverse slabs. From caudal to rostral, the divisions of the neural tube (#4281) are spinal cord, medulla (green), pons & cerebellum (yellow), midbrain (blue), diencephalon (purple), and cerebrum (uncolored). They are visible on the ventral surface of the brain as in fig 1a. **Note: The labels on fig 1a and all figures in HyperBrain are linked to the glossary definition. To learn more as you go you can click on each label. However, the text explains many of the terms directly related to the chapter.**

1. spinal cord
2. medulla oblongata = myelencephalon (#4985)
3. pons and cerebellum = metencephalon (#4984)
4. midbrain = mesencephalon (#4983)
5. diencephalon, which consists mainly of the thalamus (#4269, light blue) and hypothalamus (dark blue)
6. cerebrum = telencephalon, whose surface consists of the cerebral cortex (#8430).

Conveniently the divisions of the brain have the same names in the embryo and adult. Because of the tremendous development of the telencephalon dorsally and laterally, the midbrain and diencephalon cannot be seen externally except from the ventral surface.

II. The Cranial Nerves

A. Identify the cranial nerves:

Cranial nerves associated with the medulla (IX, X, XI, XII): Because the pons can be located easily, it serves as a good reference point (fig 1a). Caudal to the pons and tapering from it is the medulla, whose ventral surface is characterized by two pairs of elevations. The two medial elevations, one on each side of the midline furrow or ventral median fissure, are the pyramids (#5262). Lateral to each pyramid is the olive (#5261). Between the pyramid and olive of each side is a groove along which are attached the roots of cranial nerve XII (hypoglossal nerve) (#8443). This nerve innervates the striated muscles of the tongue. Does the right cranial nerve XII innervate the muscles on the left or right side of the tongue?

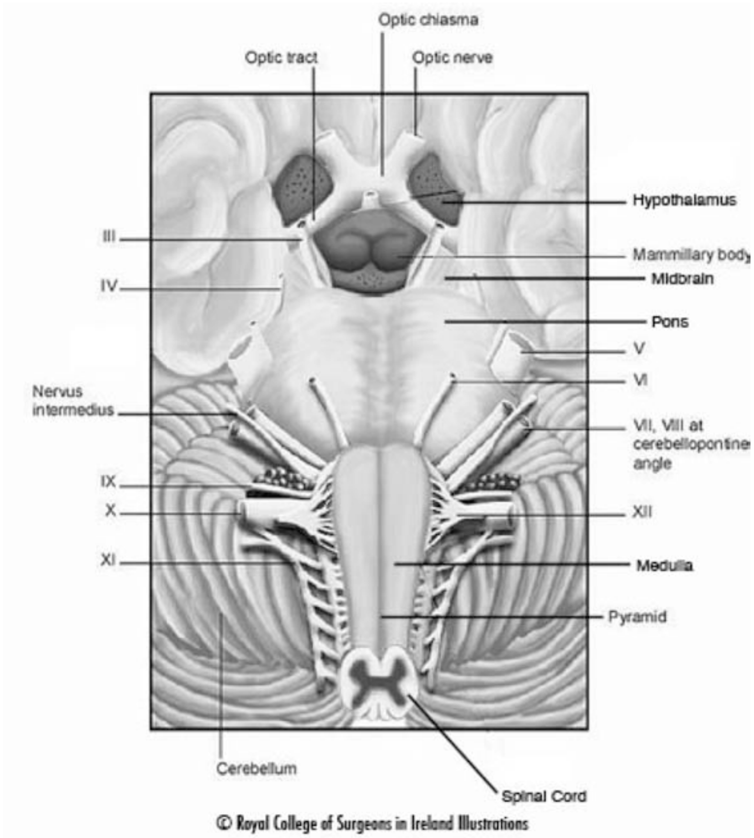

Figure 1A Ventral Surface of the Brain

Cranial nerves IX (glossopharyngeal nerve) and X (vagus nerve) emerge lateral to the olive (#11686). They are not easily distinguished unless their ganglia are attached (#7281). Cranial nerve XI (spinal accessory nerve) originates from the spinal cord and lies lateral to the medulla (#4952). It is often torn off when the brain is removed from the skull.

Cranial nerves associated with the pons (V, VI, VII, VIII): Along the border of the pons and medulla, and in line with rootlets of XII, are the roots of cranial nerve VI (abducens nerve) (#5776). This nerve innervates the lateral rectus muscle of the eye. Does it innervate the ipsilateral or contralateral muscle?

In the angle between the lateral borders of the pons and medulla and against the backdrop of the cerebellum are several large nerve roots. They comprise cranial nerves VII (facial nerve) (#5577) and VIII (vestibulocochlear nerve) (#5578). The roots of VII are medial to those of VIII. Midway along the lateral border of the pons is the largest bundle of cranial nerve rootlets; they are cranial nerve V (trigeminal nerve), the sensory nerve of the face (#5579).

Cranial nerves associated with the midbrain (III, IV): Cranial nerve IV (trochlear nerve) (#11715) is twice unique in that

1. All of its fibers decussate within the midbrain. However, once the nerve emerges, it innervates the superior oblique muscle on the same side; i.e., the right trochlear nerve innervates the right superior oblique muscle.

2. Its fibers emerge from the dorsal surface of the brain (specifically, at the junction of the pons and midbrain). It can best be seen by gently pulling down on the cerebellum to expose the dorsal surface of the brain stem and then teasing away the overlying arachnoid and vessels.

Rostral to the pons are two large fiber bundles known as the cerebral peduncles (#5264). Together they form a "V" whose two arms meet at the rostral pontine border. They consist of fibers (axons) that originate in the cerebral cortex and pass through the brain stem to the spinal cord. They represent the ventral surface of the mesencephalon or midbrain. In the angle between them, and near the pons, emerges cranial nerve III (oculomotor nerve) (#8460). The temporal lobes and blood vessels can obscure them, but gentle prying should reveal them.

Cranial nerve II: Located between the cerebral peduncles is the ventral surface of the diencephalon. What is seen is the raised portion called the tuber cinereum (#11880), to which the pituitary gland is attached. This gland is not seen because it remains in the sella turcica when the brain is removed from the skull. However, the stalk of the gland can be seen (#4738). Two small, rounded elevations occur just caudal to the tuber cinereum; these are well named the mammillary bodies (#4737). The tuber cinereum is flanked rostrally and laterally by the optic chiasm and optic tracts, which are a caudal continuation of cranial nerve II (optic nerve)(#5345).

Cranial nerve I (olfactory nerve) is associated with the telencephalon. The rootlets that make up the olfactory nerve are torn from their insertions into the olfactory bulb when the brain is removed from the skull. The olfactory bulb (#4965) and olfactory tract (#4963) are readily recognized.

B. Functional components of the cranial nerves

The cranial nerves can be understood without resorting to rhymes or nonsense verse. With the exception of I and II, the cranial nerves are nothing more than modified spinal nerves. Each spinal nerve consists of

1. a dorsal root (sensory) and
2. a ventral root (motor) (#52090, labeled a, sensory, and b, motor)

The cell bodies of the dorsal root axons are located in a dorsal root ganglion, which is located outside the CNS. These cell bodies and their axons originate from neural crest cells. The cell bodies of ventral root axons, however, are located inside the CNS in the ventral horn gray matter (#6687). These cells are derivatives of neuroectoderm. Consequently, dorsal root axons grow into the CNS and ventral root axons grow out of it.

Cranial nerves (#4175) can be summarized by considering them in relation to the plan of a typical spinal nerve. Cranial nerves III, IV, VI, and XII are comparable to ventral roots. Cranial nerves V, VII, IX, and X consist of both dorsal and ventral root components and, thus, resemble a complete spinal nerve. Therefore, one would expect that these nerves would have the equivalent of dorsal root ganglia. They do. Where are these ganglia located? What is the name given to the "dorsal root" (or sensory) ganglion of VII (#7276)? Of V? (#7275) There are other ganglia in the head such as the otic ganglion, which is an autonomic ganglion. These, of course, are not homologues to dorsal root ganglia but are autonomic ganglion, similar to sympathetic chain ganglia, except that all cranial nerve autonomic ganglia are parasympathetic rather than sympathetic.

Cranial nerve VIII is homologous to a dorsal root and does not have a ventral root component. Cranial nerve II is developmentally a cerebral vesicle evagination, not a peripheral nerve. The microscopic anatomy of CN II is significantly different from that of CN VIII. What cells form the myelin sheaths around the axons in each of these nerves? What is the origin of the cells in each case? If the axons of X are interrupted along their peripheral course, they will probably regenerate. What is the possibility that axons in the optic nerve (II) will regenerate? Why?

III. The Meninges

The meninges (meninx = membrane) consist of three membranes. The outermost and thickest is the dura mater (literally "hard" or "tough mother"), also known as the pachymeninx (pachy = thick) (#51064). The dura is folded in the midline to form the falx cerebri (#11624), which incompletely separates the two cerebral hemispheres. Its other major fold is the tentorium cerebelli (#11625), which separates the cerebellum from the cerebral hemispheres. The tentorium ("tent") stretches over the top of the posterior cranial fossa (#5911). What sits on top of the tentorium? What is immediately below it? The free edge of the tentorium forms the tentorial incisure (#15239), also called the tentorial notch. The posterior and middle cranial fossae (#5910) are continuous with one another through this notch. Suggest the functional significance of the dural membranes. The dura mater of the brain is innervated by the trigeminal nerve (V) and spinal nerves C2-3. The dura is exquisitely sensitive to pressure and mechanical distortion. Suggest possible causes for such mechanical distortion. Stimulation of these sensory nerves results in certain forms of headache.

Covering the surface of the brain (and spinal cord, too) are two other meningeal membranes, the pia mater (#4923) and the arachnoid (#4924). Together they are called the leptomeninges (lepto = slender). The pia mater fits tightly over the brain, dipping into all the crevices and furrows (#5178). The arachnoid, however, is only loosely attached to the brain (#5616). The space between the pia and arachnoid is the subarachnoid space (#5927), in which lie the cerebral arteries and cortical (superficial cerebral) veins. This space also contains cerebrospinal fluid (CSF). Connecting the arachnoid to the pia are wispy connective tissue fibers that resemble spider webs; these give the arachnoid ("cobweb-like") its name. The subarachnoid space is enlarged in certain locations to form cisterns (#5617). These act like water-filled pillows that cushion the brain and allow it to "float over," as it were, the irregular bony contours of the cranial floor. The largest subarachnoid cistern, the cisterna magna (#12605), is located between the inferior surface of the cerebellum and the dorsal surface of the medulla. The cisterns communicate with one another, as well as with the rest of the subarachnoid space.

The cranial nerves pierce the meninges to leave the cranial cavity (#15245) and the spinal nerves pierce the meninges (#51286, #5400) to exit from the vertebral canal.

The meninges can become infected, as in meningitis (#5673) in which pus accumulates in the subarachnoid space. What effect could this have on the cranial nerves? The swelling due to the inflammation will stretch the dura, hence causing headache or pain, especially when the neck is flexed.

IV. The Vasculature

Two major arterial systems supply the brain, the internal carotid (#5905) system and the vertebrobasilar system (#5907). The internal carotid system supplies most of the cerebral hemispheres except for parts of the occipital and inferior temporal lobes. The vertebrobasilar system supplies the brain stem, including part of the diencephalon, and some of the cerebral hemispheres (i.e. the inferior surface of the temporal lobe and most of the occipital lobe). The distribution of the cerebral arteries is considered more fully in subsequent chapters.

The main arteries (fig 1b, fig 1c, NOTE: all labels on the figures are linked to the glossary terms) of the internal carotid system are the anterior (#4202) and middle cerebral arteries (#4201). The left and right vertebral arteries (#8447), located on each side of the medulla, unite at the junction of the medulla and pons to form a single midline artery called the basilar artery (#8450). This artery extends the rostrocaudal length of the pons. Branches of the vertebral and basilar arteries supply the medulla, pons, and cerebellum. Rostrally, at the junction between the pons and midbrain, the basilar artery bifurcates to form the left and right posterior cerebral arteries (#4198). The two major arterial systems are united by the posterior communicating arteries (#4199). The two anterior cerebral arteries are joined by the short anterior communicating artery (#4203), thus joining the left and right halves of the internal carotid circulation. This connection, plus the connection between the internal carotid and vertebrobasilar systems, forms the Circle of Willis. This circle of arterial anastomoses provides a margin of safety should one of the major arteries be obstructed.

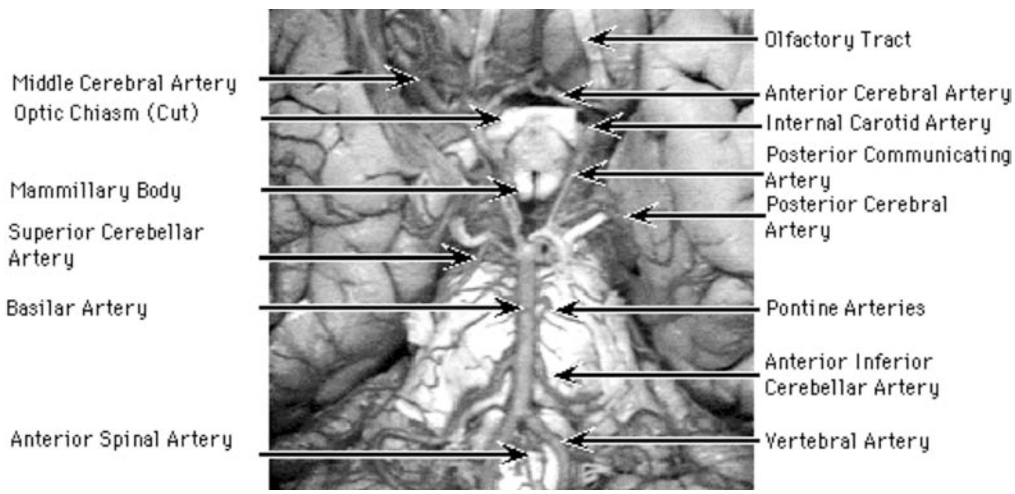

Figure 1B Vessels on Ventral Surface of the Brain

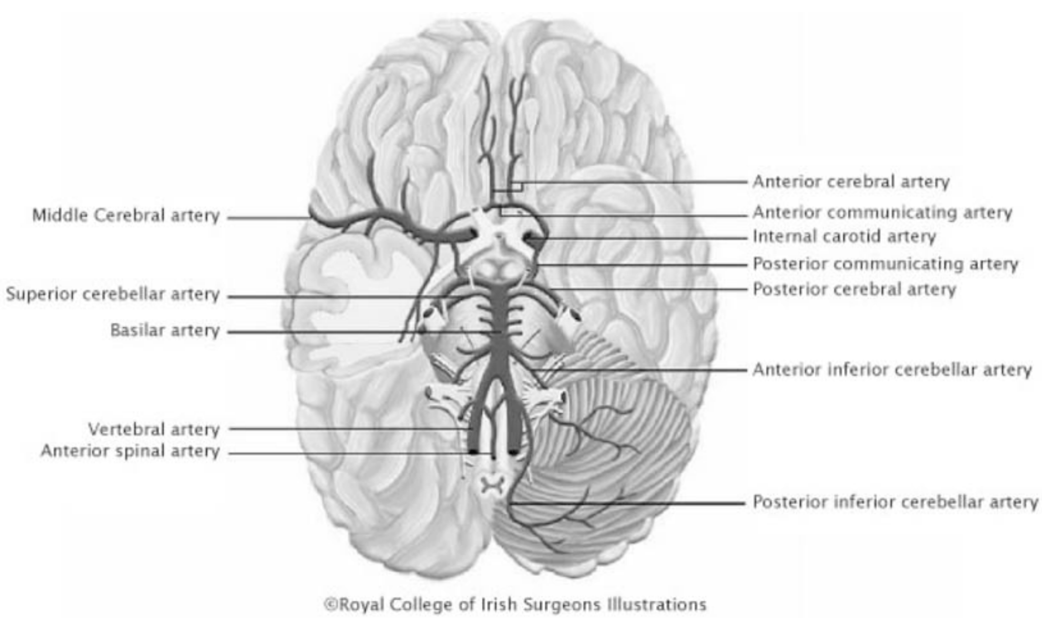

Figure 1C Vessels on Ventral Surface of the Brain

Veins of the brain (fig 1d) drain into large collecting channels in the dural folds called dural sinuses. The veins that extend between the cortical (superficial cerebral) veins on the surface of the brain and the dural sinuses are bridging veins (#8433, #7979, #7964). The dural sinus along the superior edge of the falx cerebri is the superior sagittal sinus (#7971, #51064, #12420). Running along the inferior margin of the falx cerebri is the inferior sagittal sinus (#12541). It joins the great cerebral vein (of Galen) (#12547) to form the straight sinus (#12540), which runs in the midline along the border of the falx cerebri and tentorium cerebelli. This sinus meets the superior sagittal sinus at the internal occipital protuberance, where they form the confluence of the sinuses (#4103). Continuing laterally from the confluence on each side is a transverse sinus (#11620). It goes forward along the lateral edge of the tentorium to the sigmoid sinus (#52277, #7973), which drains into the internal jugular vein (#7301) after passing through the jugular foramen (#6953).

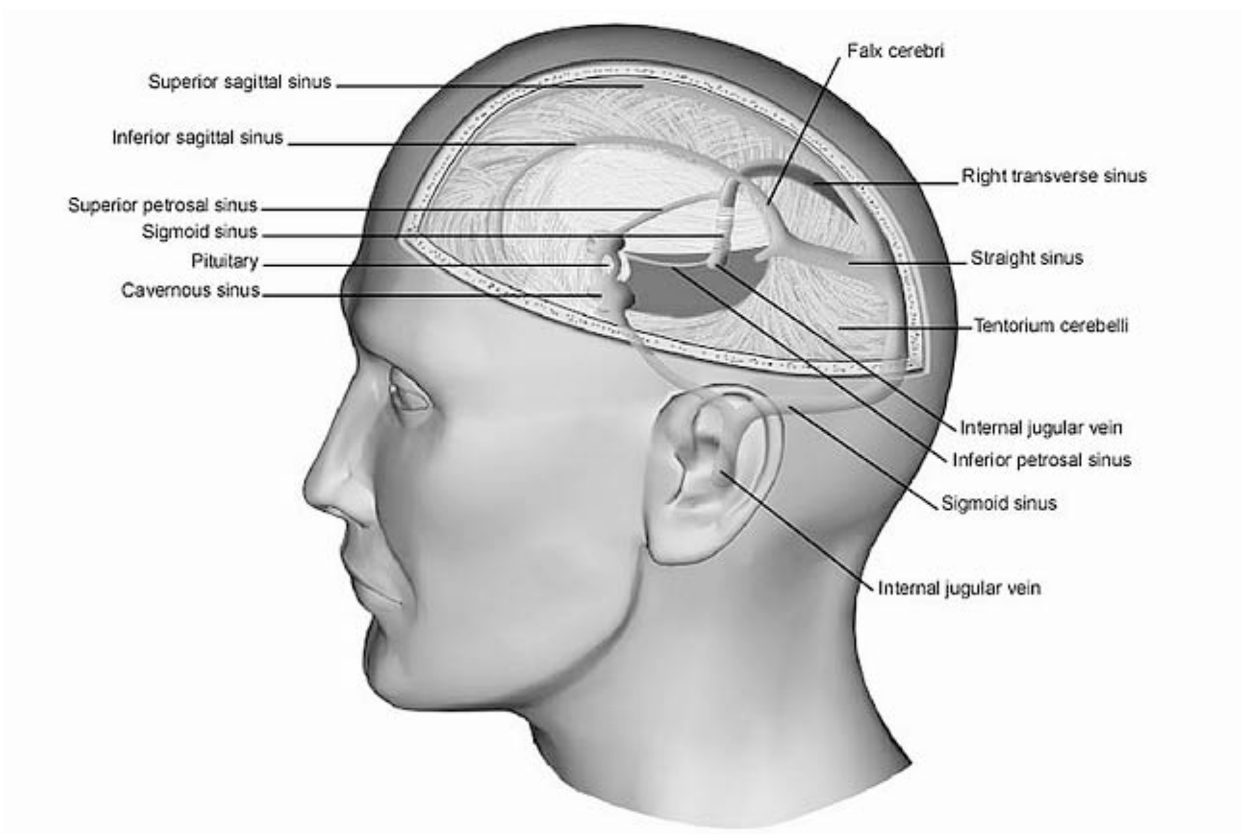

Figure 1D Cerebral Veins and Dural Sinuses

HyperBrain Chapter 1: The Cranial Nerves and the Circle Of Willis
Review of Terms

Edited by Stephen C. Voron, M.D. Revised 8/1/07

I. REGIONS OF THE CNS

neural tube
spinal cord
hindbrain
- medulla oblongata = myelencephalon
- pons and cerebellum = metencephalon

midbrain = mesencephalon
forebrain
- diencephalon – thalamus, hypothalamus
- telencephalon = cerebrum

II. THE CRANIAL NERVES

A. The 12 cranial nerves

cranial nerve I (olfactory nerve), olfactory bulb and olfactory tract
cranial nerve II (optic nerve)
cranial nerve III (oculomotor nerve)
cranial nerve IV (trochlear nerve)
cranial nerve V (trigeminal nerve)
cranial nerve VI (abducens nerve)
cranial nerve VII (facial nerve)
cranial nerve VIII (vestibulocochlear nerve)
cranial nerve IX (glossopharyngeal nerve)
cranial nerve X (vagus nerve)
cranial nerve XI (spinal accessory nerve)
cranial nerve XII (hypoglossal nerve)

B. Other terms

pyramid, olive
decussate
cerebral peduncles
tuber cinereum, mammillary bodies
spinal nerves
- dorsal root (sensory), ventral root (motor)

neuroectoderm, neural crest
dorsal horn, ventral horn
ganglia
- sensory ganglia – dorsal root ganglia
- autonomic ganglia
  - parasympathetic ganglia – otic ganglion
  - sympathetic chain ganglia

myelin

III. THE MENINGES

meninges
dura mater
- falx cerebri
- tentorium cerebelli, tentorial incisure

posterior cranial fossa, middle cranial fossa
pia mater
arachnoid
subarachnoid space
- cerebrospinal fluid
- cisterns – cisterna magna

vertebral canal
meningitis

IV. THE VASCULATURE

A. Arteries

internal carotid artery
- posterior communicating artery
- anterior cerebral artery
  - anterior communicating artery
- middle cerebral artery

vertebrobasilar system
- vertebral arteries
- basilar artery
- posterior cerebral arteries

Circle of Willis

B. Veins and dural sinuses

cortical (superficial cerebral) veins
bridging veins
superior sagittal sinus
inferior sagittal sinus
great cerebral vein (of Galen)
straight sinus
confluence of the sinuses
transverse sinus
sigmoid sinus
internal jugular vein
jugular foramen

2. The Cerebral Hemispheres

Revised 2007.

The objectives of this chapter are to identify:

1. The prominent external features of the telencephalon (cerebrum).
2. The major brain divisions and the major structures seen on a midsagittal section of the brain.
3. The vascular territories of the cerebral arteries.

To begin, review the five major divisions of the brain: the myelencephalon, metencephalon, mesencephalon, diencephalon and telencephalon. Also review the cranial nerve roots (#5302, #7917, #4175).

I. External Features of the Telencephalon (Cerebrum)

As viewed from above, the most prominent parts of the brain are the cerebral hemispheres, which are separated by the interhemispheric fissure (= longitudinal fissure) (#8431). The hemispheres consist of a superficial sheet of gray matter that is thrown into folds. The surface irregularities of the cerebrum are the sulci and gyri (#51113). A gyrus is the elevated portion between two sulci (furrows). Regardless of first impressions, the gyri and sulci form certain patterns that are generally constant from brain to brain, depending on the species. To be sure, variations do occur. Some animal brains (e.g., rat, opossum, rabbit) have few gyri and have "smooth" brains. The developing human brain is initially smooth (#4095); however, the adult brain has numerous gyri.

Each cerebral hemisphere is divided into lobes (fig 2a).

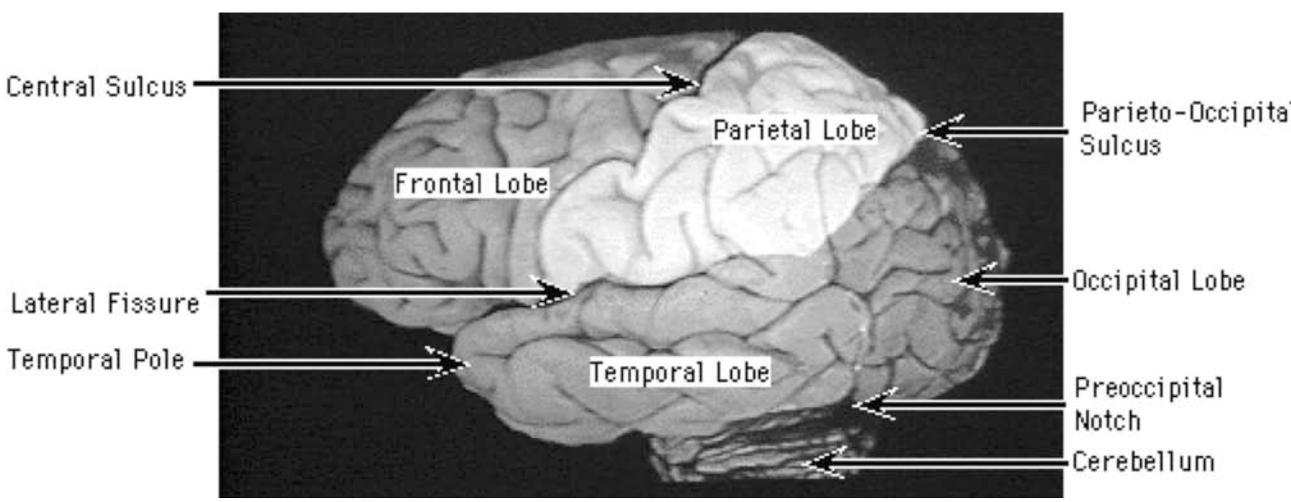

Figure 2A Lateral View

A lobe is roughly that part of the hemisphere covered by one of the calvarial bones. The frontal lobe lies under the frontal bone and the parietal lobe under the parietal bone. The lobes are defined by certain sulci. Two sulci that are standard reference points occur on the lateral surface of the hemisphere. The more distinctive one is deep and usually termed a "fissure" instead of a "sulcus." This is the lateral fissure (Sylvian fissure) (#4331).

The other standard reference sulcus is the central sulcus (Rolandic fissure) (#4207) that runs downward and forward from its origin about midway along the superior border of the hemisphere. This sulcus, as with the sulci and gyri in general, is easier to find if you first remove the overlying meninges and blood vessels. Then find the most anterior gyrus that extends without interruption from the superior margin of the hemisphere to the lateral fissure. The sulcus behind this gyrus is the central sulcus. The cortex above the lateral fissure and in front of the central sulcus forms the frontal lobe (#4216). The cortex below the lateral fissure comprises the temporal lobe (#4209).

Two additional landmarks need to be identified to define the remaining lobes. The occipital lobe (#4210) is the cortex caudal to an imaginary line drawn from the top of the parietooccipital fissure to the preoccipital notch. The cortex above the lateral fissure caudal to the central sulcus but rostral to the occipital cortex is the parietal lobe (#4206). These descriptive terms are not used only by anatomists but have a wider application, as witness the terms "temporal lobe epilepsy" and "frontal lobe syndrome."

Deep within the lateral fissure is the insula, an island (really, a peninsula) of cortex that is buried by the overgrowth of the frontal, parietal and temporal lobes. The lips of the lateral fissure have to be spread apart to see the insula (#8434).

The two cerebral hemispheres appear to be identical, and a description of one serves as well for the other. Functionally, however, they are different. This is referred to as the functional asymmetry of the hemispheres. The "dominant," usually left, hemisphere functions in language. Discrete lesions of this hemisphere produce aphasia.

The "nondominant", usually right, hemisphere is important in understanding spatial relationships, such as the recognition of patterns and forms. There is evidence that it also has special functions relative to musical expression. Presumably the two hemispheres, which are united by the corpus callosum (#4850) and the anterior commissure (#5398) (vide infra), normally function as a unit.

A. The frontal lobe

The important gyri to be identified are the precentral and inferior frontal gyri (fig 2b). The precentral gyrus (#4225) is anterior to the central sulcus. It is the primary motor cortex. The inferior frontal gyrus (#4344) borders the lateral fissure in front of the precentral gyrus. In the dominant hemisphere, the posterior two-thirds of this gyrus is Broca's area (#4077), the motor speech area. Lesions here produce motor (expressive) aphasia where patients have a deficit in speech production.

The frontal lobe is of interest because of its presumed role in emotion, learning, and executive function. The olfactory bulb (#4965) and tract (#4963) are on the lobe's ventral surface.

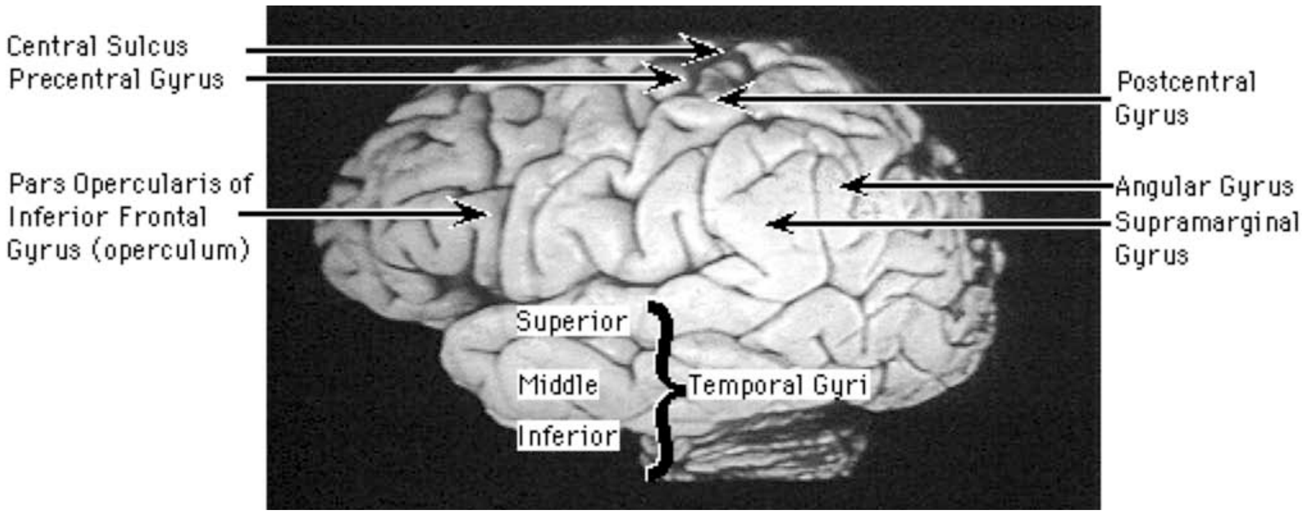

Figure 2B Lateral View

B. The parietal lobe

The postcentral gyrus (#4319) is posterior to the central sulcus (fig 2b). It is the primary cortical region for the sensations of touch and pressure and is commonly referred to as primary somatosensory (somesthetic) cortex. The parietal lobe contains two other intriguing gyri, the supramarginal and angular gyri. The supramarginal gyrus is draped over the dorsal tip of the lateral fissure. The angular gyrus (#4218) bends over the superior temporal sulcus as though to prevent this crevice from extending into the parietal lobe. In the dominant hemisphere, these two gyri function in speech, reading, and the use of numbers (calculation).

C. The temporal lobe

On its lateral surface, the temporal lobe has three distinct gyri, which, after a fashion, parallel the lateral fissure. They are the superior (#4340), middle (#4341), and inferior temporal (#4342) gyri.

Gently spread apart the lips of the lateral fissure to see the two gyri on the superior surface of the temporal lobe. These are the transverse temporal gyri (Heschl's gyri) (#8437). Both are auditory cortex. The rostral one is the primary auditory cortex. In the dominant hemisphere, the cortex adjacent to the auditory cortex in the posterior third of the superior temporal gyrus is Wernicke's area, the sensory speech area. Lesions here produce receptive aphasia where patients cannot comprehend speech.

Several longitudinally running gyri occur on the ventral surface of the temporal lobe. The medial one is the parahippocampal gyrus (#5361), which covers the most ancient part of cortex, the hippocampus. Because it is deep to the parahippocampal gyrus, the hippocampus cannot be seen without performing a special dissection. The hippocampus is of interest because of its role in memory.

D. The occipital lobe

The primary sulcus to be identified in this lobe is the calcarine fissure, which is on the medial surface of the hemisphere. Located along its banks is the primary visual cortex (#4275).

II. Midsagittal Section of the Brain

Identify the medial portions of the five major brain divisions in a midsagittal section of the brain (#4281): diencephalon (#4279), mesencephalon (#4278), pons and cerebellum (#4282), and medulla (#4276). Some of the important midsagittal structures can be seen in fig 2c.

A. The telencephalon (cerebrum)

One of the most prominent structures seen in a midsagittal section (fig 2c) is the corpus callosum (#4850). Its rostral part does a knee bend and is known as the genu ("knee") (#4834). Extending ventrally from the genu is a thin portion of the callosum, the rostrum (#4831). The thick, even part of the callosum extending posteriorly from the genu is the body (#4850), which ends as the splenium (#4833). The cingulate gyrus (#4274) is immediately above the corpus callosum. The cortex that surrounds the medial extension of the central sulcus is the paracentral lobule, a medial continuation of primary somatosensory cortex and primary motor cortex.

The bundle of myelinated axons that arches forward from under the splenium is the fornix ("arch") (#3994, #4592). The thin sheet that stretches between the fornix and corpus callosum is the septum pellucidum (#4597). It separates the ventricular cavity (lateral ventricle) of one hemisphere from that of the opposite hemisphere (#4265, partially exposed and colored pink). Occasionally there is a definite space within the septum; this is the cavum septum pellucidum (#8569). (It is not a part of the brain ventricular system.) The most rostral part of the fornix forms the anterior margin of the interventricular foramen (foramen of Monro). Through this opening, the paired lateral ventricles communicate with the midline third ventricle (outlined in blue, #4318) of the diencephalon. Below and rostral to the interventricular foramen is another telencephalic commissure, the anterior commissure (#4596 green dot).

B. The diencephalon

The sidewalls, roof, and floor of the third ventricle are formed by the diencephalon, whose major divisions are the thalamus (#7921, #4838), hypothalamus (#4270, #4848), epithalamus (pineal body) (#4839) and the subthalamus, which is deep to the surface and can only be seen on brain sections. The faint groove extending back from the interventricular foramen is the hypothalamic sulcus (#11874). It separates the thalamus above from the hypothalamus below. Recall that the tuber cinereum (#11880) and mammillary bodies (#4847) are part of the hypothalamus. The anterior commissure (#4596) and the optic chiasm (#4846) mark the rostral extent of the diencephalon. Its caudal extent is indicated by a line connecting the mammillary bodies and the pineal body (pineal gland).

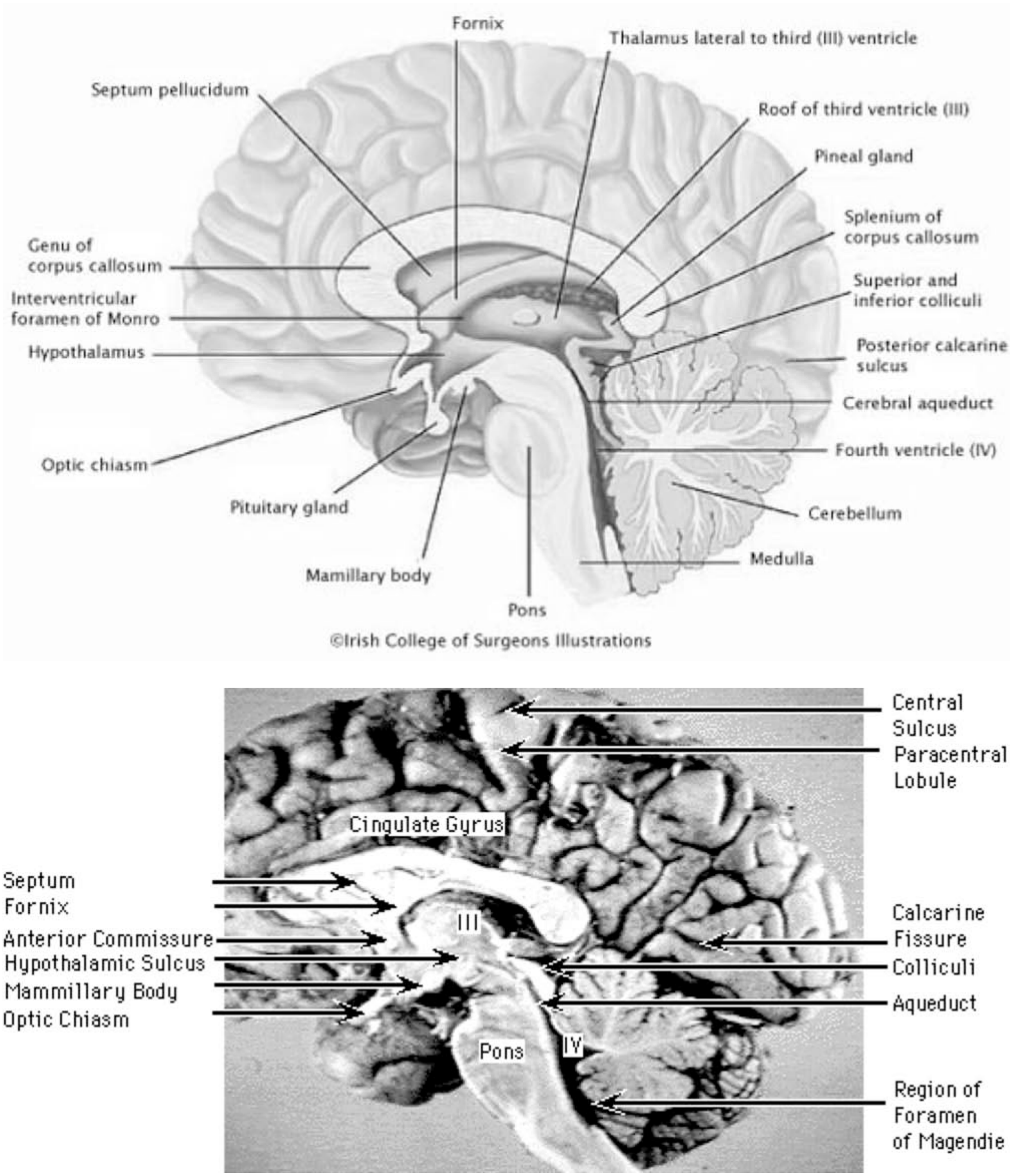

Figure 2C Midsagittal section

C. The mesencephalon

Caudally, the third ventricle narrows into the aqueduct (of Sylvius) (#4262). The aqueduct identifies the mesencephalon, whose dorsal surface has two pairs of elevations. Hence, the term quadrigeminal plate ("quadruplets") or tectum ("roof") (#8972). The rostral pair of elevations forms the superior colliculi (colliculus means "little hill " or "mound") (#4913) and the caudal pair, the inferior colliculi (#4912). The trochlear nerve (IV) (#11703) emerges from the caudal border of the inferior colliculus and curls laterally around the cerebral peduncle (#5641).

The ventral portion of the mesencephalon is formed by the cerebral peduncles (#8515, #7941). The area between the cerebral peduncles and the aqueduct is the tegmentum of the midbrain.

D. The rhombencephalon

The aqueduct drains into the fourth ventricle (#4261), which is dorsal to the pons and medulla. This ventricle is covered by the cerebellum. Ventricle IV, in turn, narrows to become the central canal of the spinal cord. (The central canal is not patent in either the newborn or adult.) In addition, ventricle IV empties into the subarachnoid space through the left and right lateral apertures of Luschka and the median aperture of Magendie (#4261).

The white matter of the cerebellum is centrally located and has the appearance of a tree: the arbor vitae ("tree of life") (#7210). The gray matter of the cerebellar cortex is elaborately, yet evenly, folded into folia ("leaves"). The folia are grouped into lobules, which are separated by cerebellar fissures.

III. Vascular Territories of the Cerebral Arteries

Review the lobes of the cerebral hemispheres in association with their vascular supply. The cerebral cortex is supplied by the anterior, middle, and posterior cerebral arteries. Fig 2d and fig 2e indicate the cortical areas vascularized by each artery. The pattern is not difficult to see. The anterior cerebral artery sends branches to the medial surface of the frontal and parietal lobes (#7981, #52081).

Most of the lateral surface of the hemisphere is supplied by the middle cerebral artery (fig 2d).

Most of the occipital lobe and most of the ventral part of the temporal lobe are supplied by the posterior cerebral artery (fig 2e). Not all of the lateral surface of the hemisphere is nourished by the middle cerebral artery; the "peripheral" portions are vascularized by branches of the anterior (#3989) and posterior cerebral arteries (#3990).

Using any information that you might have gleaned, predict what sensory loss would result from interruption of each cerebral artery. Occlusion of which artery near its origin would have the most devastating effect?

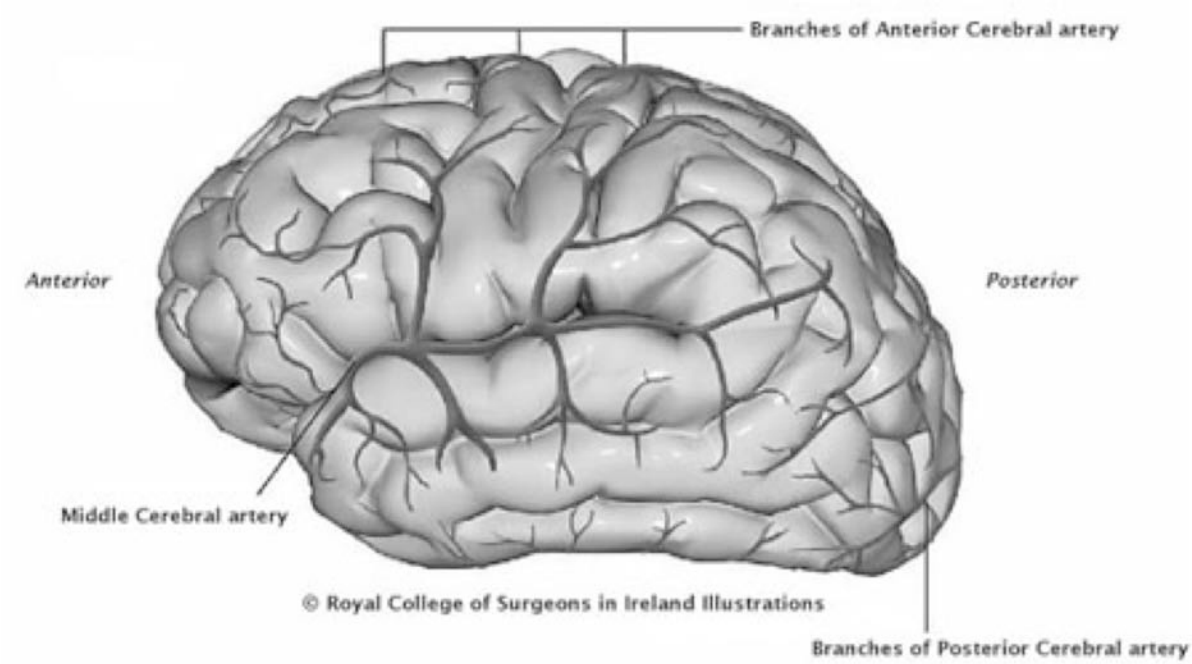

Figure 2D Lateral View

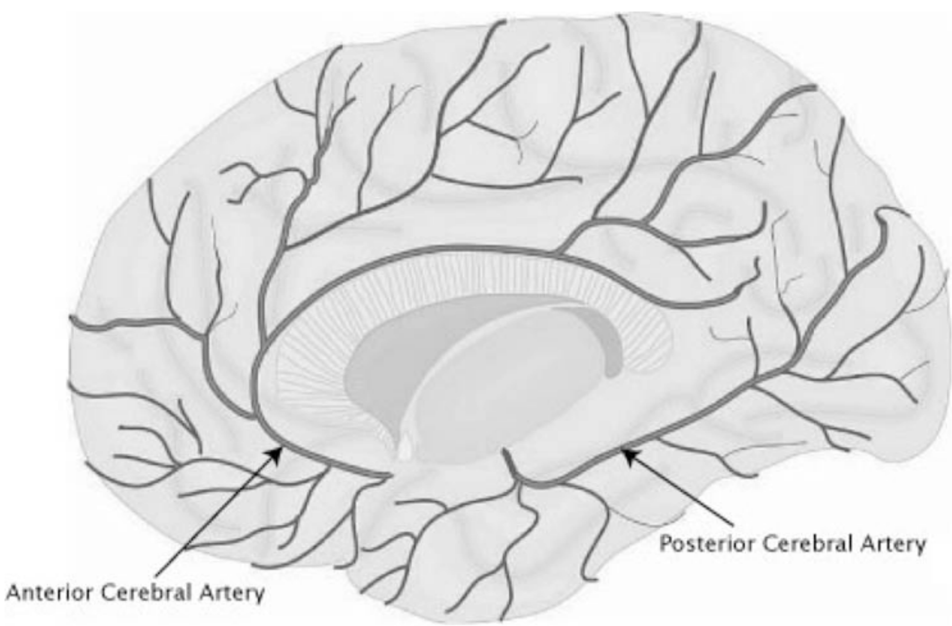

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Figure 2E Medial View

HyperBrain Chapter 2: The Cerebral Hemispheres
Review of Terms

Edited by Stephen C. Voron, M.D. Revised 2007

Review: myelencephalon, metencephalon, mesencephalon, diencephalon, telencephalon

I. EXTERNAL FEATURES OF THE TELENCEPHALON (CEREBRUM)

interhemispheric fissure (longitudinal fissure)
sulcus, sulci; gyrus, gyri
cerebral lobes
- landmarks
  - lateral fissure (Sylvian fissure)
  - central sulcus (Rolandic fissure)
  - parietooccipital fissure
  - preoccipital notch
- lobes
  - frontal lobe
  - temporal lobe
  - occipital lobe
  - parietal lobe
  - insula

dominant and nondominant hemispheres
- aphasia

A. The frontal lobe.
- precentral gyrus
  - primary motor cortex
- inferior frontal gyrus
  - Broca's area (dominant hemisphere)
- olfactory bulb and tract

B. The parietal lobe.
- postcentral gyrus
  - primary somatosensory cortex
- supramarginal and angular gyri
  - speech, reading, calculation (dominant hemisphere)

C. The temporal lobe.
- superior, middle and inferior temporal gyri
- transverse temporal gyri
  - primary auditory cortex
- parahippocampal gyrus
- hippocampus

D. The occipital lobe.
- calcarine fissure
  - primary visual cortex

II. MIDSAGITTAL SECTION OF THE BRAIN

Identify: telencephalon, diencephalon, mesencephalon, metencephalon (pons and cerebellum), and myelencephalon

A. The telencephalon (cerebrum)
- paracentral lobule
- cingulate gyrus
- corpus callosum
  - rostrum, genu, body, splenium
- septum pellucidum, lateral ventricle
- fornix
- anterior commissure
- interventricular foramen (foramen of Monro)

B. The diencephalon
- third ventricle
- pineal body (pineal gland)
- thalamus
- hypothalamic sulcus
- hypothalamus
  - tuber cinereum
  - mammillary bodies
- optic chiasm

C. The mesencephalon
- tectum (quadrigeminal plate)
  - superior colliculus
  - inferior colliculus
- aqueduct (of Sylvius)
- tegmentum of the midbrain
- cerebral peduncles

D. The rhombencephalon (cerebellum, pons, medulla)
- fourth ventricle
  - lateral apertures of Luschka
  - median aperture of Magendie
- cerebellum
  - arbor vitae
  - folia
  - cerebellar lobules

III. VASCULAR TERRITORIES OF THE CEREBRAL ARTERIES

- anterior cerebral artery
- middle cerebral artery
- posterior cerebral artery

HyperBrain Chapter 2: Midsagittal MRI

Use in conjunction with the half brain in lab.

Clinically, it will be more important to recognize brain structures on imaging studies than on brains specimens!

Start now: Identify the same structures that you can see on the half brain as well as additional structures (skull, cisterna magna, sinuses, etc.). See how many structures you can identify.

Use these images with the half brain in all future labs. They are your introduction to cranial imaging, and will appear again in lectures, tests and on clinical rotations.

3. Coronal Sections and the Ventricular System

Revised 2007

The objectives of this chapter are to identify:

1. The major brain divisions in coronal sections.
2. The ventricular system in coronal sections.
3. The origin, course, and fate of the cerebrospinal fluid (CSF).

I. The Major Brain Divisions in Coronal Sections

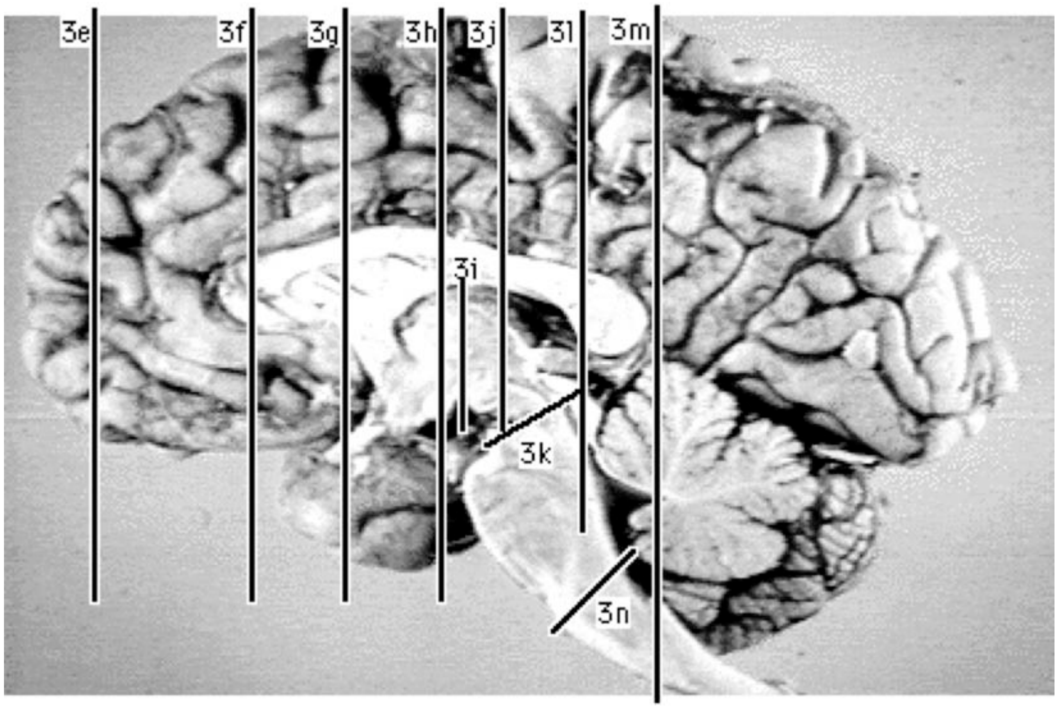

Figure 3d Midsagittal Section for Orientation to Coronal Sections
Click on the letters at the top of each of the red lines to see labeled images on each slice.
The labels on each slice are linked to the glossary terms.

Fig 3d indicates the order of the following coronal sections through the brain (Figures 3e-3n). Note that, in general, these sections proceed from anterior (rostral, frontal) to posterior (caudal, occipital) The major divisions of the brain and the ventricular system will be seen as the coronal sections are examined.

The cerebral cortex is a sheet of gray matter surrounding a core of white matter (fig 3e). What does the latter represent? Does the cortex have a uniform thickness? It has been estimated that two thirds of the cortical surface area is buried in the sulci.

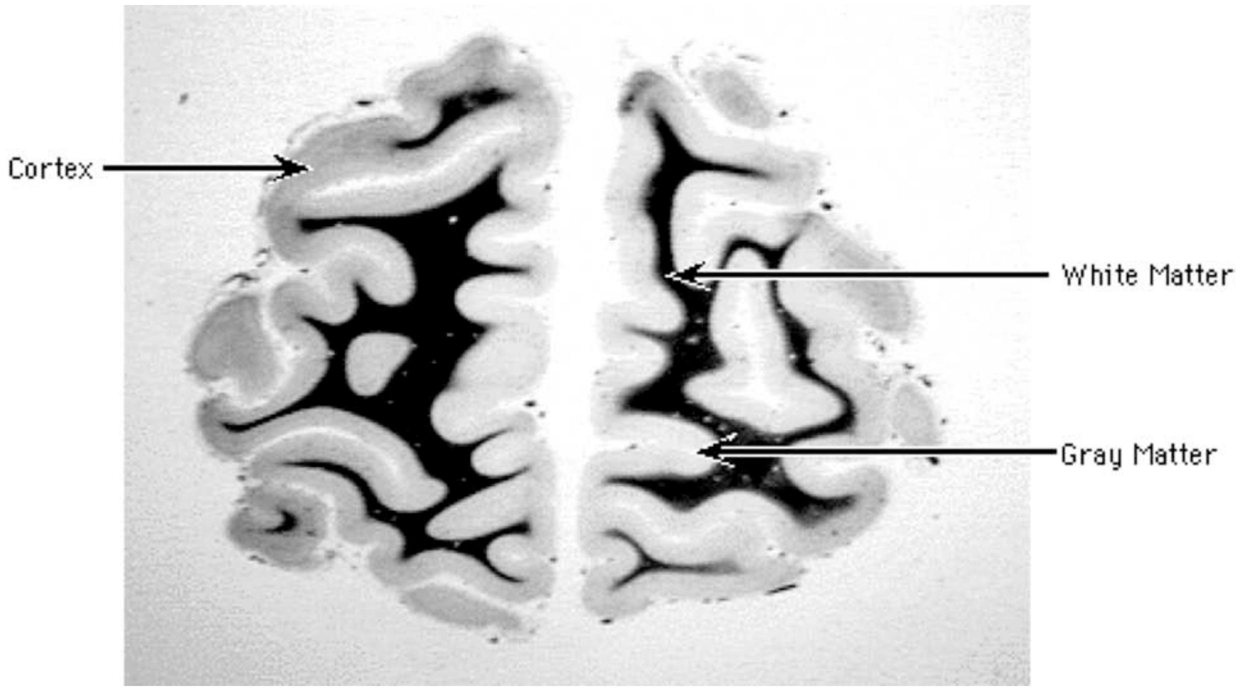

Figure 3E Frontal Pole

The corpus callosum interrupts the cortex on the medial surface of the hemisphere (fig 3f). The white matter is interrupted by a hole. This is the frontal horn of the lateral ventricle.

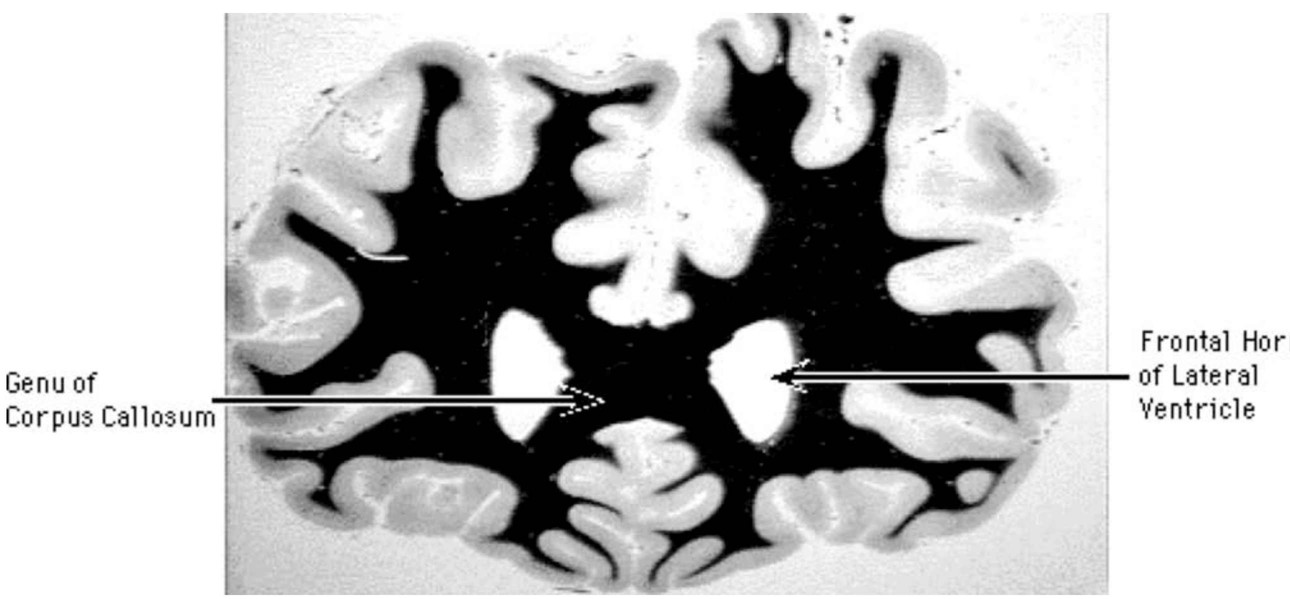

Figure 3F Section through the Frontal Lobe (Telencephalon)

Section fig 3g is similar to the previous one except that an oval-shaped mass, the caudate nucleus (a part of the basal ganglia), forms the lateral wall of the lateral ventricle. Observe that the caudate nucleus bulges into the ventricle. The medial wall of the lateral ventricle is formed by the septum pellucidum, which is composed almost entirely of glial cells.

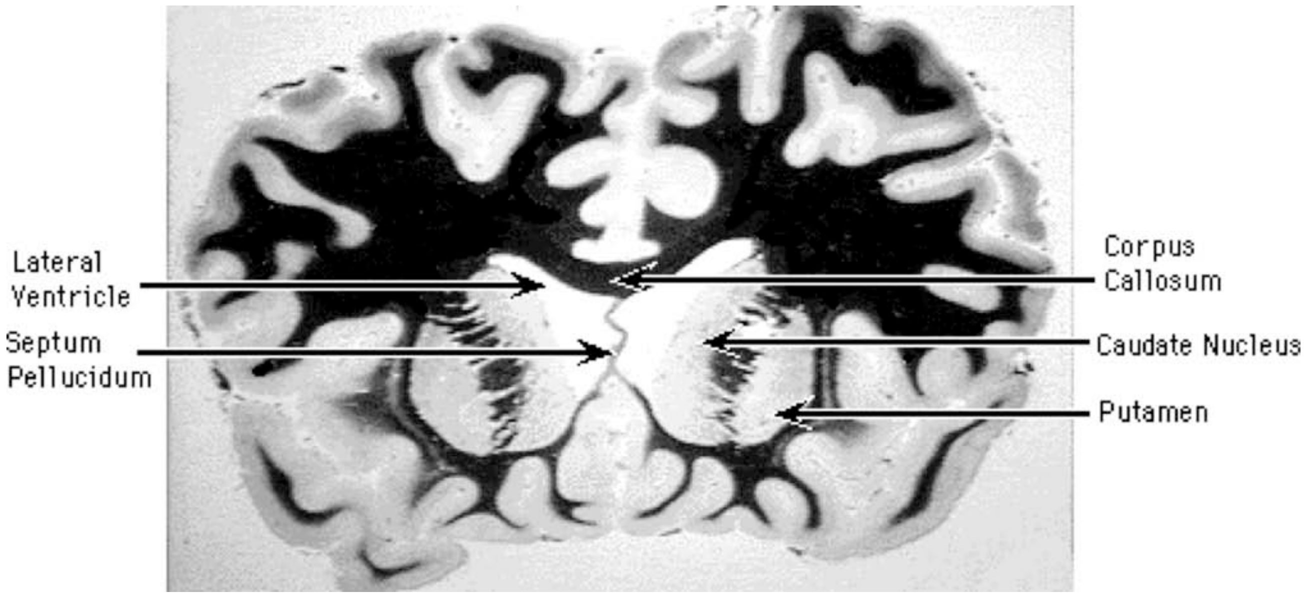

Figure 3G Telencephalon at Level of Rostral Part of Basal Ganglia

With the intrusion of the thalamus, the next section appears more complicated (fig 3h); (#6120 is slightly enlarged; #4750 is a gross section). However, there are several familiar structures that display the same topographic relationships seen in rostral sections. The caudate ("tailed") nucleus, quite reduced in size, still forms the lateral wall of the lateral ventricle, and the corpus callosum is still the roof of the ventricle. Lateral to the caudate is a group of axons that connect the cerebral cortex with the brain stem (#4756). This is the internal capsule. It separates the caudate nucleus from the other basal ganglia that are seen in this section (the putamen (#4752) and globus pallidus (#4753)). Inferior to the putamen and globus pallidus is yet another nucleus, the amygdala (#4763) ("almond-shaped").

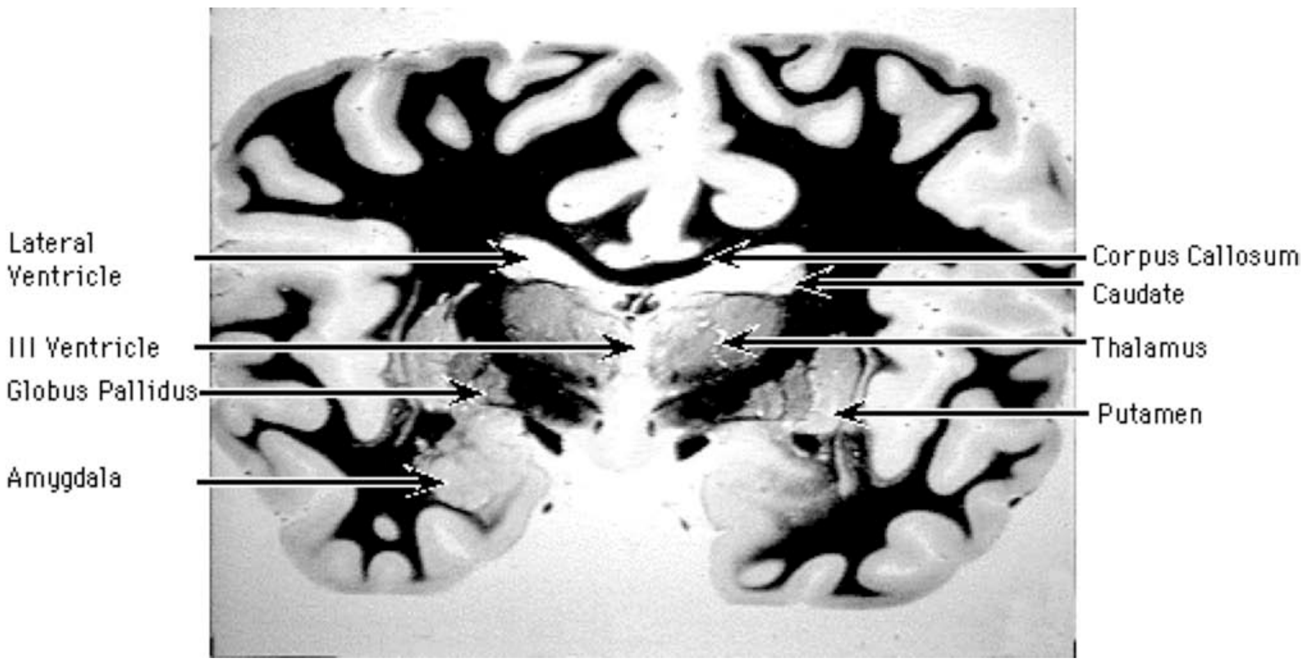

Figure 3H Telencephalon and Diencephalon

In a slightly enlarged section, the centrally placed diencephalon (the thalamus and hypothalamus) is prominent (fig 3i). You can verify that the diencephalon forms (1) the floor of the lateral ventricle as well as (2) the sidewalls and floor of the third ventricle. The thalamus on one side is usually joined to that of the opposite side by the massa intermedia (or interthalamic adhesion) (#4600). The thalamus is the portal or foyer for information flowing toward the cortex. The hypothalamus is involved in coordinating autonomic and endocrine function.

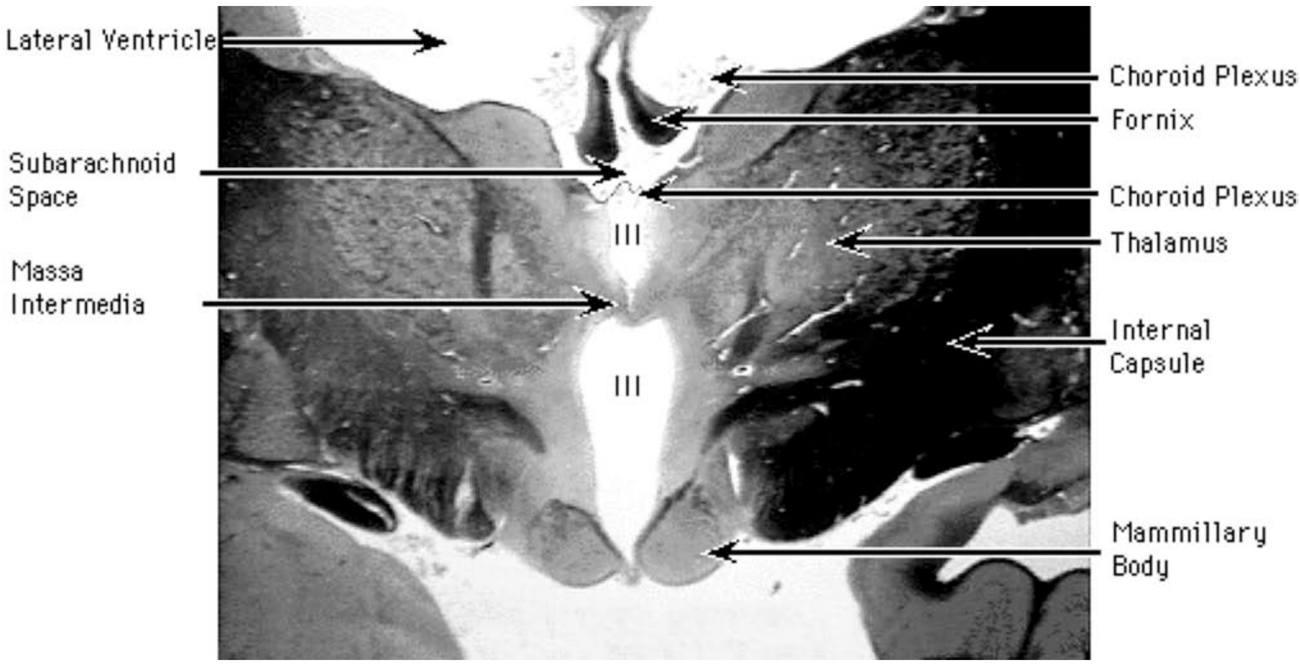

Figure 3I Diencephalon

You can see how the choroid plexus forms the roof of the third ventricle and the medial edge of the floor of the lateral ventricle. In the case of ventricle III, the choroid plexus simply runs along top of the ventricle, between one half of the thalamus and the other. To seal off the lateral ventricle, the choroid plexus extends from the fornix to the nearby thalamus. Centrally located is subarachnoid space, the cistern of the velum interpositum (#6671), which you do not need to identify. It contains the paired internal cerebral veins, which drain in the great cerebral vein (of Galen).

Section fig 3j is at the interface of the diencephalon and the mesencephalon and appears to be more complicated than the previous sections. A small bit of the caudate nucleus is tucked away in the angle of the lateral ventricle. The inferior or temporal horn of the lateral ventricle is clearly seen. Its floor and medial wall are partly formed by the hippocampus.

A practiced eye is needed to distinguish the thalamus from the midbrain. The thalamus, of course, borders the third ventricle and is dorsal to the mesencephalic structures present in this section. The mesencephalic structures present in this section include the substantia nigra and the red nucleus.

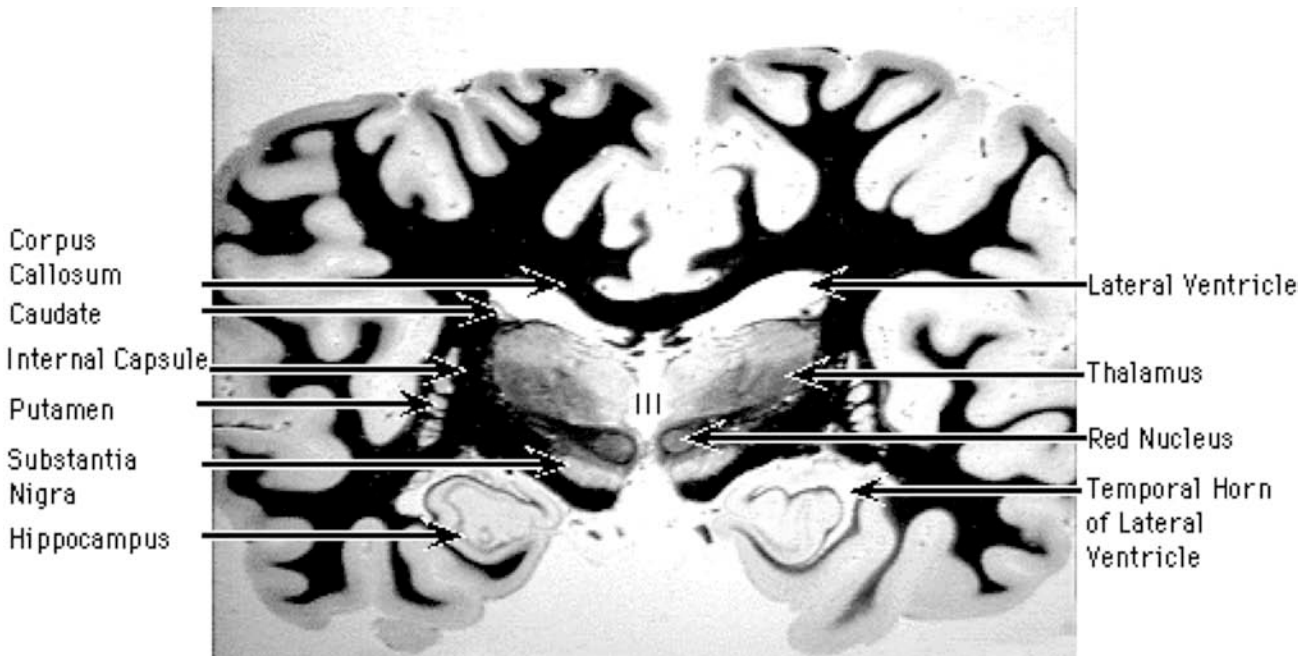

Figure 3J Telencephalon And Diencephalon

The section through the mesencephalon (fig 3k) is not coronal like the earlier sections. It is transverse to the long axis of the brainstem. (See fig 3d for orientation.) It shows the location of the aqueduct (of Sylvius). This is the narrowest portion of the ventricular system. It connects ventricles III and IV. Other midbrain structures present in this section are the substantia nigra, the tectum (superior colliculus) and the cerebral peduncle, which is an important continuation of the internal capsule.

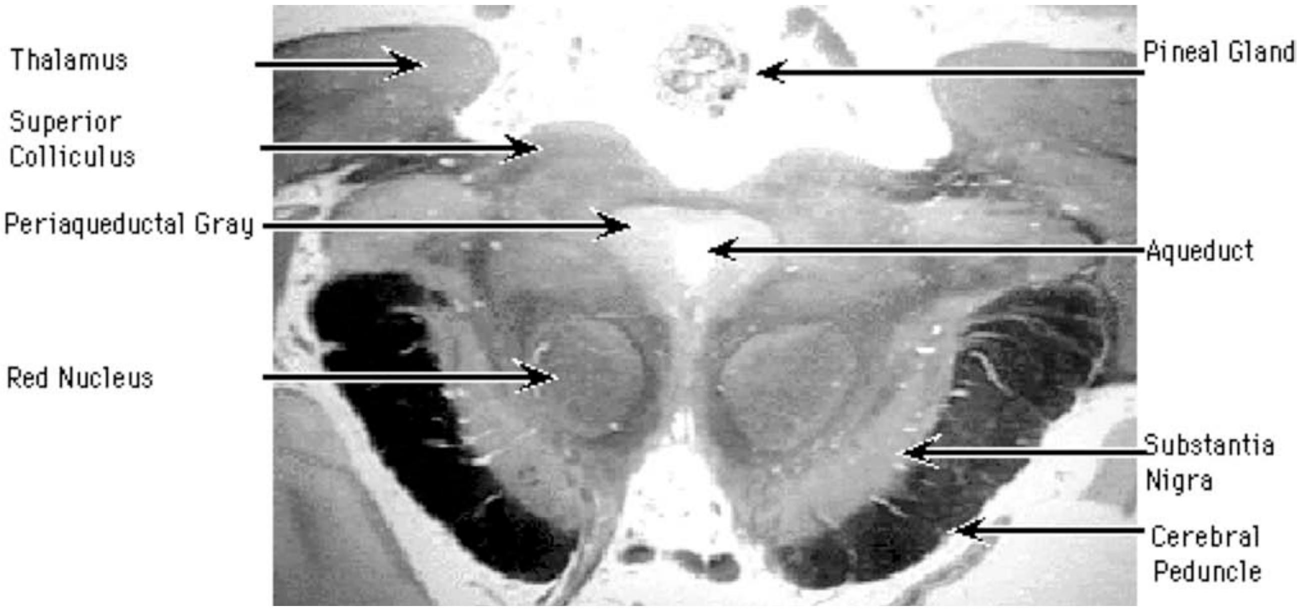

Figure 3K Mesencephalon

In the next section (fig 3l, the asterisks indicate the subarachnoid space), the telencephalon, again, has much the same appearance as in earlier sections. Note that at this level the telencephalon is not attached to the brain stem. This coronal image cuts obliquely through the midbrain and the pons. (See fig 3d for orientation.) The region around the aqueduct is part of the midbrain or mesencephalon. A thin slice of cerebellum is present to the side of the midbrain and pons. The cerebellum and pons are parts of the metencephalon. Where would the falx cerebri and the tentorium cerebelli be located in this section?

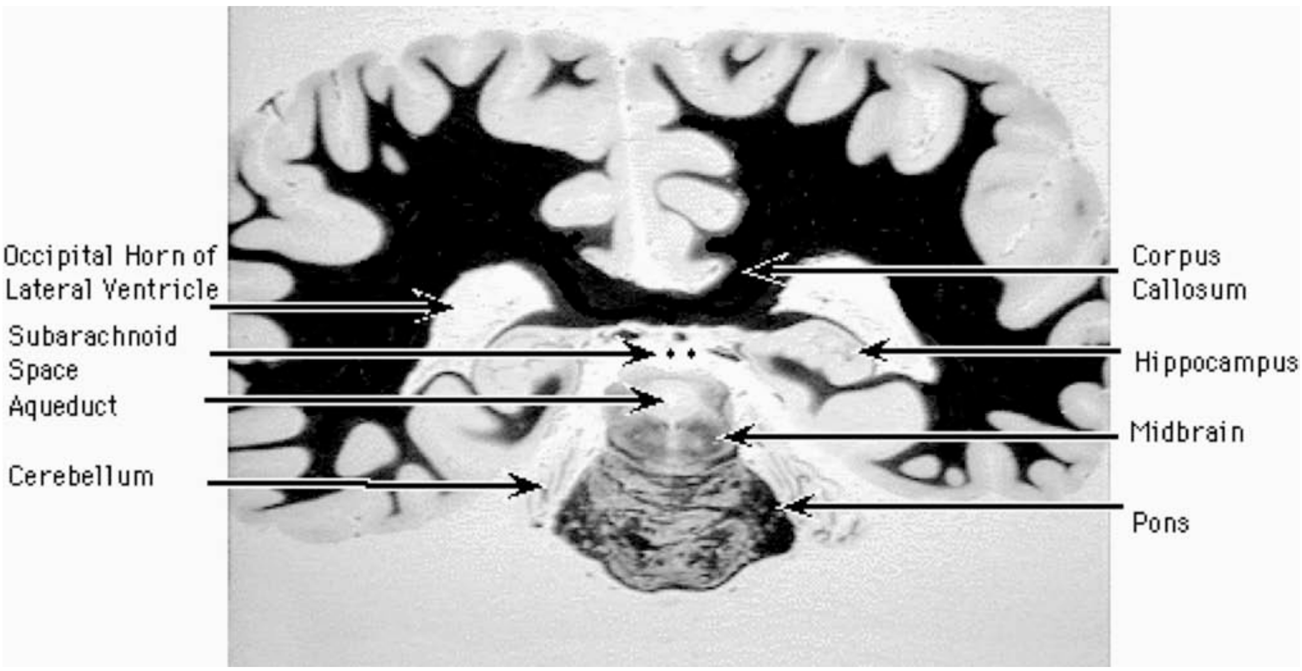

Figure 3L Telencephalon, Mesencephalon, and Metencephalon

Because the cortical gray matter in fig 3m is continuous around the circumference of the hemisphere, this section must be caudal to the corpus callosum. How does the occipital horn (or posterior horn) of the lateral ventricle, shown here, communicate with the fourth ventricle? In this section, the sidewalls and roof of ventricle IV are formed by the cerebellum. The ventricular floor is the dorsal surface of the brain stem, in this instance, the medulla. In a more rostral section, what structure would form the floor of ventricle IV? As in the previous section, indicate the positions of the falx and tentorium.

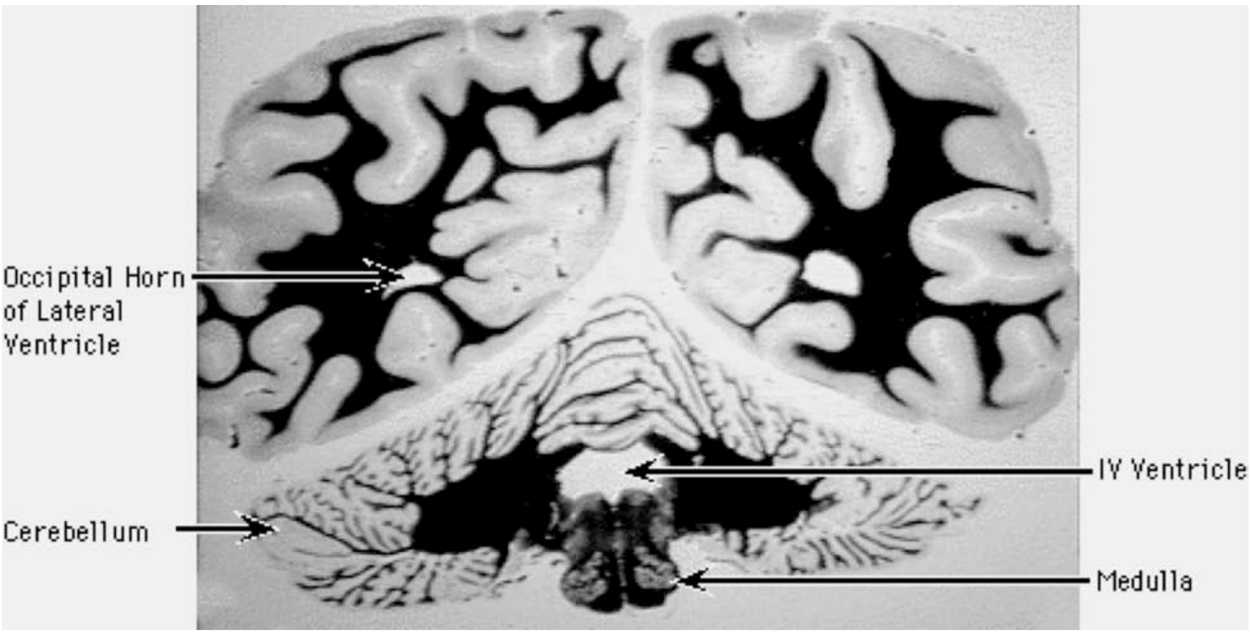

Figure 3M Telencephalon, Metencephalon, and Myelencephalon

A higher magnification of a section through the medulla (myelencephalon) (fig 3n) shows that the choroid plexus also forms part of the roof of ventricle IV.

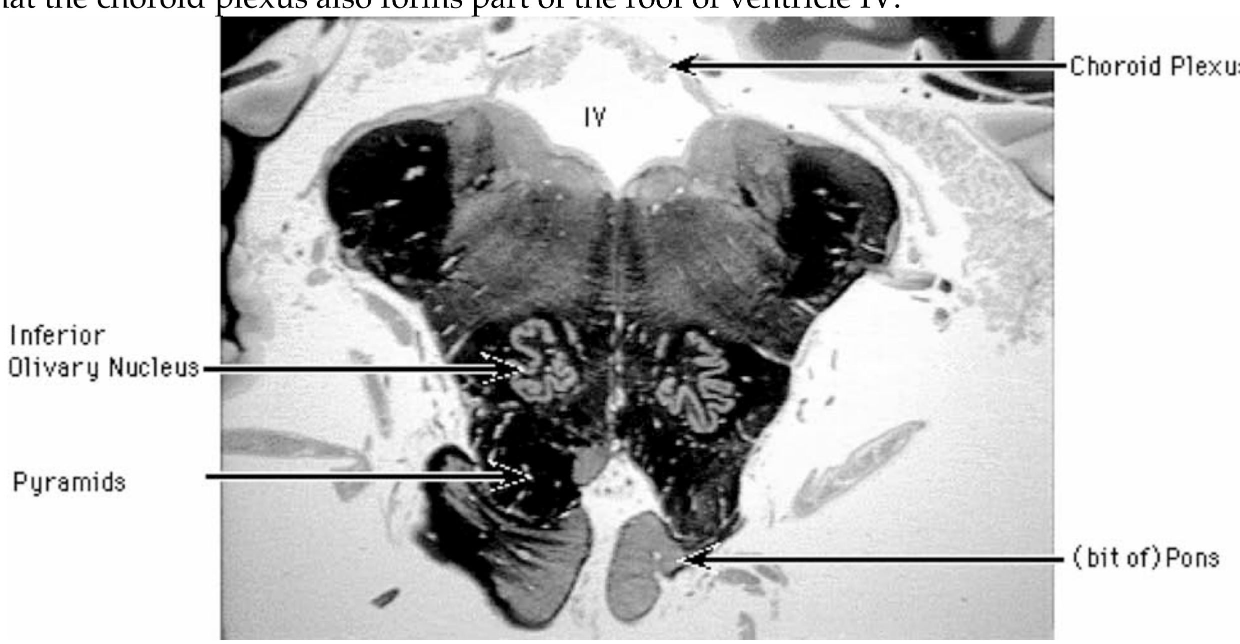

Figure 3N Myelencephalon (Medulla)

II. The Ventricular System

The brain ventricular system is filled with cerebrospinal fluid (CSF) that originates from the choroid plexus (fig 3a), which is continuous with the ependymal lining of the brain. A higher power view of the choroid plexus (fig 3b) shows the apical surface of the choroid plexus epithelial cells facing the ventricle. Their basal ends are next to a core of loose connective tissue that contains numerous capillaries.

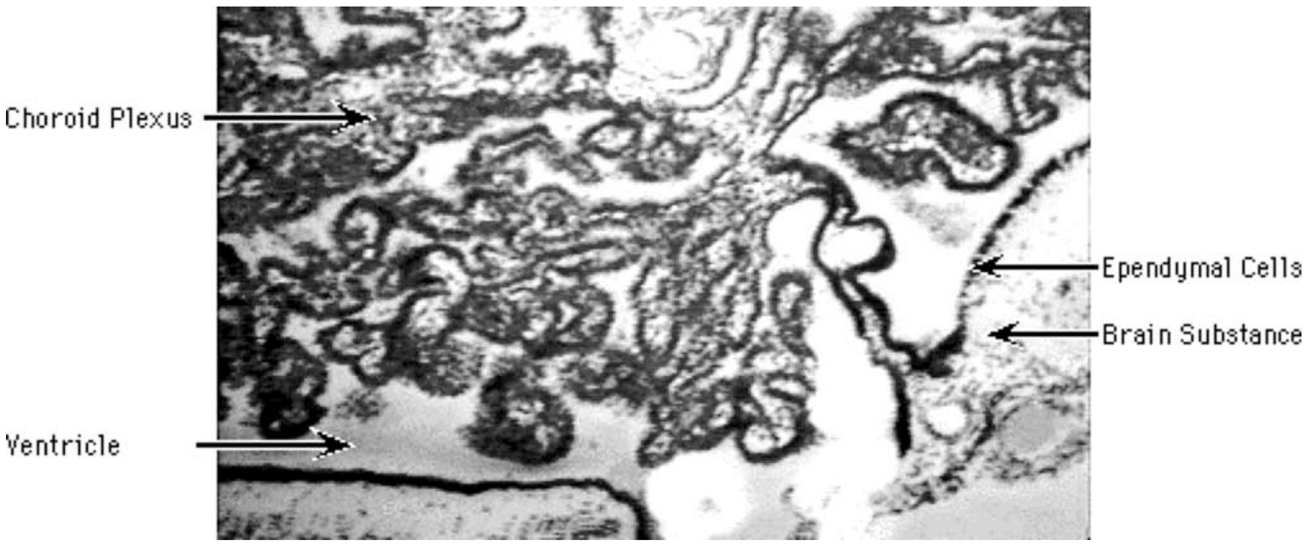

Figure 3A Choroid Plexus

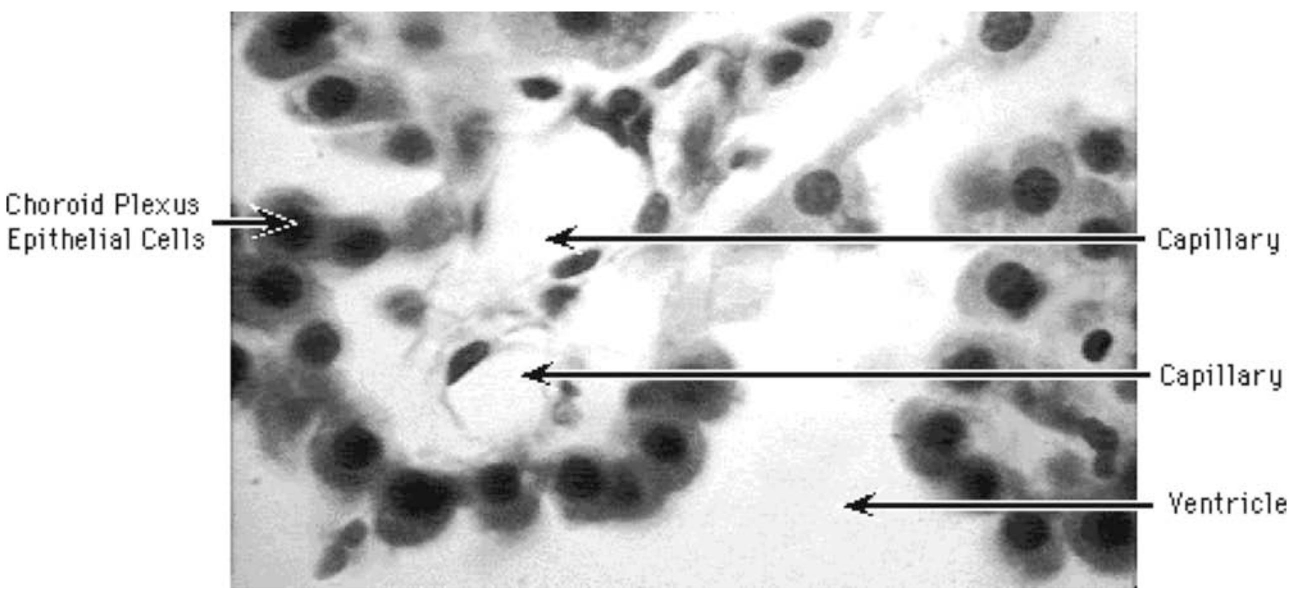

Figure 3B Choroid Plexus

Ciliated ependymal cells (fig 3c) line the ventricular system.

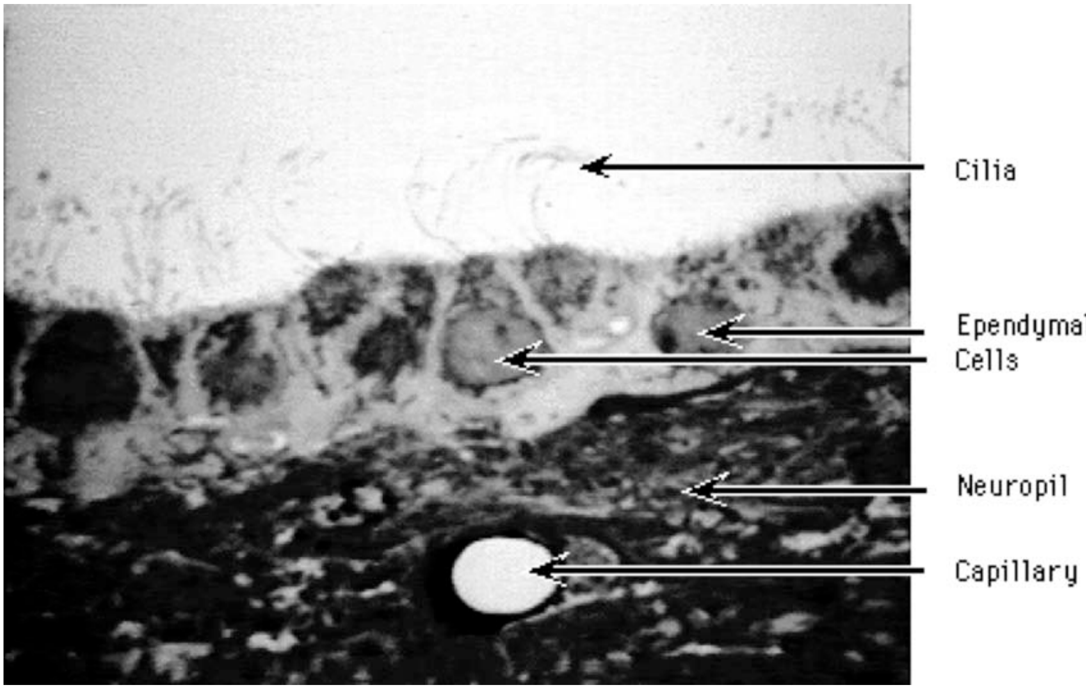

Figure 3C Ependymal Surface

Review the ventricular system (#42045, #4266). The CSF circulates through the lateral ventricles, which each have a body and three horns, the frontal (#52320), occipital (#52322), and temporal (#52321) horns. The part of the lateral ventricle where the body meets the occipital and temporal horns is the trigone (atrium). Next, the CSF passes through the interventricular foramen (of Monro) into the third ventricle (#52316). It leaves this ventricle and flows through the aqueduct (#4262) into ventricle IV (#4261). The CSF exits from the ventricular system through the lateral apertures of Luschka (#52324, #5637) and the median aperture of Magendie. It then enters the subarachnoid space and circulates around the brain. It is transported across the arachnoid granulations (#4926) into the dural sinuses (#4925) and, thus, into the venous system.

What will occur if some portion of the ventricular system, such as the aqueduct, is obstructed? What are the arachnoid granulations (#5611)? What will result if they are scarred (#9295)?

HyperBrain Chapter 3. Coronal Sections and the Ventricular System
Review of Terms

Edited by Stephen C. Voron, M.D. Revised 2007

I. CORONAL SECTIONS

falx cerebri, tentorium cerebelli

A. telencephalon
- lateral ventricles
  - septum pellucidum
- gray matter
  - cerebral cortex
  - basal ganglia
    - caudate nucleus
    - putamen
    - globus pallidus
  - amygdala
  - hippocampus
- white matter
  - corpus callosum
  - fornix
  - internal capsule

B. diencephalon
- third ventricle
- pineal gland
- thalamus
  - massa intermedia (interthalamic adhesion)
- hypothalamus
  - mammillary bodies

C. mesencephalon (midbrain)
- aqueduct (of Sylvius)
- tectum: superior and inferior colliculi
- periaqueductal gray
- red nucleus
- substantia nigra
- cerebral peduncle

D. rhombencephalon (hindbrain)
- fourth ventricle
- **metencephalon (cerebellum and pons)**
- **myelencephalon (medulla)**
  - inferior olivary nucleus, pyramids

II. VENTRICULAR SYSTEM

A. The ventricular system
- ependyma (ependymal cells)
- choroid plexus epithelial cells
- **1. lateral ventricles**
  - frontal (anterior) horn
  - body
  - trigone (atrium)
  - occipital (posterior) horn
  - temporal (inferior) horn
- **2. interventricular foramen (of Monro)**
- **3. third ventricle**
- **4. aqueduct**
- **5. fourth ventricle**
  - lateral apertures of Luschka
  - median aperture of Magendie

B. Review circulation of the CSF: ventricular system ⇒ subarachnoid space ⇒ arachnoid granulations ⇒ dural sinuses ⇒ venous system

4. General Anatomy of Nervous Tissue, the Spinal Cord and the Brain Stem

Revised 2007

The objectives of this chapter are to:

1. Identify the general features of nervous tissue, the spinal cord and the brain stem.
2. Identify the motor nuclei associated with the cranial nerves.

I. Nervous Tissue

A. Neurons and Glia

The parenchyma of the central nervous system (CNS) consists of two cell types: neurons and glia.

Neurons. In general, neurons have a centrally placed nucleus (#9853 a) and nucleolus (#4232). Distributed in the cytoplasm are clumps of basophilic material called Nissl bodies (#6682). They are collections of granular endoplasmic reticulum. Two varieties of processes taper from the cell body: the thicker and shorter processes are the dendrites (#9853 b), and the thinner, longer process is the axon. Ordinarily, a neuron has several dendrites and a single axon. Special methods of staining such as the Golgi method show the characteristic shapes and spatial relationships of neurons (hippocampus #6662, cerebral cortex #6388). The Golgi method shows the neuronal cell body with the dendrites (#4235) and axon (#4234) extending from it. Many dendrites have tiny protrusions called dendritic spines (#3986).

Axons. As shown on the left side of #6132, axons (the round, clear spaces) have various diameters and myelin sheaths of various thicknesses (black circles). Axons conduct nerve impulses between neurons. The speed of this conduction varies with the diameter of the axon and thickness of the myelin sheath. The greater the diameter and the thicker the myelin sheath, the faster the speed of conduction. The myelin sheath is interrupted at points called the nodes of Ranvier (#6923 arrows). Nerve impulses skip from node to node; this is called saltatory ("jumping") conduction. Obviously, the fewer the nodes, the faster the rate of conduction. However, not all axons have a myelin sheath. These are called unmyelinated axons. They are the thinnest axons and have the slowest conduction speeds.

Synapses. Neurons contact each other, as well as muscle and gland cells, at synapses. A typical synapse consists of an axon terminal (the presynaptic component #6787 d) ending on a dendrite (the postsynaptic component #6787 e). The intercellular space between the two components is the synaptic cleft. Axon terminals end not only on dendrites but also on cell bodies and other axons. These synapses are named axodendritic, axosomatic, and axoaxonic synapses, respectively. Special stains are used to show axon terminals (#4469) ending on cell bodies and dendrites. The structure of a typical synapse on a muscle cell is seen best in an electron micrograph (#6776). The axon terminal has many mitochondria (A) and small vesicles (B) that contain neurotransmitters. The neurotransmitters are released from the vesicles into the synaptic cleft (C) and cross it to affect the postsynaptic cell membrane.

Glia. The non-neuronal cells of nervous tissue are called glia. The four major types of CNS glia (glial cells) are astrocytes, oligodendroglial cells, microglial cells, and ependymal cells. Astrocytes (#10392) act as ionic buffers between neurons. Their processes surround the blood vessels (#8648) in the CNS, separating the vessel wall from the neurons. Oligodendroglial cells (#4238) form myelin sheaths around axons in the CNS. Microglial cells (#9872) are phagocytic cells. Ependymal cells (fig 3c) line the ventricular system.

B. Gray Matter and White Matter

The gray matter of the CNS (#6132 on the right) consists of neuronal cell bodies, dendrites, and synapses intermixed with glial cells. Because this is where the synapses are, it is where information transfer occurs in the CNS. The neuronal and glial cell processes in gray matter are called the neuropil. With conventional hematoxylin and eosin stains, this area is not stained (#5533). Other preparations demonstrate the numerous neuronal and glial cell processes that compose the neuropil (#4928). The white matter (#6132 on the left) consists of myelinated and unmyelinated axons, which conduct nerve impulses from one area of gray matter to another. What cell bodies (#4238 arrow) can be recognized in white matter? Compare the structure of gray and white matter.

II. The Spinal Cord

The spinal cord weighs only 35 g. It has two swellings, one near each end, named the cervical (#5358) and lumbosacral (#5359) enlargements. Like the brain, the cord is wrapped in meninges. The thick dura mater (#8483) forms a sac, the dural sac (#4931), in which the cord is suspended. The pia mater of the cord forms a series of collagenous ligaments, the denticulate ligaments (#8484), which anchor the cord to the dura mater helping to hold the cord in place. The pia mater also forms a ligament that extends from the caudal tip of the cord to the blind end of the dural sac. This pial ligament is named the filum terminale (#5403). Extending along the length of the cord, on either side, is a series of dorsal and ventral roots (#5400). Where are the dorsal root cell bodies found (#52090)? What are dorsal root ganglia and where are they located (#12411)?

The cord ends at the level of the disc between vertebrae L-1 and L-2. The caudal tip of the cord is the conus medullaris (#4727, transected at the arrow). What cord segments comprise the conus? What do these segments innervate (#15152)? What does the cauda equina represent (#5405)?

Spinal cord segment L-4 is not adjacent to vertebra L-4. This is the "vertebrosegmental discrepancy." At the end of the embryonic period, eight weeks post-fertilization, the cord and vertebral column are the same length. Then the rate of growth of the vertebral column exceeds that of the cord. The result is obvious: In the adult, the vertebral column is 70 cm long and the spinal cord, 45 cm. The lower portion of the dural sac contains only the dorsal and ventral roots of the cauda equina. Therefore, this is a relatively safe place to insert a needle in the subarachnoid space to withdraw a sample of cerebrospinal fluid.

Spinal segments are distinguished by their pattern of gray and white matter. The differences are seen by comparing representative sections of each level: cervical (fig 4a), thoracic (#6610), lumbar (#6136), and sacral (#6137). Note that in the cervical section there is more white matter relative to gray matter. The opposite is true in the sacral section. Why is this? Toward the upper end of the cervical cord (#6158), the gray matter and white matter are rearranged (#6211) until the structural features of the medulla emerge (#6164). The gray matter and white matter of the medulla is continuous with that of the cord. Some features are deleted and others are added.

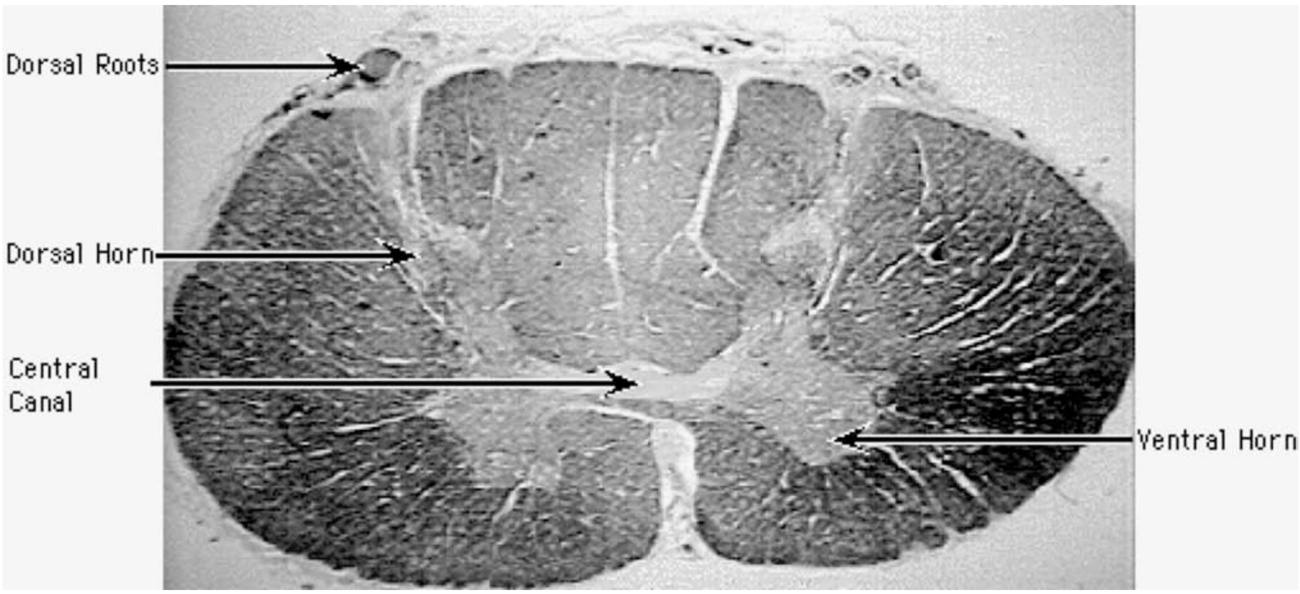

Figure 4A Cervical Spinal Cord

III. The Brain Stem and its Motor Nuclei

The structure of the brain stem (fig 4b) is usually studied by examining a series of gross and microscopic transverse sections through the medulla, pons, and midbrain. The sections are typically stained for myelin to show white matter as dark. Review the major external features and cranial nerves associated with the brain stem by clicking on each of the labels below. This should serve as a reference point for the following descriptions of cross sections.

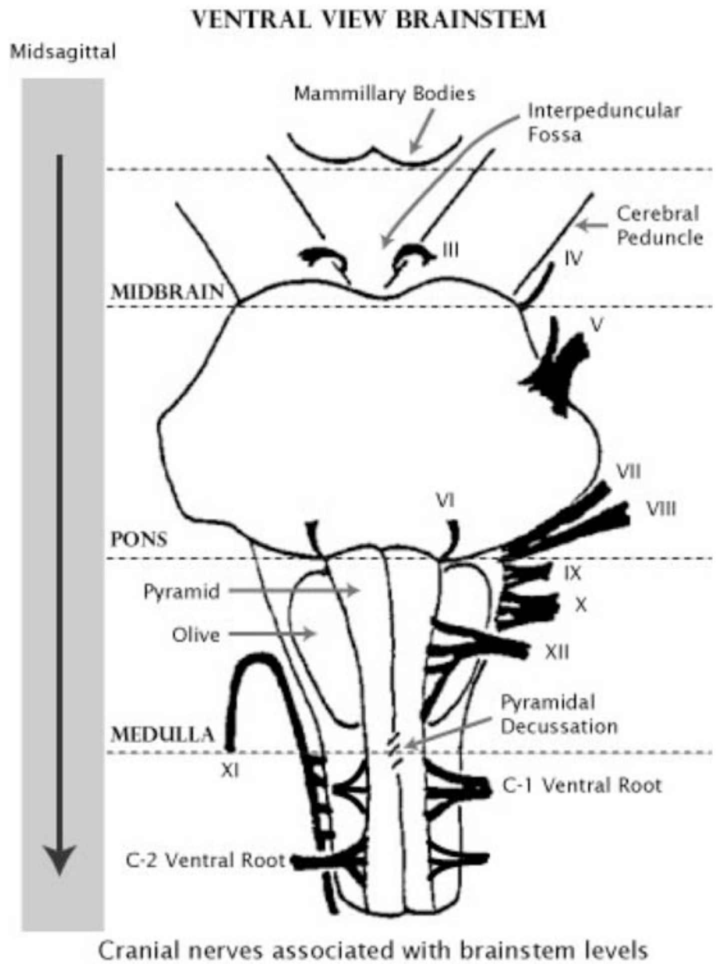

Figure 4b Ventral View of Brain Stem with Cranial Nerves

In a myelin-stained section, the gray matter appears pale. Other stains actually show the nerve cell bodies. The organization of the gray matter and white matter is characteristic for each level of the brain stem. The motor nuclei of the cranial nerves are emphasized in the following description. It is important to know which motor nuclei are present in each level of the brain stem. Knowing this and knowing what motor nuclei are not functioning allow you to predict what area of the brain stem is affected in a patient with a neurologic problem.

A. The Medulla

The first motor nucleus to be identified is that of the spinal accessory nerve, cranial nerve XI. This cranial nerve actually originates in the upper five cervical segments, #4302 (fig 4c). The axons leave the cord by forging their way across the white matter to exit halfway between the dorsal and ventral roots. The axons then turn rostrally, go along the side of the cervical cord (#4169), and pass through the foramen magnum into the posterior cranial fossa. Here they join the axons of cranial nerves IX and X to exit the posterior cranial fossa through the jugular foramen (fig 4d, #5415) The spinal accessory nerve innervates the ipsilateral sternocleidomastoid muscle and the upper portion of the trapezius muscle.

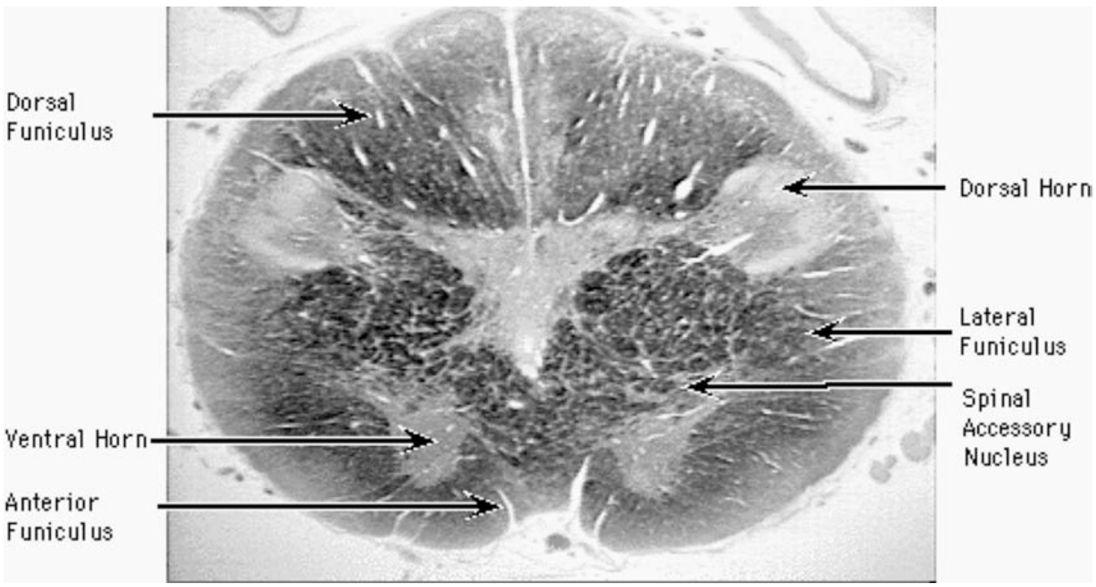

Figure 4C Junction of Spinal Cord and Medulla

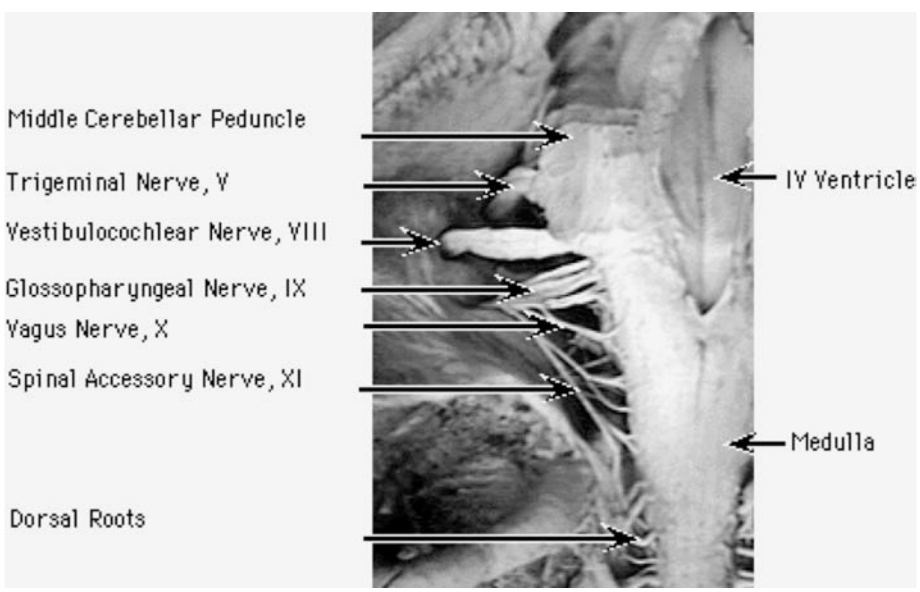

Figure 4D Posterior View of Posterior Fossa, Courtesy of Dr. Allen Bell

The medulla (fig 4e) contains the motor nuclei of cranial nerves XII, X, and IX. Two prominent structures that are characteristic of the medulla are the pyramids (#6411), composed of descending axons, and the inferior olivary nuclei (#6541). All of the medulla dorsal to the pyramids is called the tegmentum ("cover") of the medulla. On either side of the midline just beneath the ventricle floor (= the dorsal surface of the medulla) are the hypoglossal nuclei, shown in a myelin-stained section (#6319), and seen with a Klüver-Barrera stain for cell bodies (pink dots #6233). They correspond to motor nuclei in the ventral horn of the spinal cord. Where do the axons of the hypoglossal motor neurons emerge on the surface of the brain stem? (#5606). How do the axons exit from the cranial cavity? (#5187). Where do they terminate? (#51549)

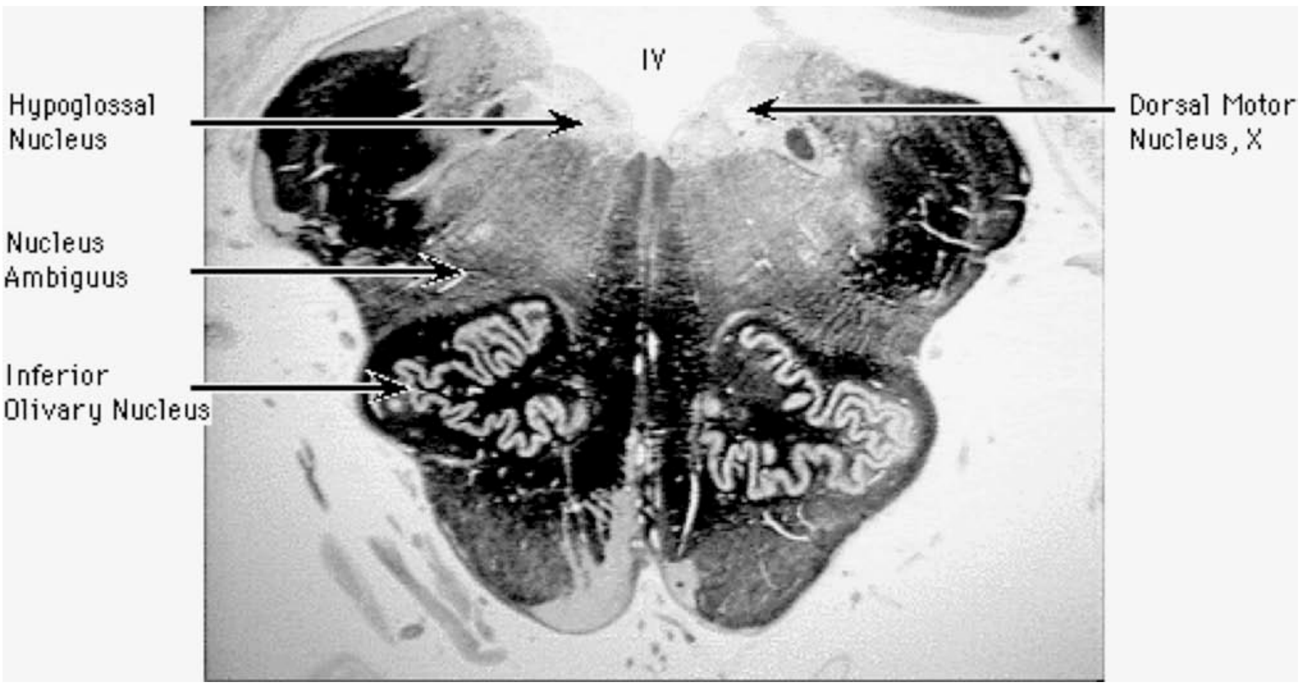

Figure 4E Medulla

The dorsal motor nucleus of X (fig 4e) (#6242) is just lateral to the hypoglossal nucleus (#6240). The dorsal motor nucleus of X is a collection of preganglionic parasympathetic cell bodies. It is one of the two motor nuclei that contribute axons to the vagus nerve (#7954). Where do the axons that originate in this nucleus terminate?

The other motor nucleus that contributes axons to cranial nerve X (#4242) is the nucleus ambiguus (#6239), located dorsal to the inferior olivary nucleus (fig 4e). The nucleus ambiguus also contributes axons to the glossopharyngeal nerve (cranial nerve IX) (#5601, #7950). Where do the axons originating in this nucleus terminate? What is the functional significance of this nucleus? Cranial nerve IX also contains preganglionic parasympathetic axons that originate from the inferior salivatory nucleus, which is directly rostral to the dorsal motor nucleus of X, but is not visible.

B. The Pons

A section of the pons (#5285) shows the fourth ventricle dorsally and, most characteristic, a large fiber bundle on each side, the middle cerebellar peduncle. The pons consists of a ventral part, the basilar pons (pons proper) and a dorsal part, the pontine tegmentum (fig 4f). The basilar part has a unique appearance with nuclei, transverse bundles of fibers, and fibers descending to the medullary pyramids. The transverse fibers cross to the cerebellum as the middle cerebellar peduncle and give the pons ("bridge") its name. Within the tegmentum are the cranial nerve nuclei.

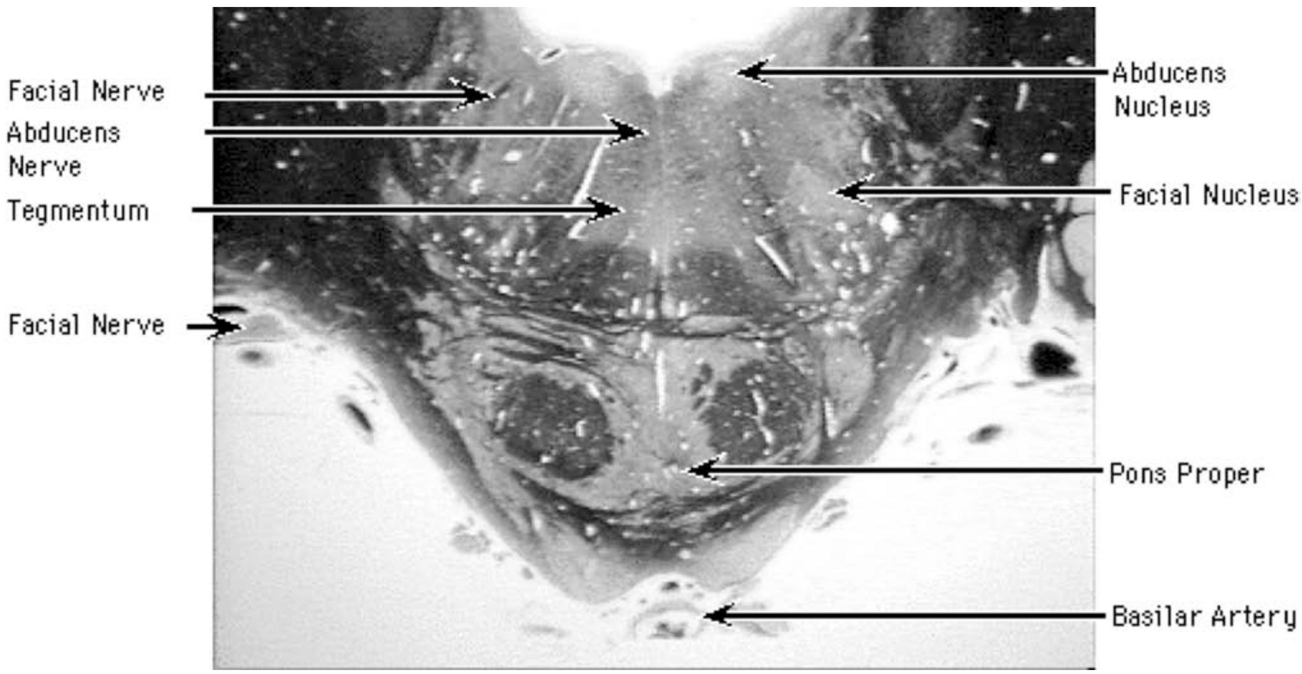

Figure 4F Pons at the Level of the Abducens Nucleus

Caudal pons. Locate motor nuclei VI (abducens) and VII (facial) in a section through the caudal pons (fig 4f). The abducens nucleus is found next to the midline directly beneath the fourth ventricle in a position corresponding to the hypoglossal nucleus in the medulla. Check the intracerebral course of the abducens axons (#6698). The axons form the nerve near the midline at the pontomedullary junction (#7955, #5280). The facial nucleus (VII) (#6176) is more ventral and lateral. It corresponds in position to the nucleus ambiguus. The axons of VII take a peculiar course within the brain stem. They go medially and dorsally and loop over the abducens nucleus before turning laterally (#6699). The abducens nucleus and overlying facial nerve rootlets form a bulge in the floor of the fourth ventricle called the facial colliculus (#4487). Portions of the course of the facial nerve within the tegmentum are seen in #9759. The facial nerve emerges between the medulla, pons, and cerebellum in a region called the cerebellopontine angle (#5305). The nerve next enters the temporal bone. What is the name of the foramen it enters (#5440)? The abducens nerve passes along the clivus (#5185) into the cavernous sinus (#7885). What is innervated by the axons originating in the abducens and facial nuclei?

Recall that cranial nerve VII also contains preganglionic parasympathetic axons. They should not be confused with the axons arising in the facial nucleus. In what nucleus are the cell bodies for these autonomic fibers located? The nucleus is so tiny that it cannot easily be identified in these sections.

Mid pons. The motor nucleus of V (fig 4g) is rostral to the abducens and facial nuclei. Its axons go through the middle cerebellar peduncle to emerge on its surface on the side the pons (#6701, #4736). What is the distribution of axons arising in this nucleus?

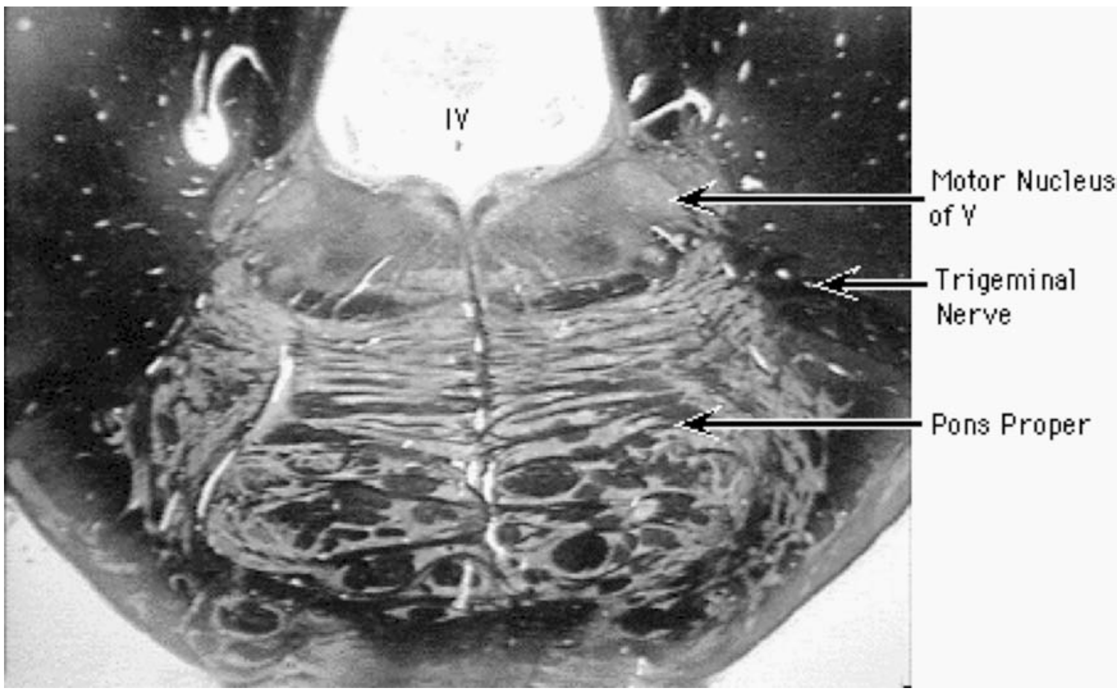

Figure 4G Mid-Pons

Nerve cells in the nucleus ambiguus and in the facial and trigeminal motor nuclei innervate skeletal muscle that is derived from the pharyngeal (branchial) arches instead of myotomes, the typical source of skeletal muscle. The pharyngeal arch-derived skeletal muscle is called branchiomeric muscle to emphasize its homology with the branchial (gill) arch muscle system of fish. Our facial and pharyngeal muscles are branchiomeric. Are there other examples? The three nuclei (ambiguus, facial, motor nucleus of the trigeminal) really represent one nuclear group that has been interrupted so that instead of seeing one, long continuous nucleus, we see three separate ones.

C. The Mesencephalon or Midbrain

The features that identify a section through the midbrain are 1) the narrow aqueduct, 2) the large ventral cerebral peduncles, containing axons descending to the basilar pons and medullary pyramids, and 3) rounded eminences dorsally (fig 4h). The rounded eminences (#8520) are the superior colliculi and inferior colliculi, collectively called the quadrigeminal plate or tectum ("roof"). The aqueduct is surround by periaqueductal gray (central gray). The substantia nigra is dorsal to the cerebral peduncles. The midbrain tegmentum is between the substantia nigra and the aqueduct (fig 4h).

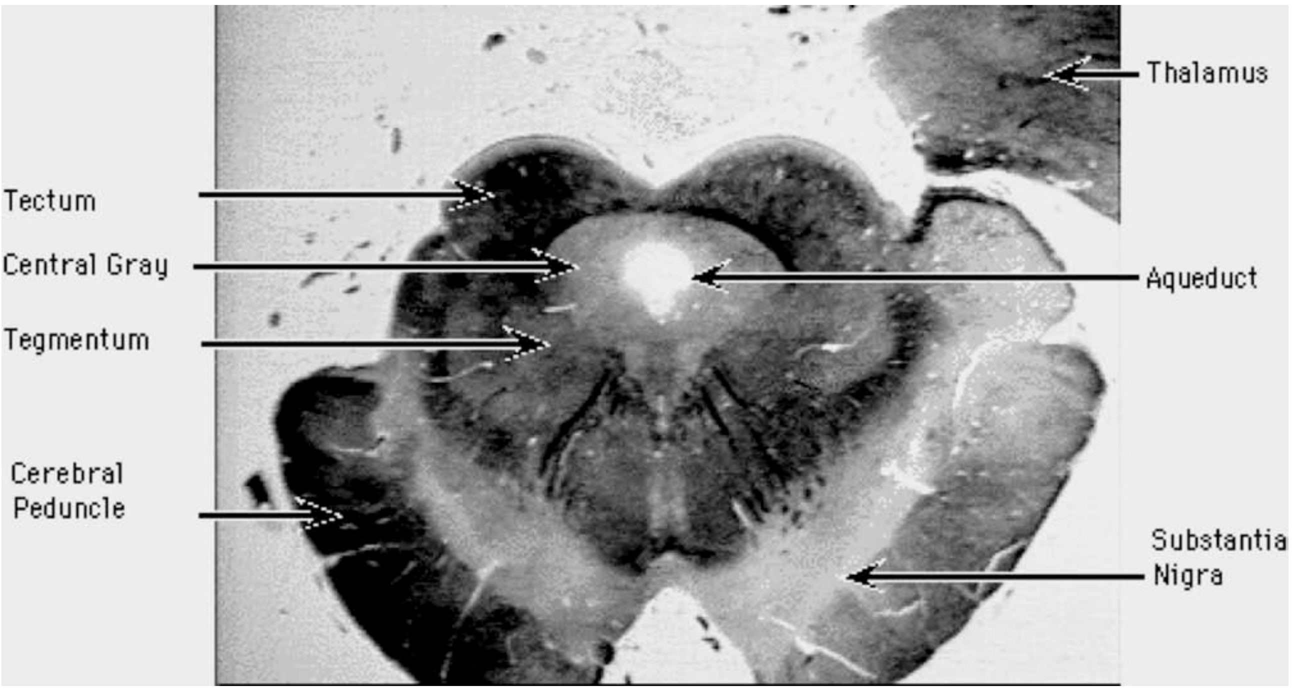

Figure 4H Midbrain at Level of Superior Colliculus

Caudal midbrain at level of inferior colliculi. The nuclei and fibers of cranial nerve IV are seen in fig 4i and fig 4j. The axons of this nerve have a unique intracranial course. They leave the trochlear nucleus to go dorsally along the central gray (#6704) and cross dorsal to the fourth ventricle as it is about to become the aqueduct (#4461). They emerge on the opposite dorsal side of the brain stem just below the inferior colliculi (#4357, #11715). The axons then pass lateral to the cerebral peduncle (#5641) and go forward through the cavernous sinus (#7885) and superior orbital fissure (#6958) into the orbital cavity. Which muscle(s) do these axons innervate? Does the right trochlear nerve innervate muscle(s) on the left side or on the right side?

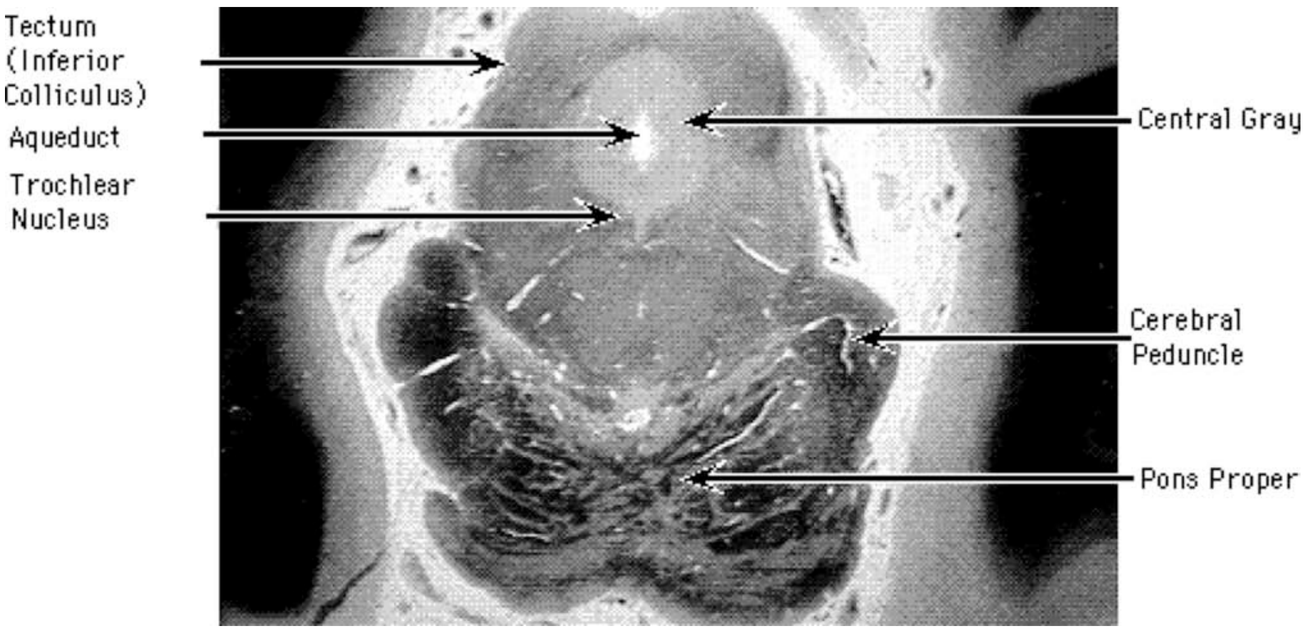

Figure 4I Midbrain at Level of Inferior Colliculus

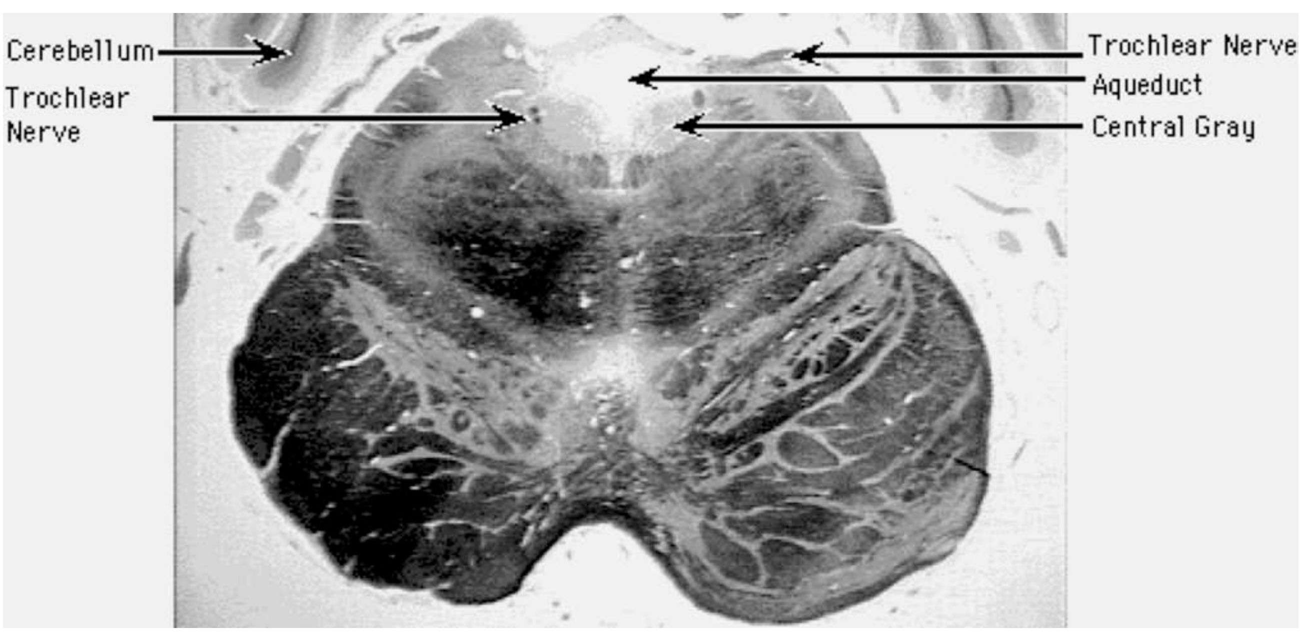

Figure 4J Junction of Pons and Midbrain, Emergence of Trochlear Nerve

Rostral midbrain at level of superior colliculi. The axons of cranial nerve III are shown in fig 4k. They originate in the oculomotor nuclei (#6310), which are next to the midline just ventral to the central gray at the level of the superior colliculus. This is a complex nuclear group consisting of several nuclei. Each nucleus gives rise to axons that innervate a specific extraocular muscle as well as the levator palpebrae superioris. The axons leave the nucleus and travel ventrally through the tegmentum. They leave the brain stem and enter the interpeduncular fossa (#5322, #11724). As the nerve goes into the cavernous sinus, it passes near the free edge of the tentorium cerebelli (#15236). The nerve enters the orbit through the superior orbital fissure (#6958).

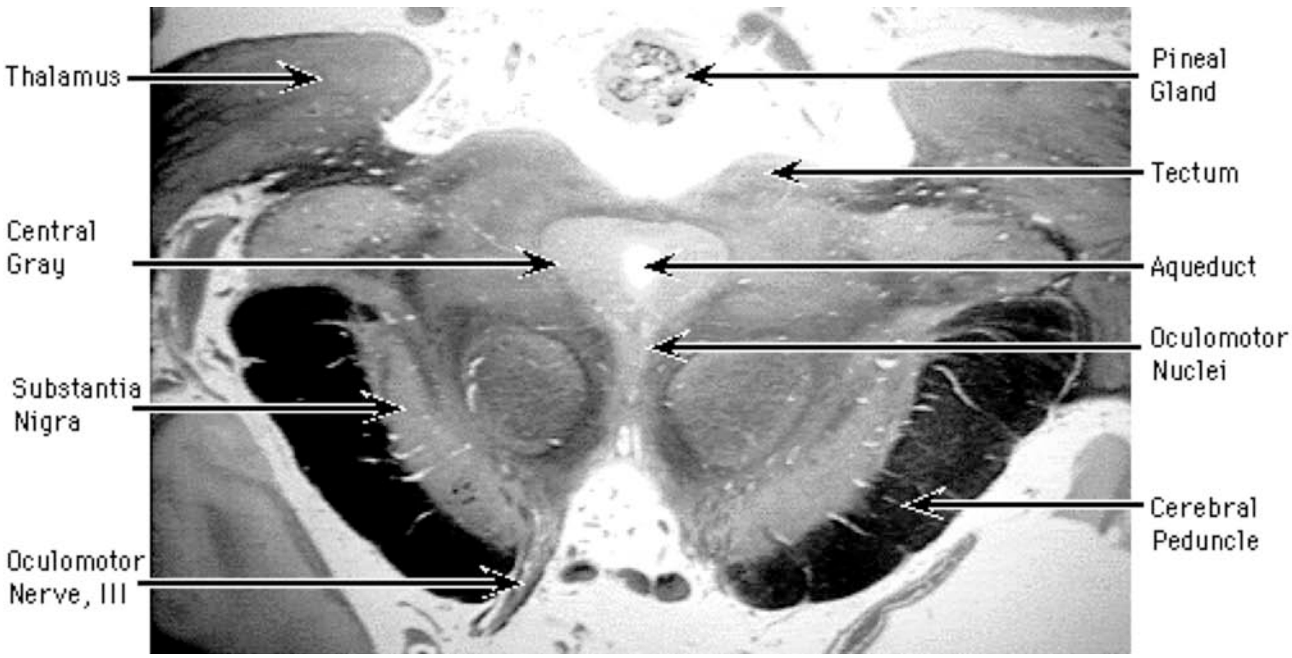

Figure 4K Midbrain - Diencephalon Junction

In addition to the somatic motor fibers, cranial nerve III contains preganglionic parasympathetic axons from the Edinger-Westphal nucleus for autonomic innervation of the eye. Depending on the author, this nucleus is either part of the oculomotor nucleus or an adjacent separate nucleus.

By way of review, identify all levels of the brain stem by using the dorsal view of the brain stem (fig 4m) with **links** to each level (click on each view arrow). It is important to remember what cranial nerves are associated with each level. Specifically, what cranial nerves are associated with the medulla #7920, pons #7919, and midbrain #7918?

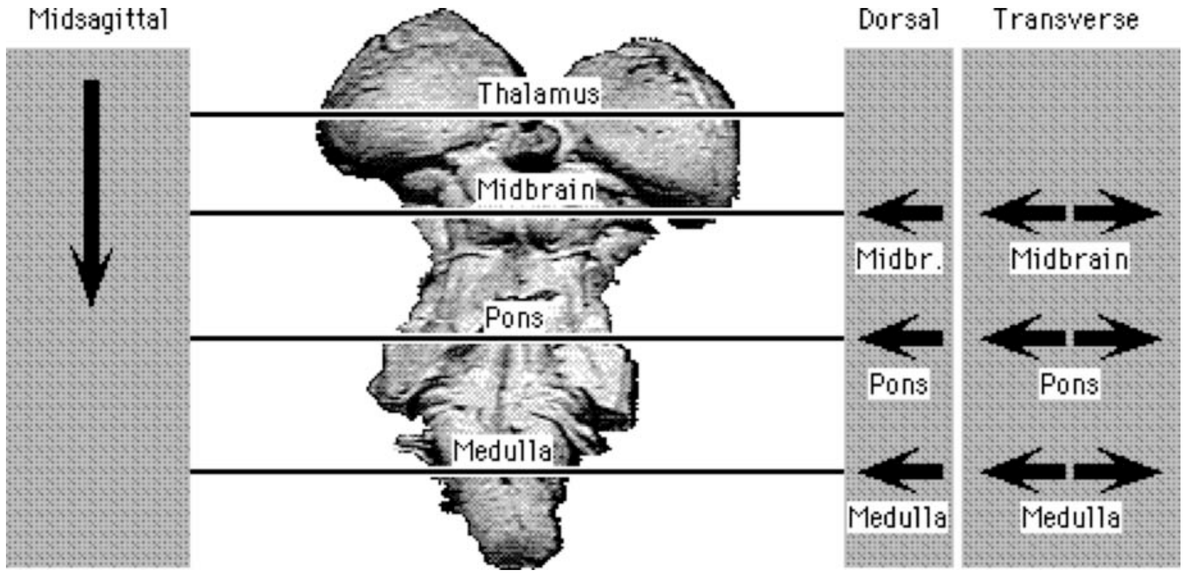

Figure 4M Dorsal Surface Of Isolated Brain Stem

HyperBrain Chapter 4:
General Anatomy of Nervous Tissue, the Spinal Cord and the Brain Stem
Review of Terms

Edited by Stephen C. Voron, M.D. 2008

I. Nervous Tissue

Neurons
- Nissl bodies, granular endoplasmic reticulum
- **Dendrites**
  - dendritic spines
- **Axons**
  - myelinated axons
    - nodes of Ranvier, saltatory conduction
  - unmyelinated axons
- **Synapses**
  - presynaptic: axon terminal
    - vesicles, neurotransmitters
  - synaptic cleft
  - postsynaptic: dendrite

Glia (glial cells)
- astrocytes
- oligodendroglial cells
- microglial cells
- ependymal cells

Gray Matter
- neuropil

White Matter

II. The Spinal Cord

- cervical and lumbosacral enlargements
- meninges
  - dura mater, dural sac
  - pia mater, denticulate ligaments, filum terminale
- dorsal and ventral roots
- dorsal root ganglia
- conus medullaris
- cauda equina
- vertebrosegmental discrepancy
- subarachnoid space, cerebrospinal fluid
- spinal cord segments: cervical, thoracic, lumbar, sacral, coccygeal

III. The Brain Stem and its Motor Nuclei

- brain stem = medulla + pons + midbrain
- branchiomeric muscle

A. The Medulla

Identifying features of a medulla section
1. pyramids
2. inferior olivary nuclei
3. tegmentum of the medulla

Cranial nerve XI (spinal accessory nerve)
- foramen magnum, posterior cranial fossa, jugular foramen
- sternocleidomastoid and trapezius muscles

Cranial nerve XII (hypoglossal nerve)
- hypoglossal nucleus

Cranial nerve X (vagus nerve)
- nucleus ambiguus
- dorsal motor nucleus of X
  - preganglionic parasympathetic cell bodies

Cranial nerve IX (glossopharyngeal nerve)
- inferior salivatory nucleus

B. The Pons

Identifying features of a pons section
1. fourth ventricle
2. middle cerebellar peduncle
3. basilar pons (pons proper)
4. pontine tegmentum

Caudal pons
- motor nucleus VI (abducens)
  - abducens nucleus
  - abducens nerve, clivus, cavernous sinus
- facial nucleus (VII) motor nucleus VII (facial)
  - facial colliculus
  - cerebellopontine angle, temporal bone

Mid pons
- motor nucleus of V

C. The Mesencephalon or Midbrain

Identifying features of a midbrain section
1. aqueduct, periaqueductal gray (central gray)
2. cerebral peduncles
3. quadrigeminal plate = tectum =
4. superior and inferior colliculi
5. substantia nigra
6. midbrain tegmentum

Caudal midbrain at level of inferior colliculi
- cranial nerve IV
- trochlear nucleus
- cavernous sinus, superior orbital fissure, orbit

Rostral midbrain at level of superior colliculi
- cranial nerve III
  - oculomotor nuclei
  - extraocular muscles, levator palpebrae superioris
  - interpeduncular fossa
  - tentorium cerebelli
- Edinger-Westphal nucleus

5. Somatic Sensation

Revised 2010

The learning objectives of this chapter are to:

Describe the organization of the anterolateral system and the dorsal column-medial lemniscus system. In particular, be able to

1. Describe the location of the primary, secondary, and tertiary sensory neurons for each system.
2. Name the structures both systems have in common.
3. For each system, describe the location of the axons of the second-order neurons at each major brain stem level.
4. Describe the spatial relations between the two systems at each level.
5. Describe the positions of these systems relative to the cranial nerve motor nuclei.

Somatic sensation is sensation that originates from receptors in the skin, muscles and joints. This chapter describes the two main systems that mediate conscious perception of somatic sensation from the body (somatic sensation from the head is covered in the next chapter):

1. The anterolateral system (ALS), which includes the spinothalamic tract, mediates pain (clinically tested by pinprick), temperature, and light (simple, crude) touch.

2. The dorsal column-medial lemniscus (DCML) system mediates
   - Two-point tactile discrimination: the ability to recognize that two blunt points closely applied to the skin are not a single point
   - Stereognosis (recognition of object size, basic shape, and texture), tactile object recognition (identification of an object, e.g., as a key or a coin), and graphesthesia (identification of letters and numbers written on the skin)
   - Vibration
   - Proprioception (kinesthesia): Limb/joint position and direction of movement
   - Light (simple, crude) touch

   With disease of the DCML system, in addition to impairment of the above functions, the following three signs may occur:
   - Sensory ataxia: ataxia (awkward movement) due to impaired proprioception
   - Positive Romberg sign: With the feet together, upon eye closure, body sway increases dramatically.
   - Areflexia/hyporeflexia – if the primary sensory neurons (the dorsal root ganglion cells) of the DCML system are affected.

Note that there will be little deficit in light touch if only one system is affected.

I. The Anterolateral System (ALS) (Spinothalamic Tract)

The anterolateral system is a three-neuron pathway.

Receptors

The peripheral axons of the primary sensory neurons of the anterolateral system end as unencapsulated free nerve endings. These are the sensory receptors for the anterolateral system.

Primary sensory neurons

The primary sensory axons of the anterolateral system are mainly small-diameter myelinated (Aδ) and unmyelinated (C) cutaneous fibers (and the corresponding groups III and IV fibers in muscle nerves).

The cell bodies of the primary sensory neurons of both the anterolateral and DCML systems are located in dorsal root ganglia (DRG, spinal ganglia) (#4295). The bluish structures are myelinated axons. The large neuronal cell bodies are surrounded by numerous densely staining satellite cells (#4363) (actually only their nuclei are stained). The DRG neuronal cell bodies of the anterolateral system are smaller than those of the DCML system, corresponding to the diameters of their axons. Dorsal root ganglion neurons, which develop from neural crest cells, have a peripheral axonal process and a central axonal process. The peripheral axons of one dorsal root ganglion innervate a particular stretch of skin called a dermatome. The central process enters the spinal cord through a dorsal root.

In sections through the spinal cord, identify the dorsal horn (#6683) and Lissauer's tract (dorsolateral fasciculus) (#4542, fig 5a, fig 5b, fig 5c, fig 5d). What forms this tract? What is its functional significance?

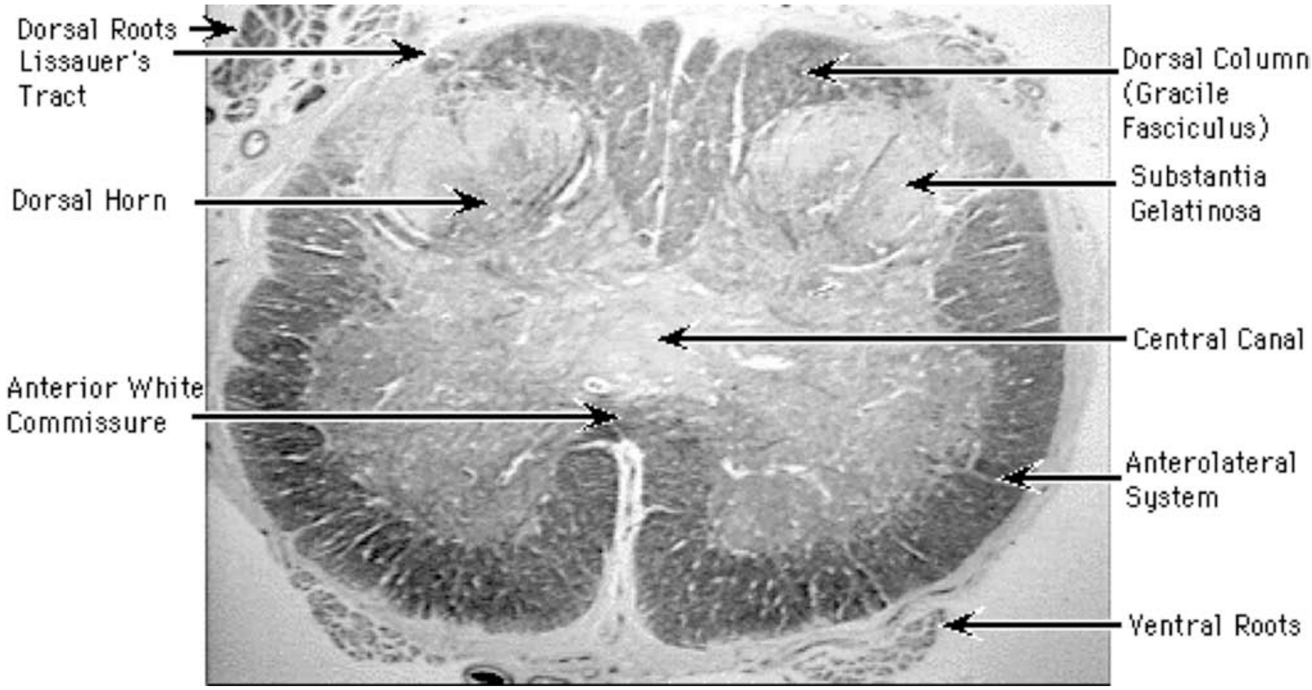

Figure 5A Sacral Spinal Cord

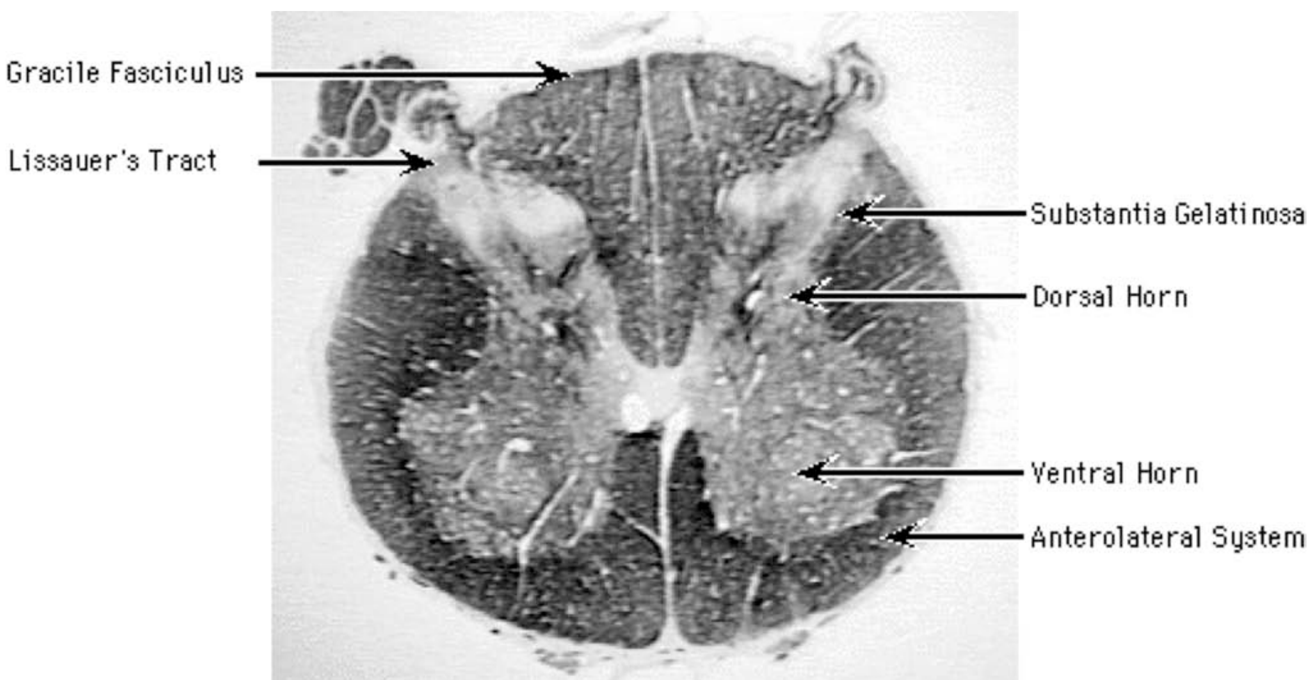

Figure 5B Lumbar Spinal Cord

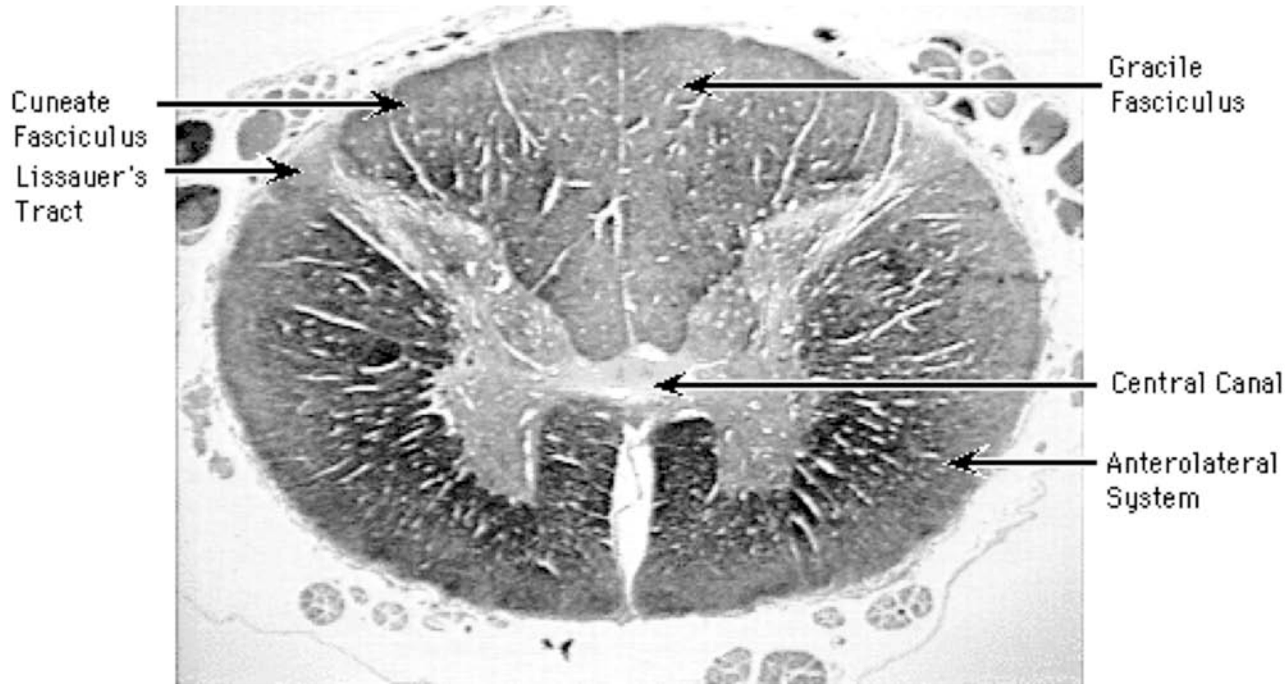

Figure 5C Thoracic Spinal Cord

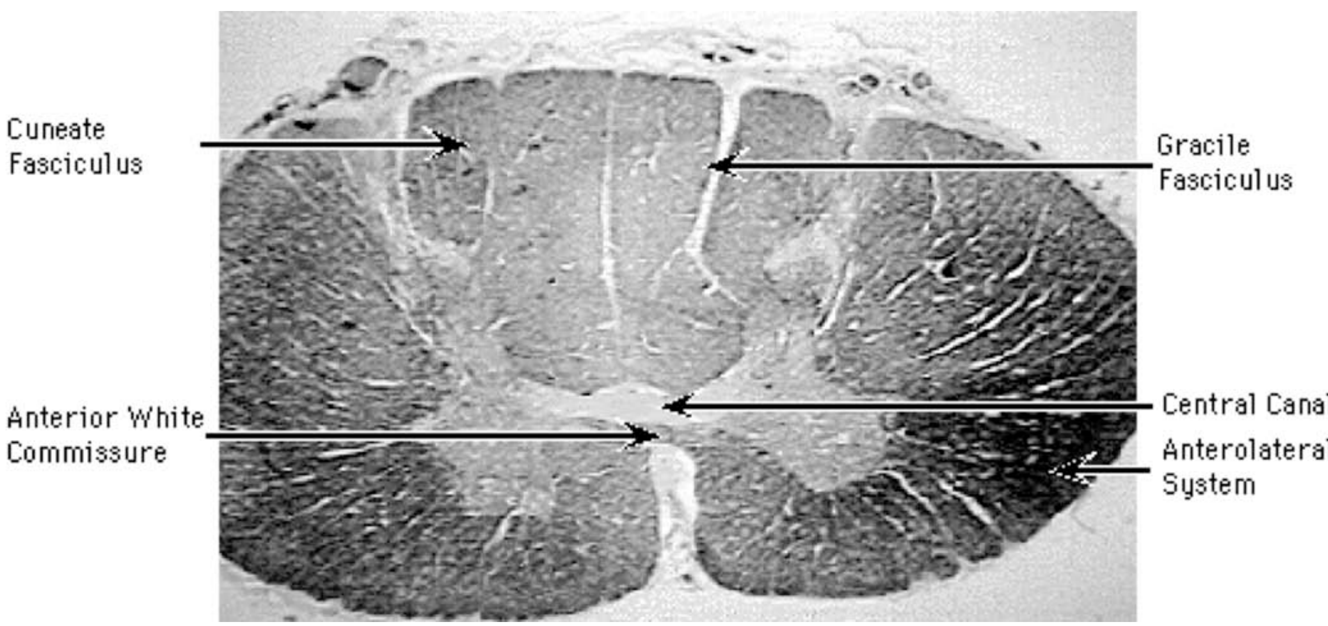

Figure 5D Cervical Spinal Cord

Secondary sensory neurons

The cell bodies of the secondary sensory neurons of the anterolateral system are located in the dorsal horn.

The secondary sensory axons sweep across the midline, ventral to the central canal, in the anterior white commissure, and then ascend in the contralateral anterolateral white matter as a diffuse collection of fibers, the anterolateral system (#6717). **The most important component of the anterolateral system is the spinothalamic tract**, which is the major pathway in humans for pain and temperature sensation. How are the dermatomes represented in the anterolateral system?

In fig 5a, observe the central canal and notice its proximity to the anterior white commissure (#6713), in which the secondary sensory axons decussate (cross) to the other side of the cord. Should the canal expand, as in syringomyelia (#11730), what will happen to the commissure? What will be the result?

In the medulla, the anterolateral system axons (fig 6c, #6170) are lateral and dorsal to the inferior olivary nucleus. Where are they in respect to the nucleus ambiguus (fig 4e)? The anterolateral system and nucleus ambiguus are both in the dorsolateral quadrant of the medulla, nourished by branches of the vertebral artery, including small direct branches as well as the posterior inferior cerebellar artery (#8469). Hence, both the anterolateral system and the nucleus ambiguus are affected by infarction of this area (#9728) as part of the lateral medullary syndrome (Wallenberg's syndrome).

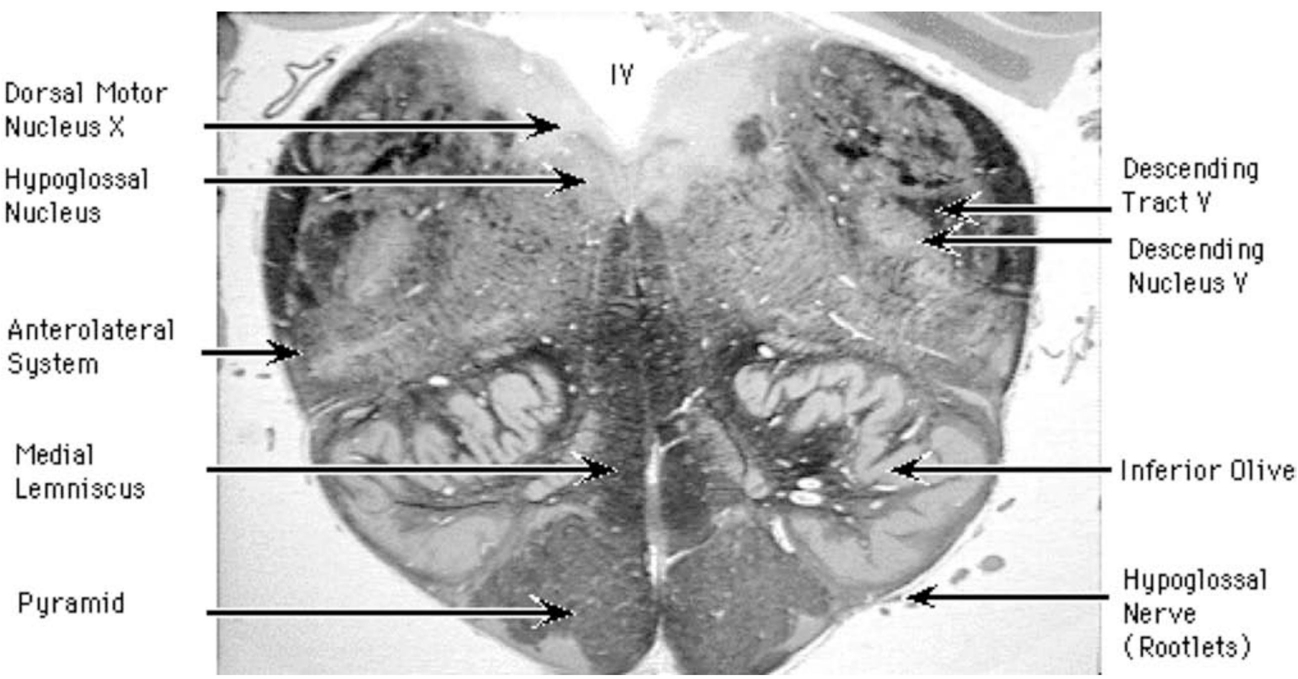

Figure 6C Caudal Medulla

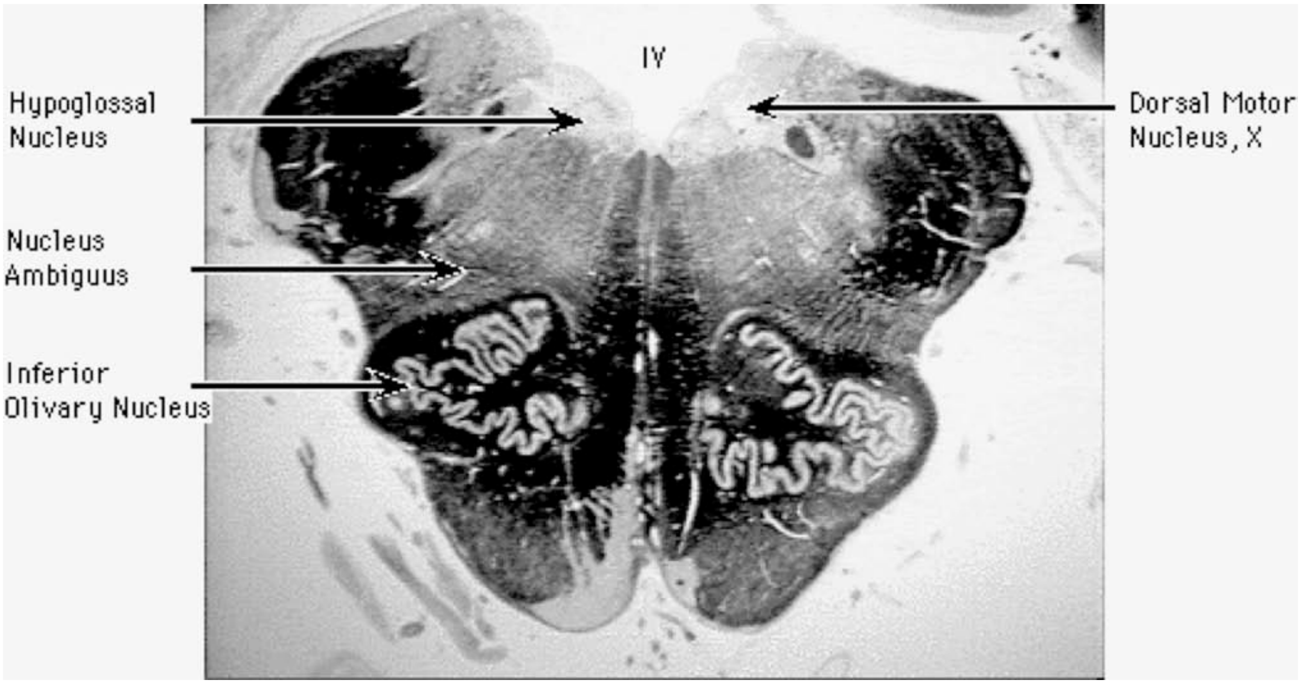

Figure 4E Medulla

In the pons (fig 5f, fig 5g), the anterolateral system is in the ventrolateral tegmentum, similar to its location in the medulla. It maintains this relative position throughout its course in the brain stem (fig 5h). It is near the pial surface at the level of the inferior colliculus (#6606).

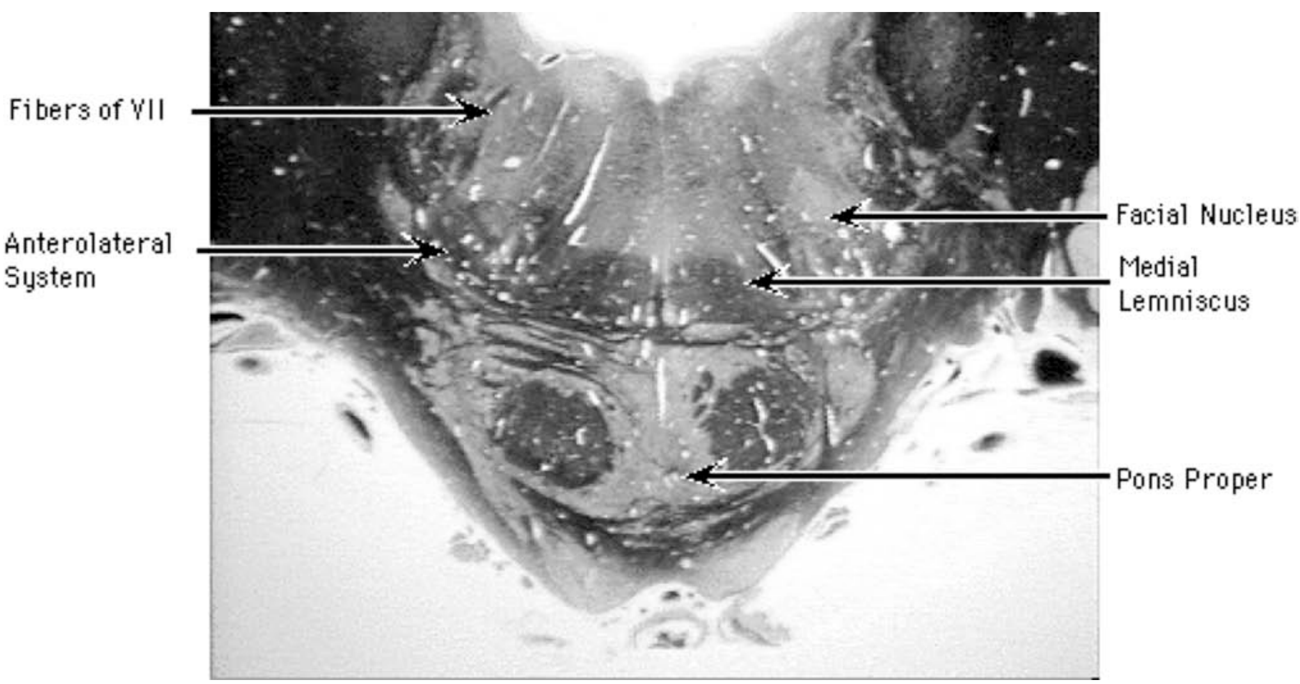

Figure 5F Pons

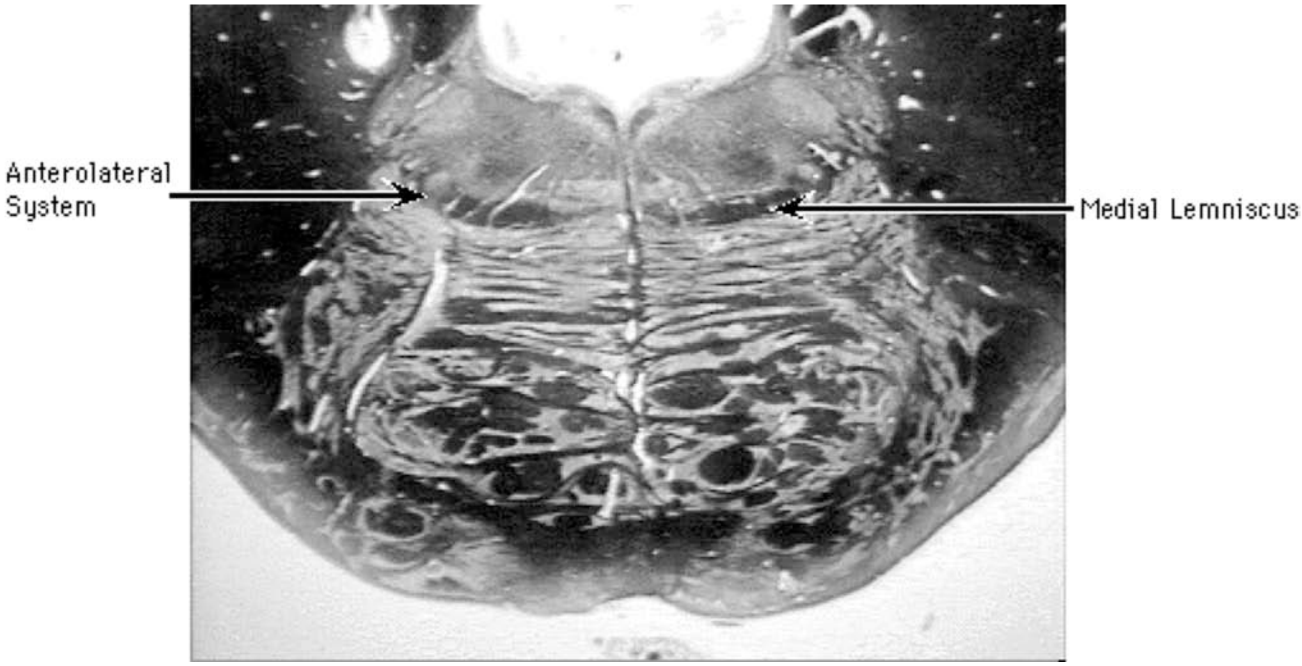

Figure 5G Pons

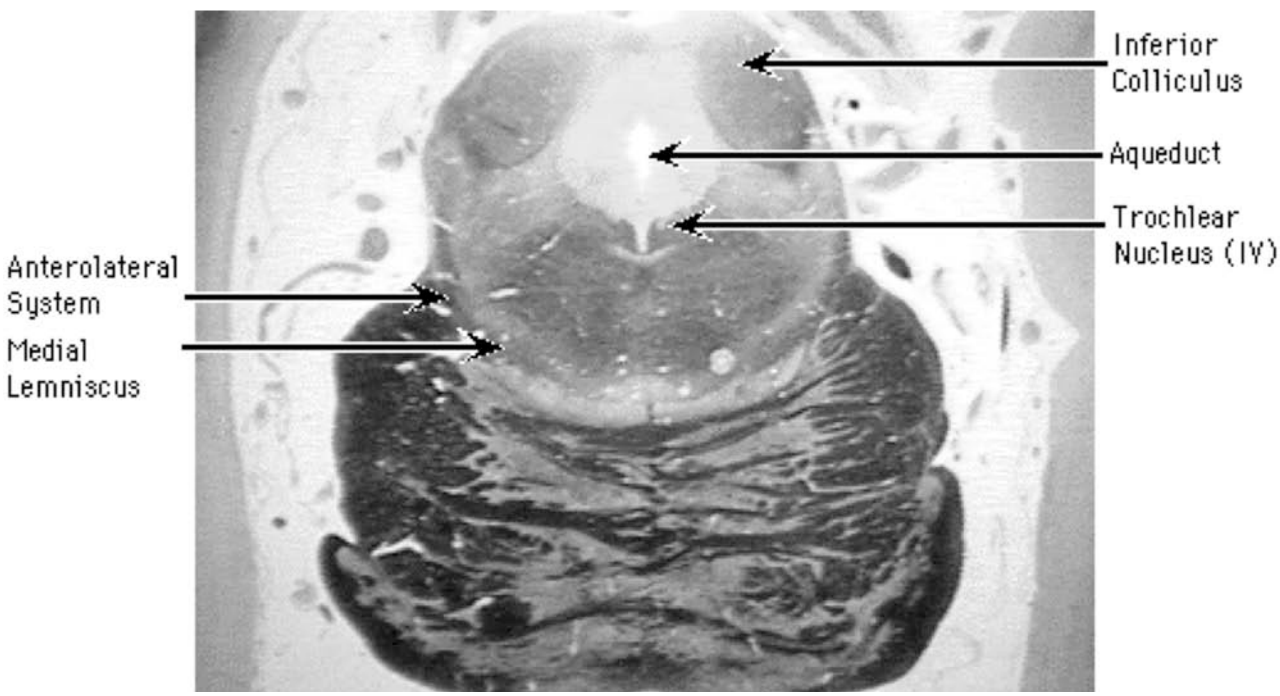

Figure 5H Midbrain at the Level of the Inferior Colliculus

At the level of the junction between the midbrain and thalamus, the anterolateral system fibers join with those of the medial lemniscus (to be discussed next) (fig 5i). They can be followed together into the thalamus (fig 5j). Both the anterolateral system and medial lemniscus terminate in the ventral posterolateral nucleus (VPL) of the thalamus (#6734), the main relay nucleus of the thalamus for somatic sensation from the body. The axons of the anterolateral system that reach the thalamus are the spinothalamic tract.

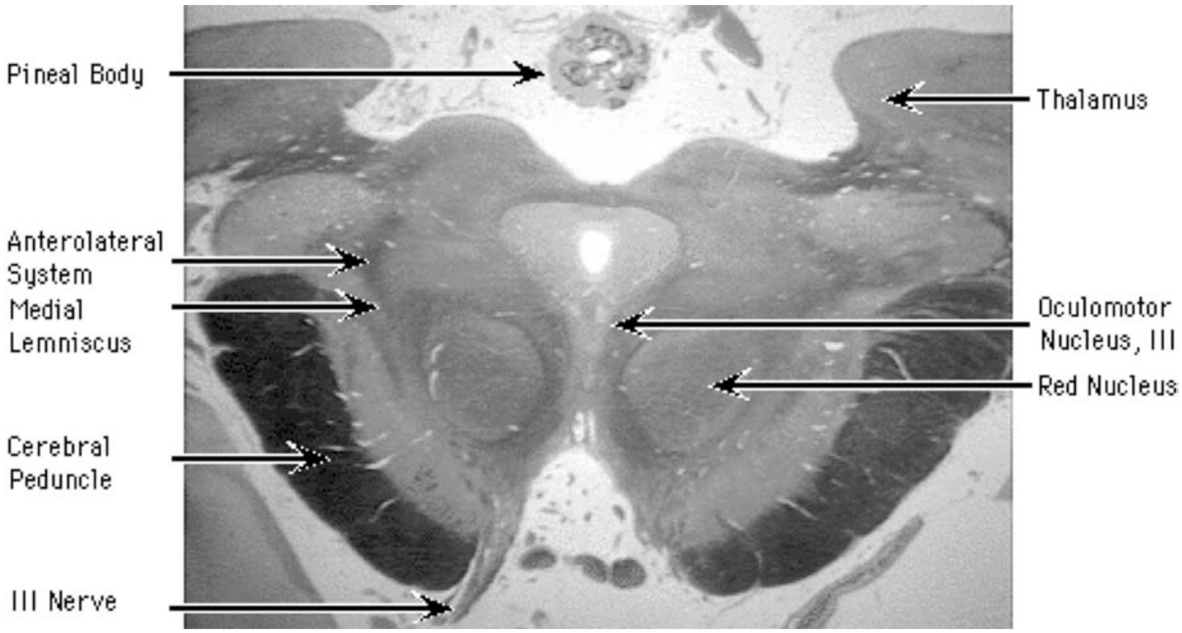

Figure 5I Midbrain at the Level of the Superior Colliculus

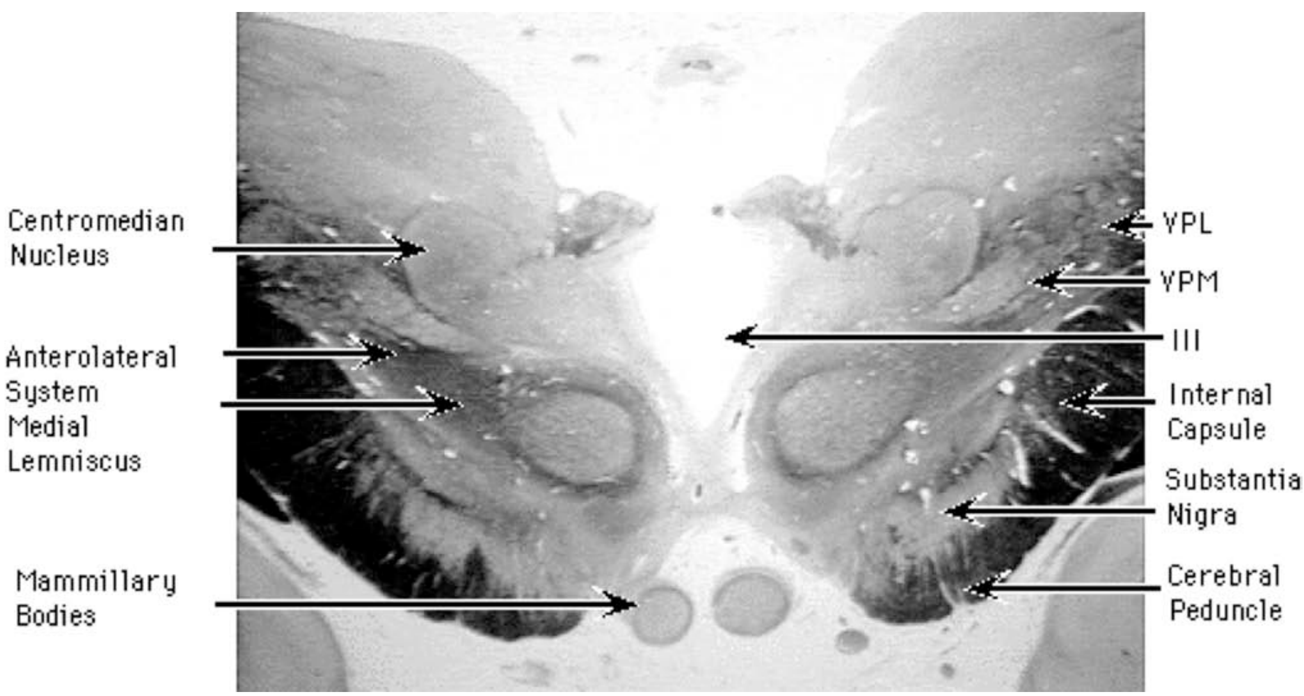

Figure 5J Thalamus at the Level of the Mammillary Bodies

(Spinothalamic axons also end in other thalamic nuclei besides the VPL. It should also be noted that many axons in the anterolateral system in the spinal cord do not reach the thalamus. Instead, they synapse in such areas as the reticular formation and the periaqueductal gray (#4772).)

II. The Dorsal Column Medial Lemniscus (DCML) System

Like the anterolateral system, the dorsal column-medial lemniscus (DCML) system is a three-neuron pathway.

Receptors

Receptors for the DCML system consist of cutaneous (skin) receptors and deep (muscle and joint) receptors. The four main types in glabrous (hairless) skin are Meissner corpuscles (#3999), Merkel cells, Ruffini endings, and Pacinian corpuscles (#15160). The main deep receptors are muscle spindles.

Primary sensory neurons

The primary sensory axons of the DCML system are mainly large-diameter myelinated fibers: Aα/β cutaneous fibers, and groups I and II fibers in muscle nerves.

The central axonal processes of the primary sensory neurons of the DCML system ascend in the ipsilateral dorsal column of the cord (#11684, fig 5a). In the lower cord, the dorsal column on each side consists of a single fasciculus, the gracile fasciculus (fig 5a sacral cord, fig 5b the lumbar cord). In the upper cord, each dorsal column consists of two fasciculi, the gracile fasciculus and the cuneate fasciculus (fig 5c, upper thoracic cord, fig 5d cervical cord).

How are the axons arranged in these fasciculi? What dermatomes are represented in the gracile fasciculus? In the cuneate fasciculus? Is there a cuneate fasciculus in sacral segments? Where are the cell bodies for the axons in these fasciculi? Is the cuneate fasciculus on the left side ipsilateral or contralateral to the dermatomes represented in it?

Secondary sensory neurons

The cell bodies of the DCML secondary sensory neurons are within the *dorsal column nuclei*, and their axons form the *medial lemniscus*.

Dorsal column nuclei

The dorsal column axons (#6691) ascend to the caudal medulla, where they synapse in the gracile nuclei and cuneate nuclei (fig 5k), which together are called the dorsal column nuclei. They contain the cell bodies of the secondary sensory neurons of the DCML system. On the dorsal surface of the medulla, on either side of midline, are protuberances known as the gracile tubercle (#5274) and the cuneate tubercle (#5275). Located in them are the gracile and cuneate nuclei.

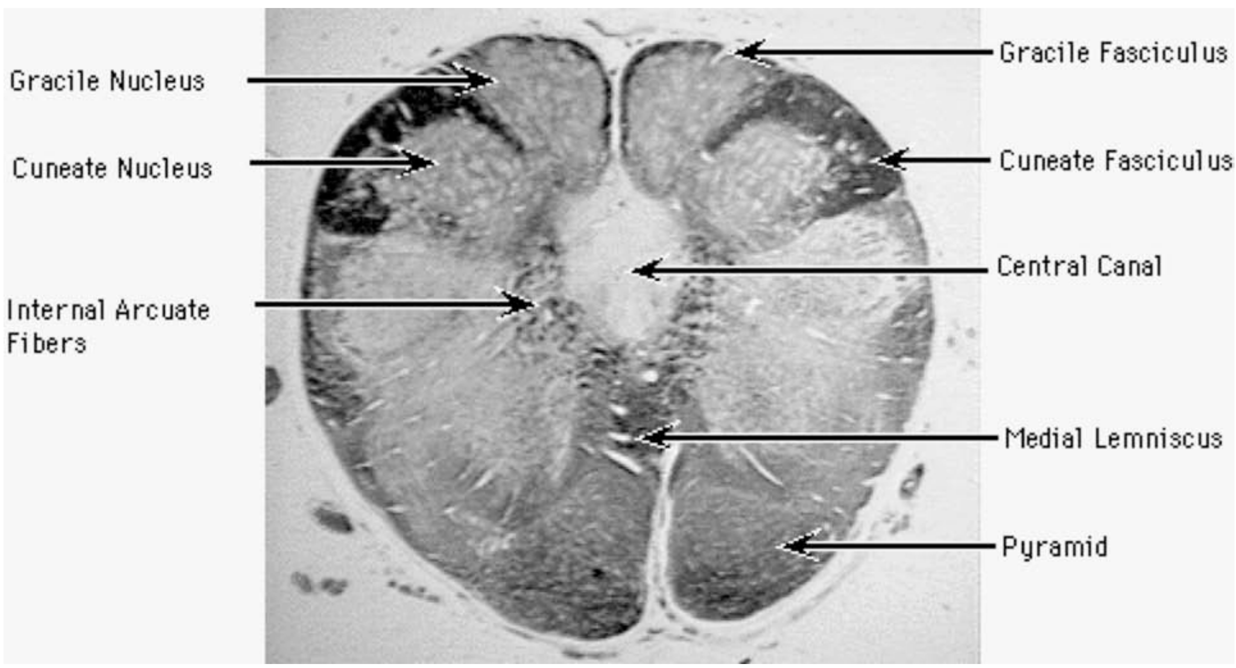

Figure 5K Spinomedullary Junction, Courtesy of Dr. Diane E. Smith

What axons synapse in these nuclei? What dermatomes are represented in the gracile nuclei? In the cuneate nuclei? Is the cuneate nucleus on the left ipsilateral or contralateral to the dermatomes that are represented in it?

Medial lemniscus

The axons from the gracile and cuneate nuclei sweep ventrally and medially through the tegmentum. Along this portion of their course, they are called the internal arcuate fibers (fig 5k, #4063). They cross the midline (#4064) and turn rostrally. Along the rest of their course, these axons are known as the medial lemniscus (fig 6c). (Note: only the ventral two-thirds of the axons along the midline of the medulla belong to the medial lemniscus (fig 8b).) Thus, the medial lemniscus is composed of the secondary sensory axons of the DCML system.

In the medulla, the medial lemniscus is a column of axons ventral to the hypoglossal nucleus and dorsal to the pyramid (fig 6c); and the hypoglossal nerve rootlets are adjacent to the medial lemniscus on their way to exiting the medulla. All these structures are vascularized by branches of the anterior spinal artery in the caudal medulla, and by penetrating branches of the vertebral artery and vertebral-basilar junction in the rostral medulla. Medial medullary Infarction (which usually occurs in the rostral medulla) (#41976), thus involves hypoglossal function, the medial lemniscus, and the pyramids, and will produce symptoms, the medial medullary syndrome, different from those of the lateral medullary syndrome.

In the caudal pons at the level of the abducens nucleus the medial lemniscus rounds up (#6175). In the mid pons at the level of the motor nucleus of V, it stretches out like a fibrous lid over the basilar pons (basis pontis, pons proper). It is at this level in the mid pons that the medial lemniscus (#6178) and anterolateral system (#6731) finally meet. The anterolateral system is located at the lateral edge of the medial lemniscus.

In the midbrain, as the medial lemniscus becomes displaced laterally (#6180), the anterolateral system (#6606) shifts dorsolaterally, but it is still joined to the medial lemniscus (fig 5i).

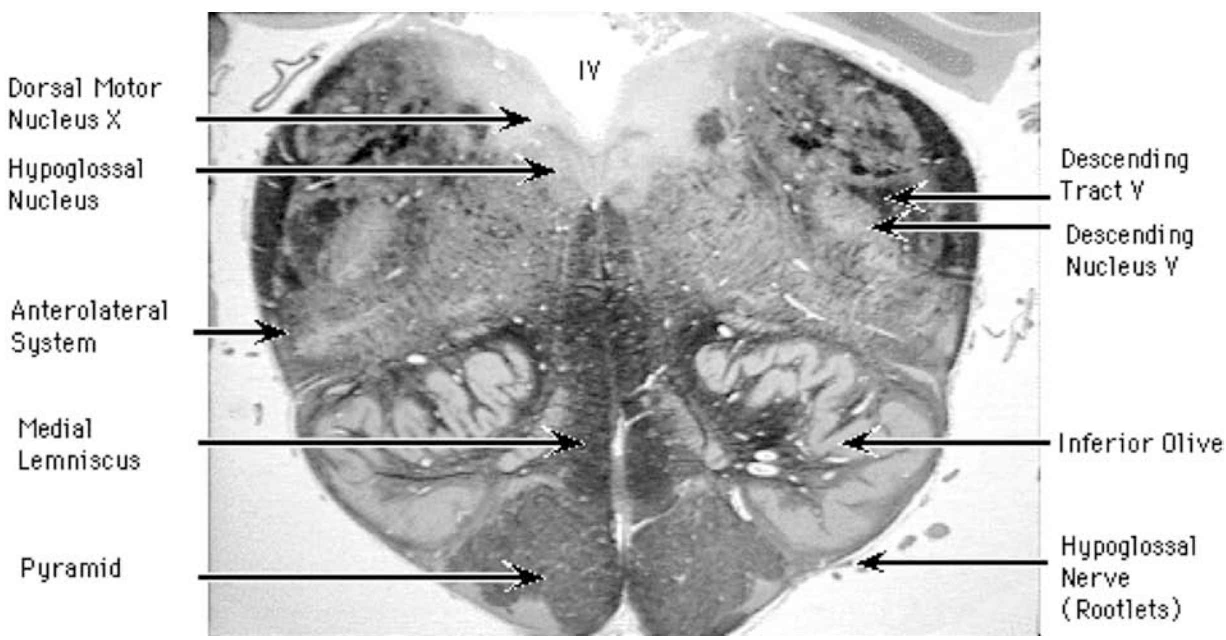

Figure 6C Caudal Medulla

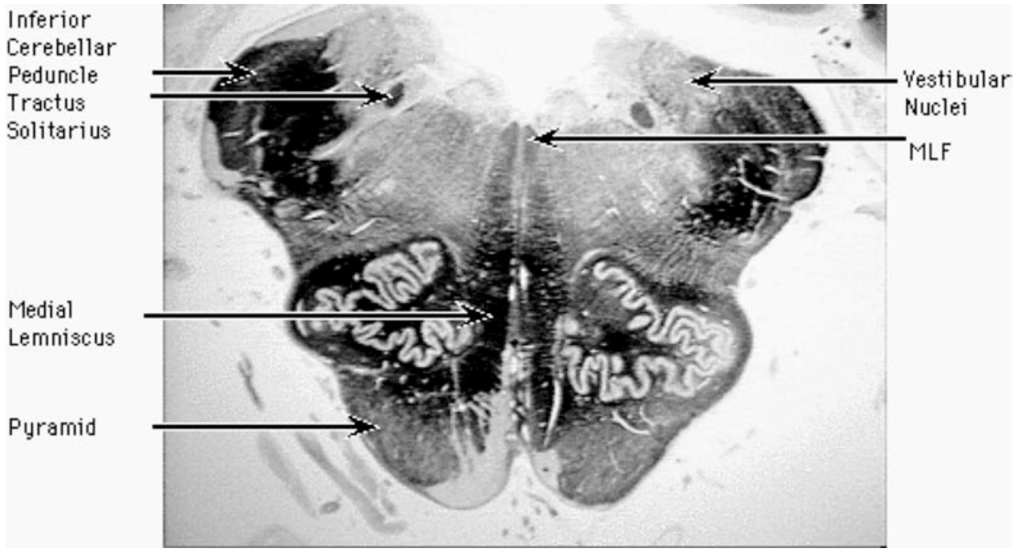

Figure 8B Mid-Medulla

Sensory dissociation

Sensory dissociation is a pattern of somatosensory loss in which only one of the two primary somatosensory systems (pain/temperature vs. vibration/proprioception/tactile discrimination) is affected in a specific body region.

Notice that in fig 5d and fig 6c, the DCML and anterolateral systems are separated and can be separately involved in neurologic problems. For example, a lesion in the dorsolateral medulla (e.g., lateral medullary syndrome) can interrupt the function of the anterolateral system but not the DCML. Thus, there will be a loss of temperature and pain sensation on the opposite side of the body. Discrete tactile and position sense, however, will be spared.

Another example is a lesion of the medial medulla (e.g., medial medullary syndrome) that disrupts the medial lemniscus and not the anterolateral system. In this case, discrete touch and position sense are lost on the opposite side of the body while temperature sensation and pain remain intact.

What sensory dissociation occurs with a lesion involving all the left half of the cord?

III. Thalamocortical Connections of the Anterolateral and DCML Systems

Tertiary sensory neurons

The cell bodies of the tertiary sensory neurons of both systems are within the *thalamus*, and their axons project to the *primary somatosensory cortex*.

Thalamus

The medial lemniscus and anterolateral system are dorsal and lateral to the red nucleus, producing a "Cleopatra eye-like" effect (fig 5l). They travel forward into the thalamus and terminate in the ventral posterolateral nucleus (VPL) (#6750) of the thalamus. VPL contains the cell bodies of the tertiary sensory neurons of the anterolateral and DCML systems. It is organized somatotopically with the lower limb laterally and the upper limb medially. Does the left VPL represent the ipsilateral or contralateral body?

VPL is vascularized by thalamic branches of the posterior cerebral artery. Disease of these vessels can produce pure sensory strokes. What sensations will be lost? Where will the sensory loss occur?

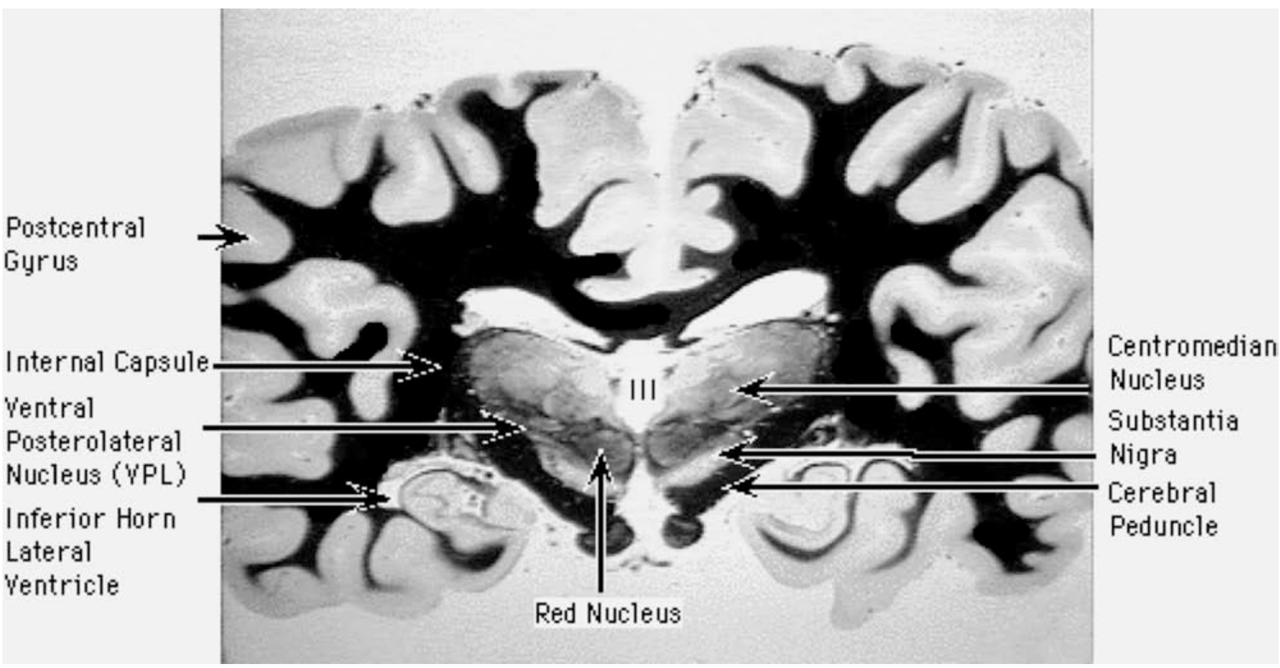

Figure 5L Midbrain, Thalamus, and Cerebral Cortex

Primary somatosensory cortex

The thalamus is the foyer to the cerebral cortex. The sensory systems project to specific thalamic nuclei that, in turn, project to restricted areas of the cerebral cortex.

Axons of VPL neurons project through the posterior limb of the internal capsule (fig 5l, #6390) to the primary somatosensory cortex (SI; Brodmann's areas 3a, 3b, 1, and 2), which occupies the postcentral gyrus (#4208, #74246) and the adjacent posterior part of the paracentral lobule (#74248, #74247). These axons are called the somatosensory radiation. They terminate in a somatotopic manner in the primary somatosensory cortex. The foot and leg are represented medially in the posterior part of the paracentral lobule; and the trunk, arm, and hand are represented laterally in the upper half of the postcentral gyrus. What body regions are exaggerated in relation to the rest of the body? What is the basis for this?

Recall that the medial surface of the hemisphere is supplied by branches of the anterior cerebral artery (#51167, fig 2e), and the lateral surface and the internal capsule by branches of the middle cerebral artery (fig 2d). What will be the sensory loss due to interruption of the middle cerebral artery (MCA) near its origin? Where will the sensory loss occur with a more distal MCA lesion if the internal capsule is spared?

Other cortical processing

Affective response to pain. The pain pathway activates other cortical areas in addition to the primary somatosensory cortex. In particular, activation of the anterior cingulate gyrus is believed to be involved with the processing of the affective (emotional) / motivational responses to pain.

Graphesthesia and tactile object recognition. Perception of pain, temperature, light touch, two-point tactile discrimination, stereognosis, vibration, and proprioception all occur within the primary somatosensory cortex (SI). However, graphesthesia and tactile object recognition require synthesis of SI perceptions in other areas of the parietal cortex, and then association with previous knowledge to identify the figure drawn on the skin or the object being manually examined. In unusual cases, a lesion of the extra-SI parietal cortex may result in contralateral agraphesthesia or tactile agnosia while stereognosis and the other SI functions are little affected.

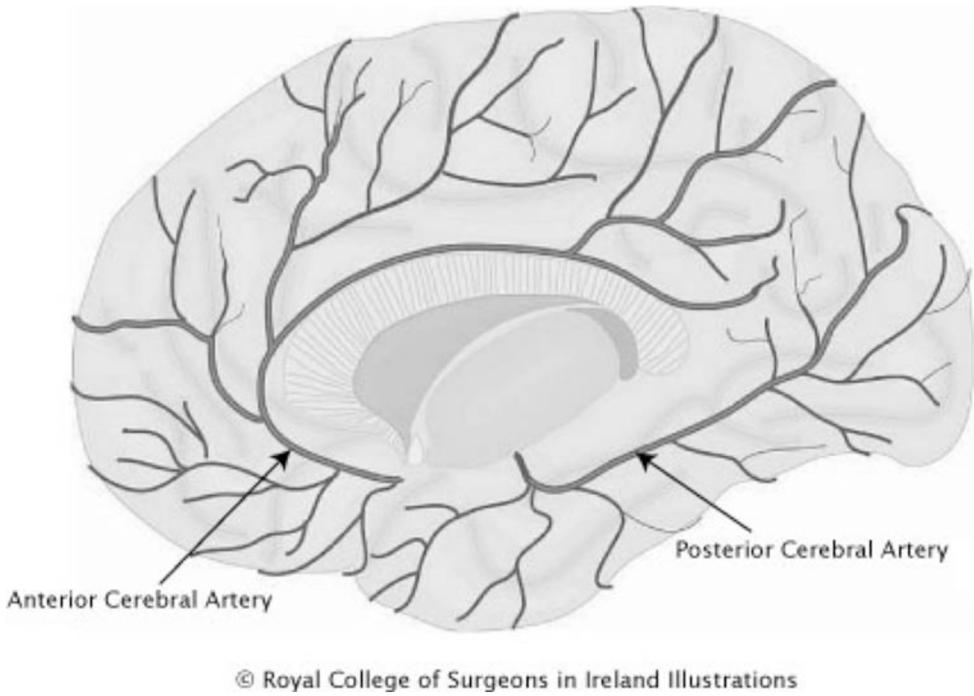

Figure 2E Medial View

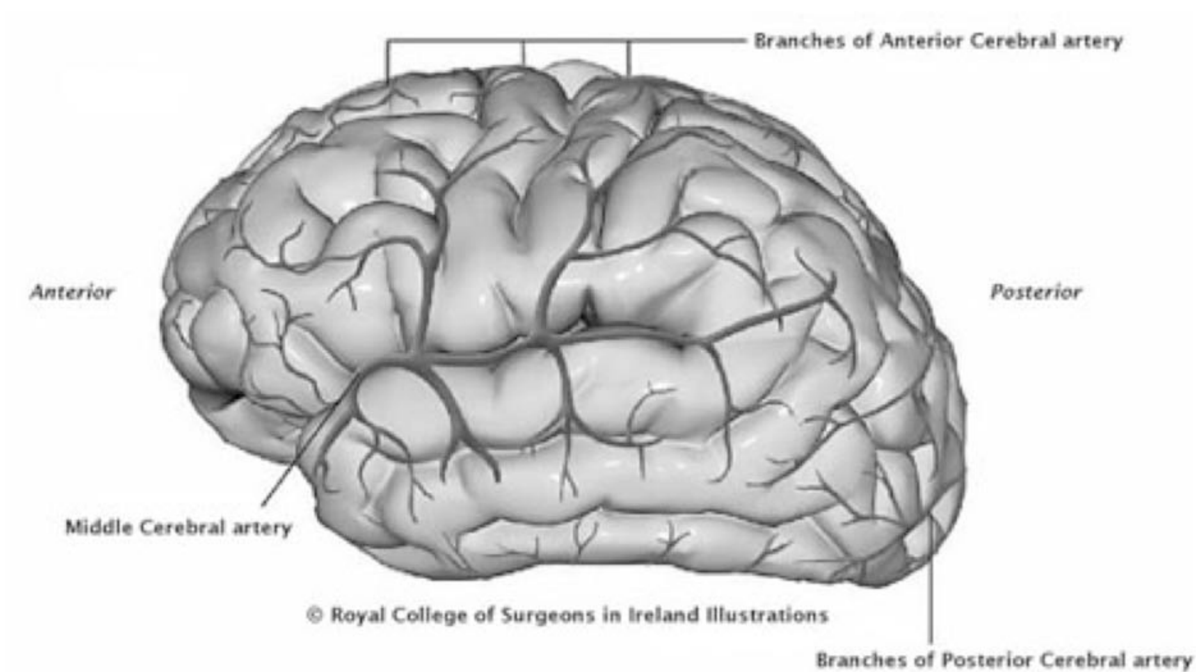

Figure 2D Lateral View

HyperBrain Chapter 5. Somatic Sensation
Review of Terms

Stephen C. Voron, M.D. 2010

Functional anatomy of SOMATIC SENSATION from the body in a nutshell:

A. ALS (Spinothalamic Tract): Pain & temperature
   Three-neuron pathway: Crosses in cord within a couple of levels of the entry of the primary sensory neurons

B. DCML System: Discriminative touch, vibration and proprioception
   Three-neuron pathway: Crosses in caudal medulla

FUNCTIONS AND SIGNS

A. ALS (spinothalamic tract)

Functions
1. pain (pinprick)
2. temperature
3. light (simple, crude) touch

B. DCML System

Functions
1. Two-point tactile discrimination
2. Stereognosis, tactile object recognition, and graphesthesia
3. Vibration
4. Proprioception (kinesthesia)
5. Light (simple, crude) touch

Additional signs
1. Sensory ataxia
2. Romberg sign
3. Areflexia/hyporeflexia (if DCML primary sensory neurons are affected)

I. ANTEROLATERAL SYSTEM (ALS) (Spinothalamic Tract)

Receptors
- Free nerve endings

Primary sensory neurons
- Aδ and C cutaneous fibers
- dorsal root ganglion (DRG, spinal ganglion)
- dermatome
- Lissauer's tract (dorsolateral fasciculus)
- dorsal horn

Secondary sensory neurons
- anterior white commissure
  - decussation
    - syringomyelia
- anterolateral system
  - spinothalamic tract
- lateral medullary syndrome (Wallenberg's syndrome).

II. DORSAL COLUMN MEDIAL LEMNISCUS (DCML) SYSTEM

Receptors
- cutaneous (skin) receptors
  - Meissner corpuscles
  - Merkel cells
  - Ruffini endings
  - Pacinian corpuscles
- deep (muscle & joint) receptors
  - muscle spindles

Primary sensory neurons
- Aα/β cutaneous fibers, and
  - groups I and II fibers in muscle nerves
- ipsilateral dorsal column
  - gracile fasciculus, cuneate fasciculus

Secondary sensory neurons
- ***Dorsal column nuclei***
  - gracile nucleus, cuneate nucleus
  - gracile tubercle, cuneate tubercle
- ***Medial lemniscus***
  - internal arcuate fibers
  - medial lemniscus
  - medial medullary syndrome

Sensory dissociation

III. THALAMOCORTICAL CONNECTIONS of the ANTEROLATERAL and DCML SYSTEMS

Tertiary sensory neurons
- ***Thalamus***
  - ventral posterolateral nucleus (VPL)
    - relay nucleus for somatic sensation from the body
- ***Primary somatosensory cortex***
  - internal capsule
  - somatosensory radiation
  - primary somatosensory cortex (SI)
    - postcentral gyrus
    - posterior part of paracentral lobule

Other cortical processing
- ***Affective response to pain***
  - anterior cingulate gyrus
- ***Graphesthesia & tactile object recognition***
  - Extra-SI parietal cortex

6. Somatic and Visceral Sensory Systems of the Head

Revised 2010

The objectives of this chapter are to:

1. Describe the organization of the trigeminal sensory system, the somatic sensory system of the head.
2. Describe the organization of the visceral sensory system of the head, including taste sensation.

The **trigeminal sensory system** is the somatic sensory system of the face and mouth.

The **cranial nerves mediating visceral sensation**, including taste, are VII, IX and X. (Smell is described in Chapter 14.)

I. TRIGEMINAL SENSORY SYSTEM

The sensory portion of the trigeminal nerve (V) (#5323) innervates the skin of the face, except the angle of the jaw, and head as far back as the vertex, and the anterior external ear (#11459). Review briefly the three major sensory divisions of the trigeminal ("triplet") nerve. What is the peripheral dermatomal distribution of each division? In addition to innervating skin, these sensory nerves also innervate the

- Lips, oral mucosa, teeth and oral tongue (anterior two-thirds)
  Cornea and conjunctiva, eyes and orbital contents
  Nasal, paranasal sinus, and nasopharyngeal mucosa
  Tympanic membrane
- Temporomandibular joint
- Cranial dura, dural vessels, dural sinuses and major cerebral arteries (except for the posterior cranial fossa)

The organization of the conscious somatosensory system of the head is similar to the organization of the anterolateral and DCML systems.

A. *Primary sensory neurons* have cell bodies in a sensory ganglion and send central axonal processes into the CNS.
B. *Secondary sensory neurons* have cell bodies in the CNS. Their axons terminate in a sensory relay nucleus of the thalamus.
C. *Tertiary sensory neurons* have cell bodies in the relay nucleus of the thalamus and send axons to the primary somatosensory cortex.

A. Primary Sensory Neurons

The cell bodies (#6194) of the primary sensory neurons are in the trigeminal (semilunar, gasserian) ganglion (#52286, #7982). This ganglion is a homologue of what structures associated with the spinal cord? The centrally directed first-order sensory axons form the large sensory (major) root of V, which enters the brain stem at the midpontine level (#4152). It tunnels through the middle cerebellar peduncle (#5638) to enter the lateral pontine tegmentum (fig 6a). If a tumor (#5825) produces sufficient pressure on the middle cerebellar peduncle, these sensory axons will degenerate. What will result?

(Interestingly, the cell bodies of some primary sensory neurons of V are uniquely located within the CNS, within the mesencephalic nucleus of V. These primary neurons mainly innervate muscle spindles in the jaw muscles.)

In the pons, most primary sensory axons

1. Terminate in the principal (chief) sensory nucleus of V (#6197).
2. Turn caudally to form the spinal (descending) tract of V (#4621) (fig 6b) and end in the spinal (descending) nucleus of V.

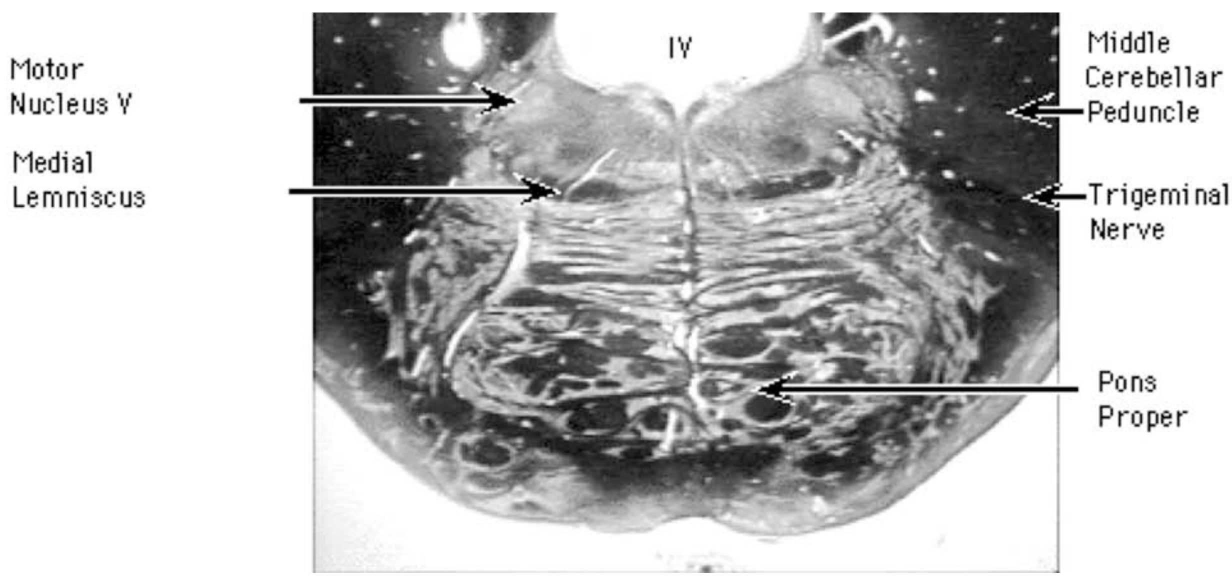

Figure 6A Mid-Pons

B. Secondary Sensory Neurons

The **principal sensory nucleus** is at the midpontine level, at the same level as the motor nucleus of V. It is functionally equivalent to the dorsal column nuclei. It and its projections subserve fine (discriminatory) tactile sensation of the face.

The **spinal nucleus of V** is functionally equivalent to the dorsal horn. It and its connections subserve pain, temperature and light touch. The spinal tract and spinal nucleus both descend to the level of C2, where they merge with Lissauer's tract and the dorsal horn, respectively. In the medulla, identify the descending tract and nucleus of V (fig 6b, fig 6c, fig 6d). Observe that they have the same relative positions as Lissauer's tract and the dorsal horn (#6683) in the cord. Where are the cell bodies for the axons of the descending tract? Is this tract efferent from or afferent to the descending nucleus? Note also that the tract and nucleus are located near the anterolateral system fibers (#6508). Branches of what artery supply this area of the medulla (#5284)?

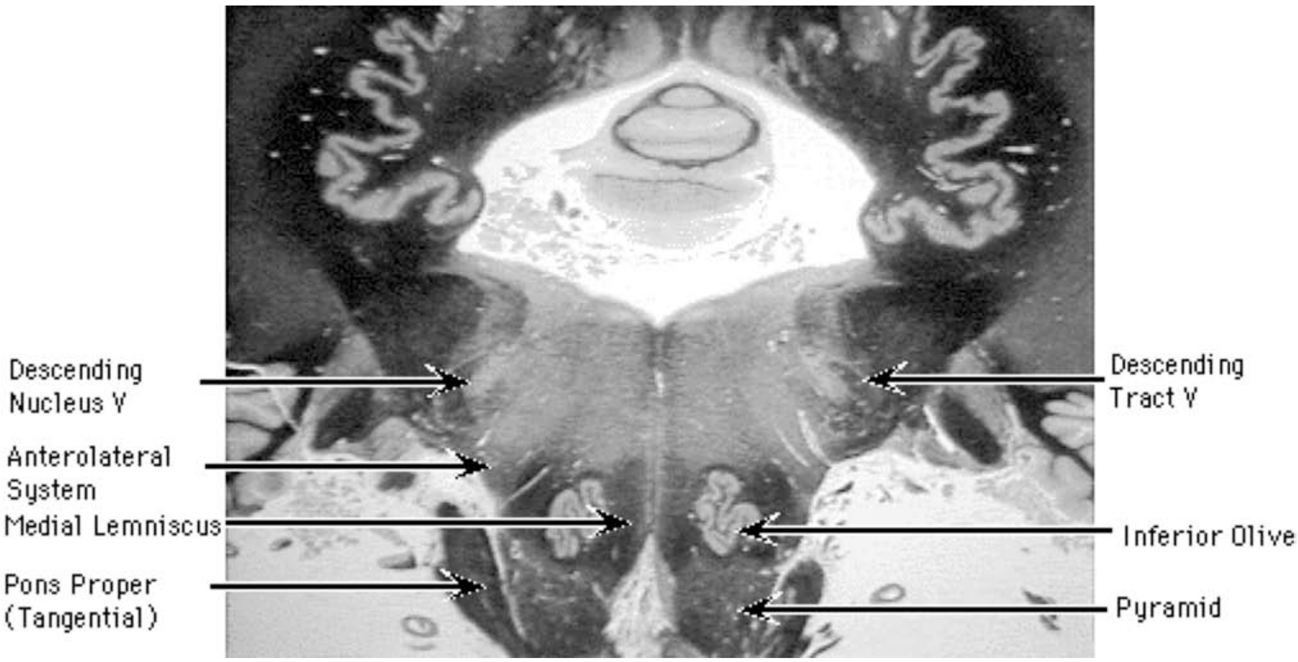

Figure 6B Rostral Medulla

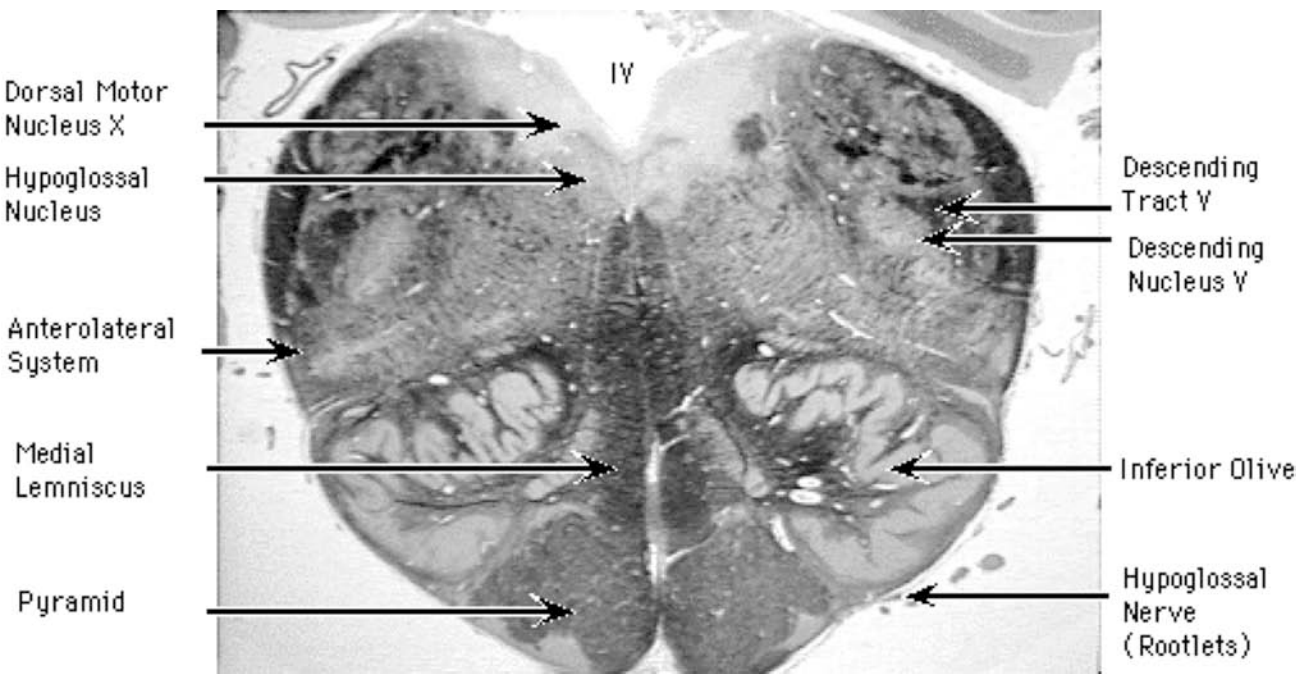

Figure 6C Caudal Medulla

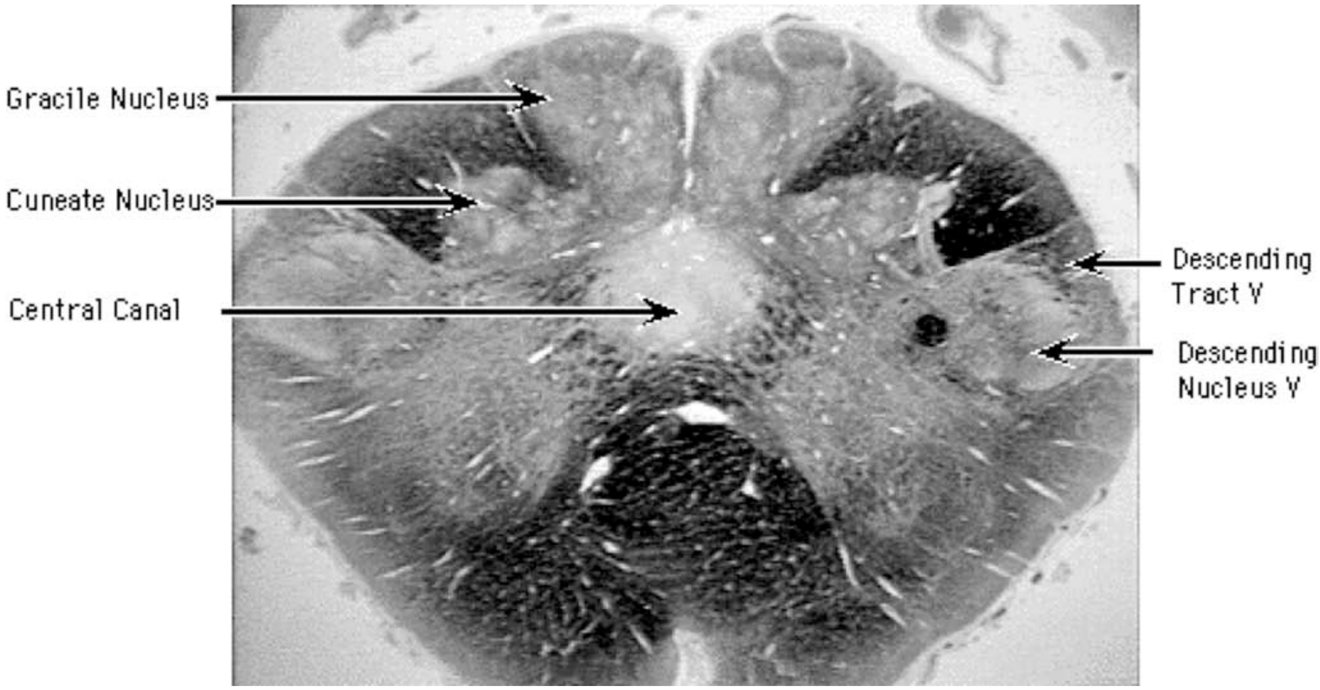

Figure 6D Spinomedullary Junction

Ventral trigeminothalamic tract. The secondary sensory axons arise from the principal sensory nucleus and from the spinal nucleus throughout its length and cross the midline from the mid-pons to C2. The crossed axons ascend as the ventral (anterior) trigeminothalamic tract (#10148). They accompany the medial lemniscus (#4245, #6178) and anterolateral system (#10130) to the thalamus, where they end in the ventral posteromedial nucleus (VPM) (fig 6e). What is its location with respect to the ventral posterolateral nucleus (VPL)?

(**Dorsal trigeminothalamic tract.** Reports of this tract in humans are few and conflicting. In monkeys, this tract arises mainly from the intraoral part of the principal sensory nucleus and projects to the ipsilateral VPM. However, there is little or no clinical correlation for this tract in humans.)

Corneal reflex. Neurons of the spinal nucleus send axons not only to the thalamus but also to the facial nuclei (#6729) bilaterally for mediation of the corneal reflex. If it were absent, how could you tell whether the afferent limb or efferent limb is involved? If the afferent limb is interrupted, how could you tell whether the difficulty is located along the peripheral nerve or within the brain stem?

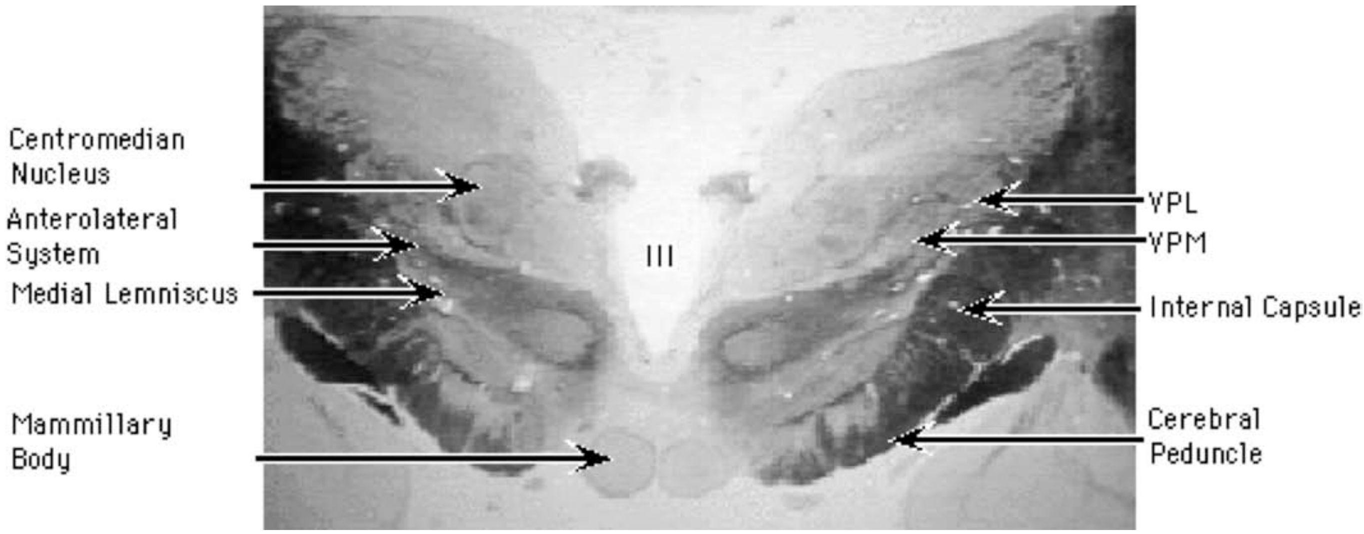

Figure 6E Midbrain and Thalamus

C. Tertiary Sensory Neurons

VPM (#6189) lies medial to VPL. The adjacent part of VPL is the fingers/hand region.

The axons of VPM project to the primary somatosensory cortex (#4208). How do they reach this cortical area? The face, lips, tongue, and mouth are represented in the lower half of the postcentral gyrus. Branches of what cerebral artery supply this region (#12425)? What other body areas are represented in this vascular territory?

II. VISCERAL SENSATION MEDIATED BY CRANIAL NERVES

Visceral sensation is traditionally divided into *general visceral sensation* and special visceral sensation, which refers to *taste* and smell (which is covered in chapter 14).

A. General visceral sensation (IX and X)

The cranial nerves mediating general visceral sensation are the glossopharyngeal nerve (IX) and the vagus nerve (X). Their cell bodies are in the inferior ganglia of IX (the petrosal ganglion) and X (the nodose ganglion). The glossopharyngeal and vagus nerves mediate

- **Conscious** mucosal pain and temperature sensation
  Via IX: from the oropharynx, posterior third of the tongue, and soft palate
  Via X: from the hypopharynx, larynx, and trachea

- **Unconscious information for reflexes**, such as
  Via IX afferents: Carotid sinus reflex, carotid body reflex, gag reflex
  Via X afferents: Cough reflex, vomiting reflex (via gut vagal afferents)

The IX and X sensory axons for general visceral sensation enter the medulla and join the solitary tract (tractus solitarius) (#5963). This tract runs most of the length of the medulla. The tract is easily identified in fig 6f and fig 6g. The reason for its name leaps out at you. it appears solitary or isolated because it is surrounded by the solitary nucleus (nucleus of the solitary tract, nucleus solitarius) (#5962, #5964). The fundamental plan is similar to that of the descending tract of V and descending nucleus of V: primary sensory axons enter the solitary tract, run for varying distances along it, and terminate in the nucleus solitarius. IX and X general visceral sensory axons end in the *caudal* (visceral) part of the solitary nucleus.

The solitary nucleus sends axons to nearby reticular formation interneurons, which mediate a number of visceral reflexes. For example, pressure receptors in the carotid sinus, innervated by cranial nerve IX, project to the solitary nucleus. They have a role in blood pressure regulation via the carotid sinus reflex.

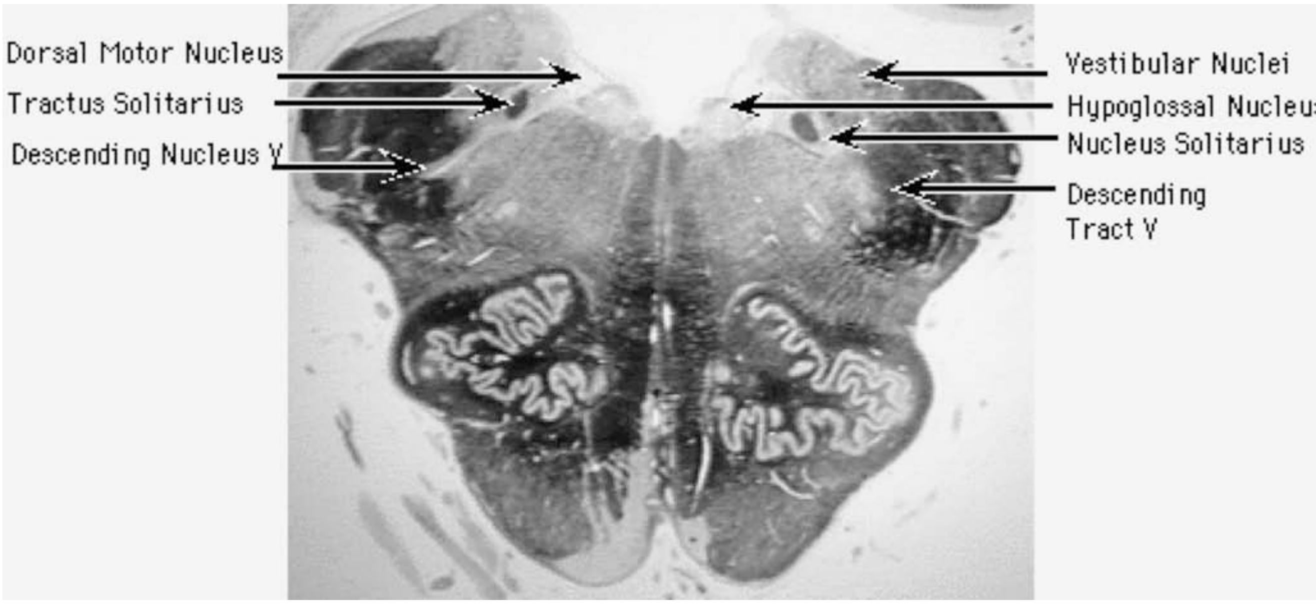

Figure 6F Medulla

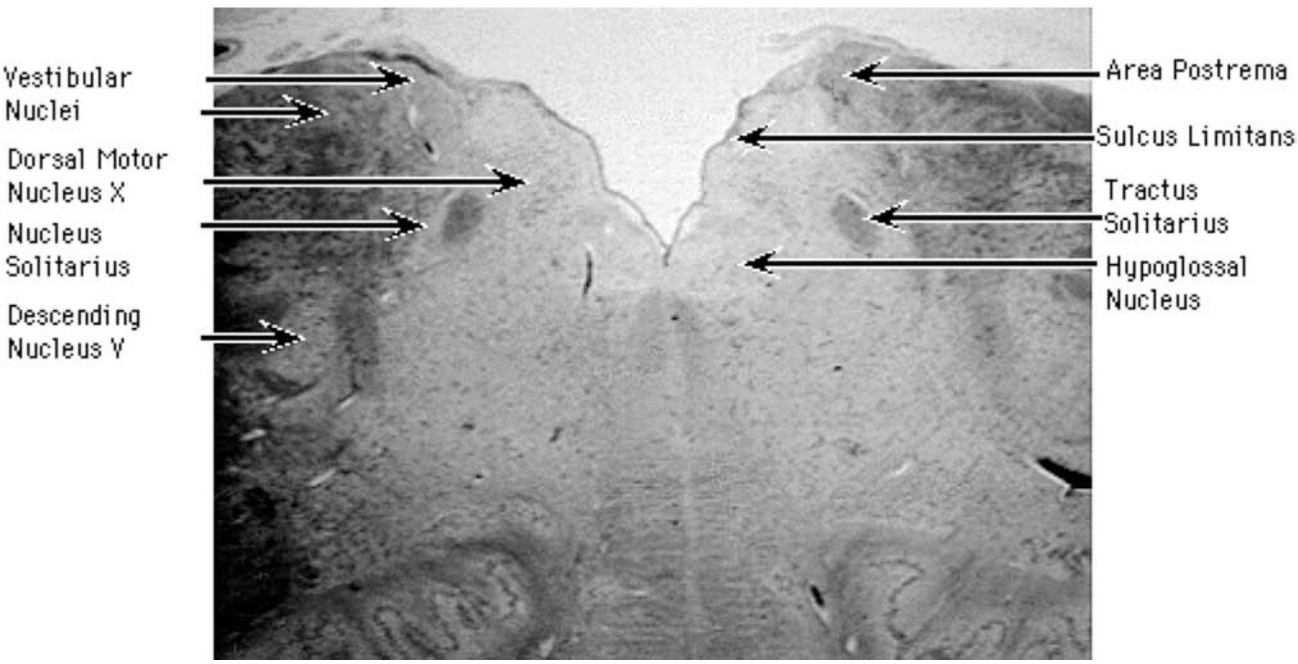

Figure 6G Caudal Medulla (Cell and Myelin Stain)

Vomiting

An area of the reticular formation near the solitary nucleus is known as the vomiting center. Activation of this region results in the salivary secretion and muscle contraction, both smooth and skeletal, that are characteristic of vomiting. The contraction of thoracic and abdominal striated muscles depends on the stimulation of ventral horn cells at the appropriate spinal cord levels. How is the nucleus solitarius connected with these? What are the natural stimuli that usually provoke vomiting?

Vomiting can also be induced by the ingestion of certain chemicals, such as apomorphine, that are called emetic substances. These substances do not act directly on the nucleus solitarius. Instead, they excite neurons in a chemosensitive area of the medulla known as the area postrema (#5308 arrow). The blood brain barrier is leaky in this area. The area postrema is conveniently located in the floor of ventricle IV adjacent to the nucleus solitarius (#6236) and sends axons to it. By means of this connection, stimulation of the area postrema triggers vomiting.

B. Taste (VII, IX and X)

The taste (gustatory) system is responsible for the perception of sweet, salty, bitter, and sour. Most patients reporting a taste deficit actually have an olfactory deficit. Conversely, patients with actual taste deficits frequently do not recognize the loss. The taste system is a three-neuron pathway.

Receptors. An example of a taste bud is shown in (#6223). What innervates these visceral receptors?

Primary sensory neurons: VII, IX and X

The cranial nerves innervating taste buds are the facial nerve (VII), IX and X. In the human, the known innervations for taste perception are

- **VII:** Taste buds in the fungiform papillae on the anterior tongue and some of the taste buds of the foliate papillae along the lateral edge of the tongue.
- **IX:** The remaining taste buds in the foliate papillae and all those in the circumvallate papillae on the posterior third of the tongue.
- **X:** Taste buds of the larynx. However, the extralingual taste buds more likely protect the airway from fluid aspiration than participate in taste perception, and have no role in the clinical evaluation of taste.

The cell bodies of the primary sensory neurons are located in the geniculate ganglion (#7276) and in the inferior ganglia of IX and X. They project via the solitary tract to the *rostral* (gustatory) solitary nucleus.

Secondary sensory neurons: rostral (gustatory) solitary nucleus

Gustatory nerve fibers from VII, IX and X synapse in the rostral half (gustatory division) of the ipsilateral solitary nucleus. Lesions such as dorsolateral infarction of the rostral medulla (Wallenberg or lateral medullary syndrome) that affect the solitary tract and nucleus (#4383) may cause ipsilateral ageusia (absence of taste).

The axons of these neurons ascend through the pons (in the ipsilateral central tegmental tract). Patients with pontine tegmentum damage may demonstrate ipsilateral taste deficits, or bilateral ageusia if both sides are involved.

Laterality of projection above the pons, through the midbrain to the thalamus and the cortex, is unclear. It may be predominantly bilateral (explaining why taste disorders due to stroke are relatively infrequent), contralateral or unilateral. Both contralateral and ipsilateral hypoageusia have been reported after unilateral midbrain, thalamic and cortical lesions.

Tertiary sensory neurons: VPMpc

Axons of the gustatory division of the solitary nucleus ascend to VPMpc (the ventral posteromedial nucleus, parvicellular division) of the thalamus. VPMpc is directly medial to VPM, the thalamic somatosensory nucleus for the face and mouth. The adjacent part of VPM is the tongue region.

Taste cortex. The neurons of VPMpc project to the cerebral cortex. The primary taste (gustatory) cortex in humans is located in the cortex marginating the sulcus above the insula (the junction of the frontoparietal operculum and the insula). (Previously, it was believed to be in Brodmann's area 43.) The primary cortex projects to secondary gustatory cortex in the rostral insula.

HyperBrain Chapter 6. Somatic and Visceral Sensory Systems of the Head
Review of Terms

Stephen C. Voron, M.D. 2010

I. TRIGEMINAL SENSORY SYSTEM

somatic sensory system of the face and mouth
three-neuron pathway: crosses from mid-pons to C2

A. Primary Sensory Neurons

trigeminal nerve (V)
trigeminal (semilunar, gasserian) ganglion
spinal (descending) tract of V

B. Secondary Sensory Neurons

principal (chief) sensory nucleus of V and
spinal (descending) nucleus of V
ventral trigeminothalamic tract

corneal reflex: afferent limb, efferent limb

C. Tertiary Sensory Neurons

thalamus
- VPM: ventral posteromedial nucleus
  - relay nucleus for somatic sensation from the face and mouth

primary somatosensory cortex in lower half of postcentral gyrus

II. VISCERAL SENSATION mediated by CRANIAL NERVES

A. General visceral sensation (IX and X)

- **Conscious** mucosal pain and temp sensation
  - IX: oropharynx, post 1/3 tongue, soft palate
  - X: hypopharynx, larynx, trachea
- **Unconscious information for reflexes**, such as
  - Via IX afferents: carotid sinus reflex, carotid body reflex, gag reflex
  - Via X afferents: cough reflex, vomiting reflex

glossopharyngeal nerve (IX) and vagus nerve (X)
inferior ganglia of IX (petrosal ganglion) and X (nodose ganglion)
solitary tract (tractus solitarius)
caudal (visceral) part of the solitary nucleus (nucleus of the solitary tract, nucleus solitarius)
reticular formation interneurons

vomiting
- vomiting center
- area postrema
  - lacks blood brain barrier

B. Taste (VII, IX and X)

special visceral sensation

Receptors in taste buds

Primary sensory neurons: VII, IX and X
- facial nerve (VII), IX and X
- geniculate ganglion and inferior ganglia of IX and X
- solitary tract

Secondary Sensory Neurons
- *rostral* (gustatory) solitary nucleus

Tertiary Sensory Neurons
- thalamus
  - VPMpc: ventral posteromedial nucleus, parvicellular division
    - relay nucleus for taste

Taste Cortex
- primary taste (gustatory) cortex
  - bordering sulcus above insula (junction of frontoparietal operculum and insula).
- secondary gustatory cortex
  - in rostral insula

7. The Visual System

Revised 2007

The objectives of this chapter are to

1. Describe the organization of the visual system.
2. Describe the neuroanatomy of two important visual reflexes, the pupillary light reflex and the near response.

It is assumed that you have already studied the gross anatomy and histology of the eye.

I. The Visual Pathway

Eyeball and retina: The visual pathway begins in the eyeball (fig 7a). Light waves pass through the cornea and lens to impinge on the retina. The receptors for the visual system are specialized neurons called photoreceptors, rods and cones, which are located in the retina. The retina contains several cell types that are arranged in distinct layers. The outermost layer, i.e., the layer adjacent to the choroid, is the retinal pigment epithelium (#52211). What is the origin of these cells (fig 7b)? What is their functional significance? Embedded in the pigment epithelium (#9927) (c) are the processes (b) of the photoreceptor cells whose cell bodies are shown in (a). The entire retina, other than the pigment epithelium, is termed the neural retina. Retinal detachment occurs along the junction between the pigment epithelium and the photoreceptors in the neural retina (fig 7a).

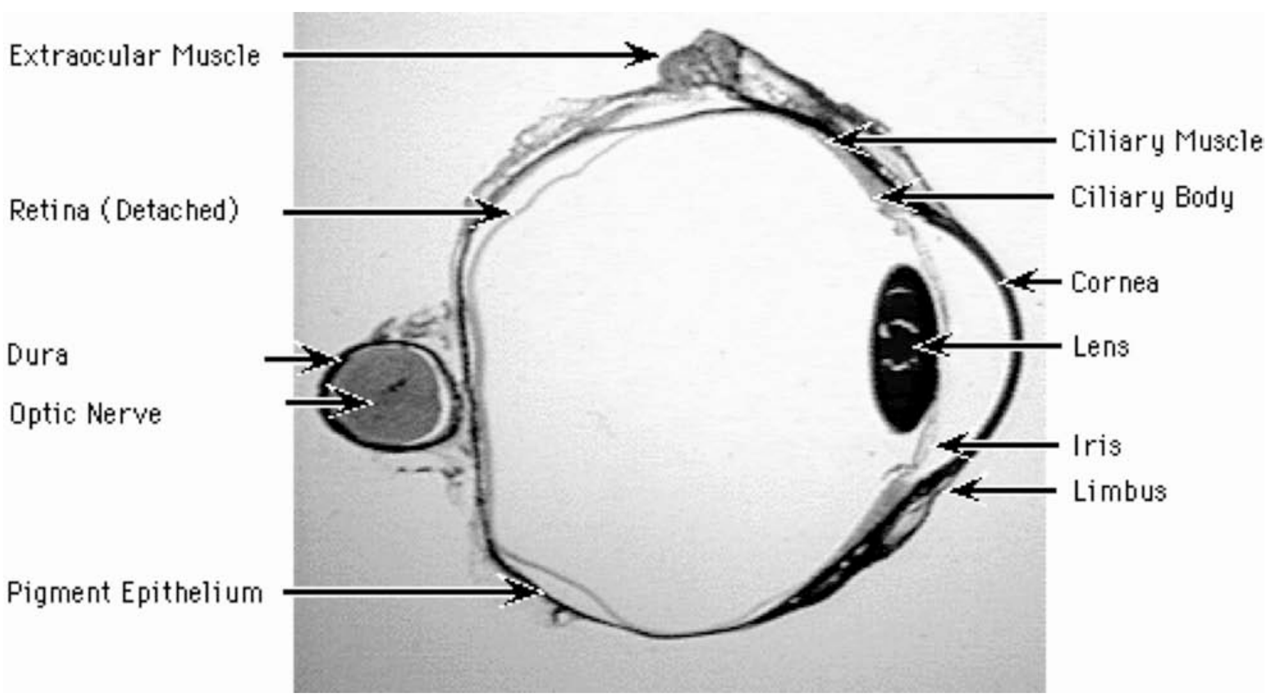

Figure 7A The Eye

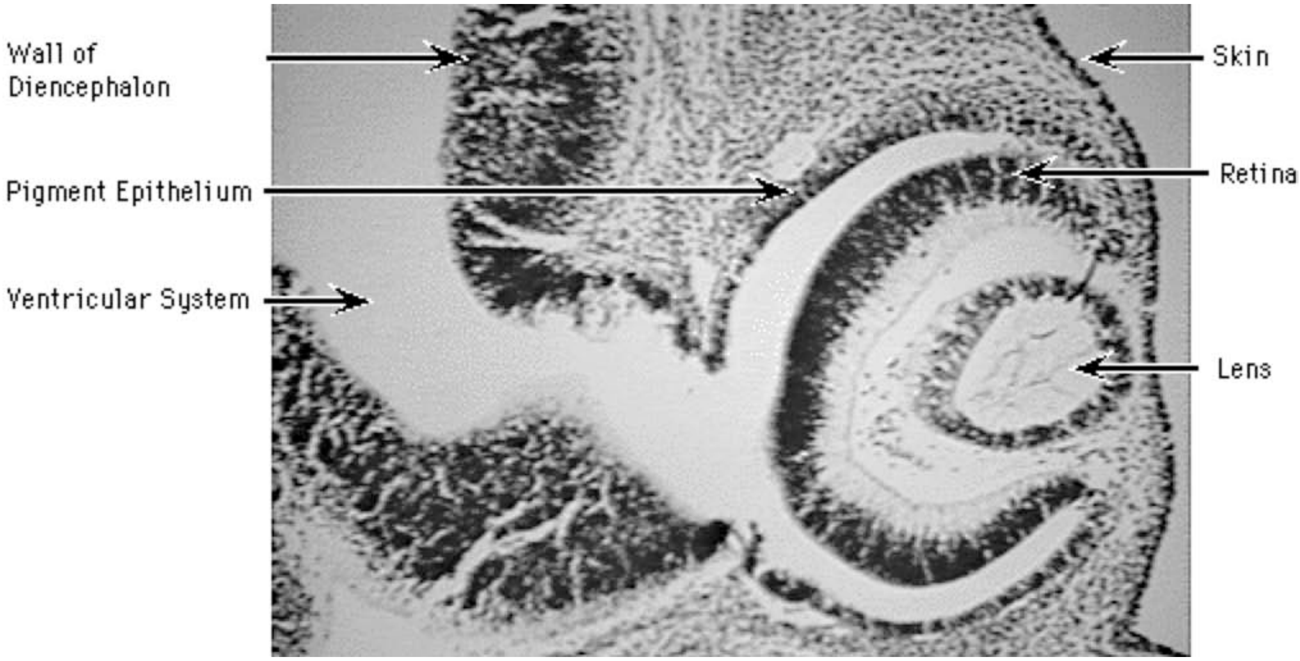

Figure 7B Embryology of the Eye, Courtesy of Dr. Allen Bell

The cell bodies of the photoreceptors make up the outer nuclear layer of the retina. The photoreceptors make contact with the bipolar cells, whose cell bodies constitute the inner nuclear layer of the retina (#52207, #7962). Bipolar cells, in turn, end on ganglion cells of the retina, whose cell bodies make up the ganglion cell layer (#52204, #5341). The layered arrangement of the retina is modified in the fovea, the retinal area that is essential for acute color vision (#367). The fovea is structurally specialized in the following ways: (1) the ganglion cell (#4395) and bipolar cell (#4396) layers are thinner here than elsewhere in the retina; (2) the cell bodies of the bipolar and ganglion cells are displaced laterally and (3) the fovea is avascular (#5338). What is the name of the photoreceptor in the central retina (#4397)? How do the two types of photoreceptors differ functionally?

Ganglion cell axons: Ganglion cell axons penetrate the back of the eyeball in an area called the optic disc (#6914 B, #5337) and form the optic nerve (#6914 A), cranial nerve II. Here the ganglion cell axons become myelinated. What cells form their myelin sheaths? If severed, do these axons regenerate? It is also at this point that the optic nerve becomes invested by the meninges. The thick outer coat of cranial nerve II, the dura mater (#7600), is continuous with the sclera (#52213). Near the center of the optic nerve is the central retinal artery (#52202). What is its origin? (#12396) Its distribution? How does the optic nerve enter the middle cranial fossa (#5435, #6934)?

Follow the intracranial course of the ganglion cell axons by identifying, in order, the optic nerve (#11711), optic chiasm (#11712), and optic tract (#11713). The optic nerves partially decussate in the optic chiasm. Which axons decussate? The optic nerve and tract both consist of ganglion cell axons. How are the two structures different? The relationship of the optic chiasm (Fig 7c) and tract to the hypothalamus (#6258) and cerebral peduncle (fig 7d, #6265) is best seen in sections through the brain. Note that the chiasm is just ventral to the rostral part of the third ventricle (#4318, #6253). What is the spatial relationship between the optic chiasm and the pituitary gland (#4980)? Pituitary tumors (#12192, #7967) can press on the chiasm and cause a specific visual field defect. What is the name of this deficit?

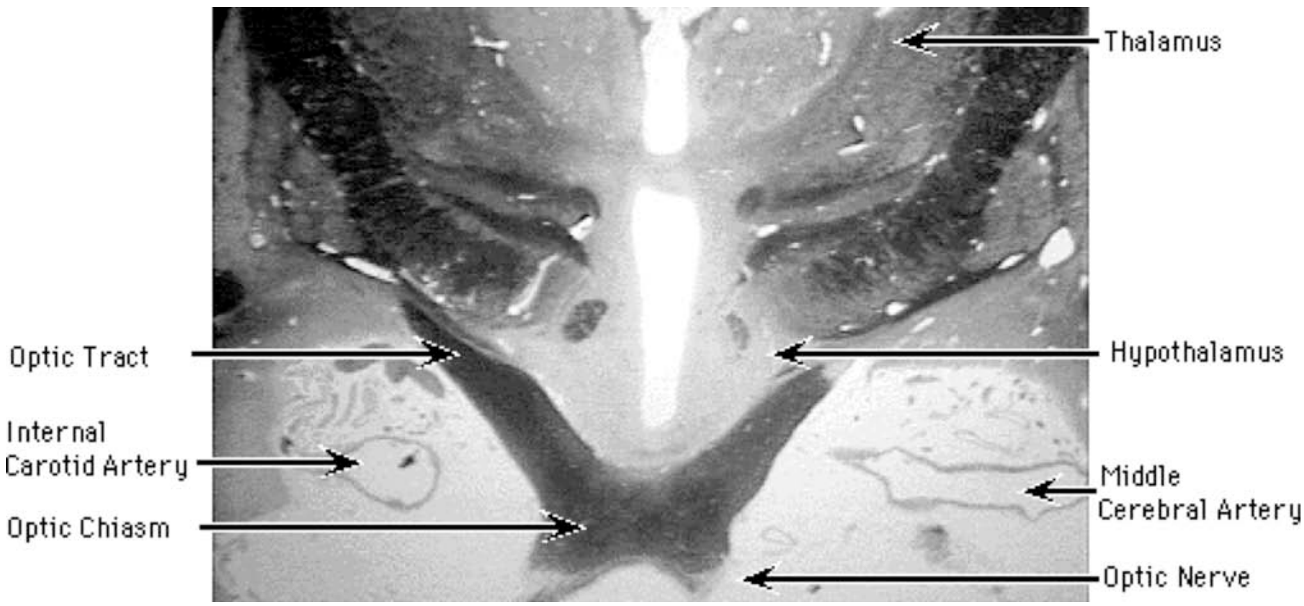

Figure 7C Diencephalon at Level of Optic Chiasm

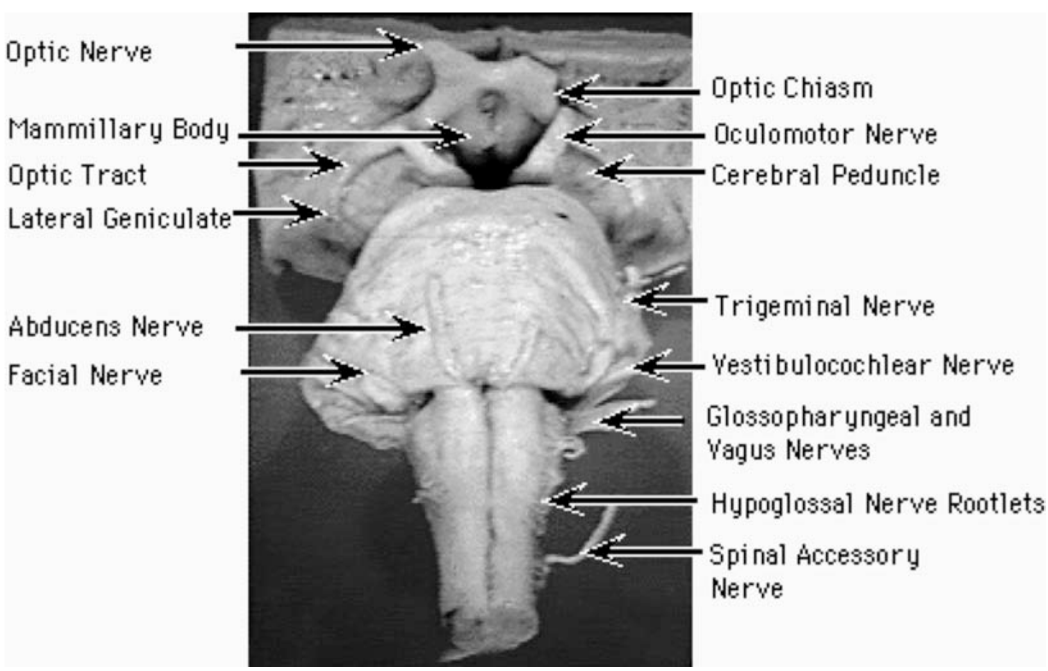

Figure 7D Ventral Surface of the Brain Stem, Courtesy of Dr. Bruce Updyke

Lateral geniculate nucleus and axons: The optic tract goes around the cerebral peduncle to end in the lateral geniculate nucleus (fig 7d), the relay nucleus of the thalamus for the visual system. This nucleus is best seen from the dorsal surface of the brain stem (fig 7e). The relationship of the lateral geniculate nucleus (#6465) to the cerebral peduncle (#6463) is illustrated in sections through the brain. It is evident in these sections that the lateral geniculate nucleus is a layered structure (#8290, #6275). Axons from ipsilateral and contralateral ganglion cells end in different layers.

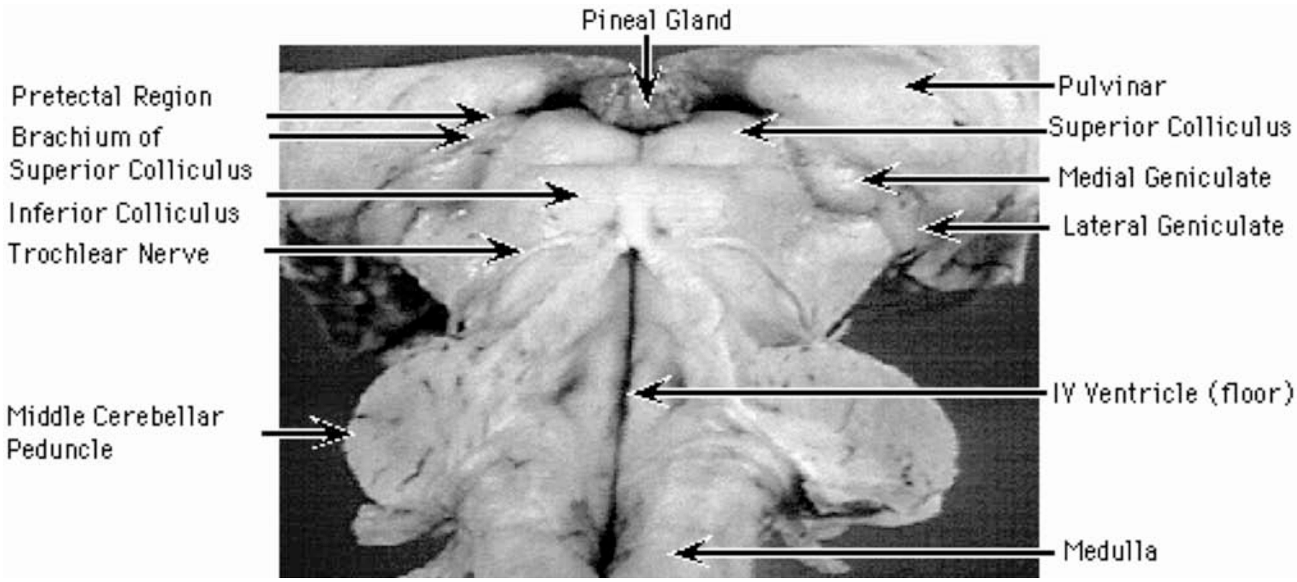

Figure 7E Dorsal View, Brain Stem, Courtesy of Dr. Bruce Updyke

Axons from the lateral geniculate nucleus project to primary visual cortex, the cortex bordering the calcarine sulcus. This projection is called the optic (visual) radiation or geniculocalcarine tract. The axons leave the lateral geniculate nucleus and enter the most caudal part of the posterior limb of the internal capsule (fig 7f). The optic radiations pass through the temporal and parietal lobes (#7923) to the lateral side of the atrium (trigone) and occipital horn of the lateral ventricle (#5372, #6519, #5240). Especially note the relationship between the radiations and the lateral ventricle. What artery(ies) supply(ies) the optic radiations as they course deep in the white matter to the occipital lobe?

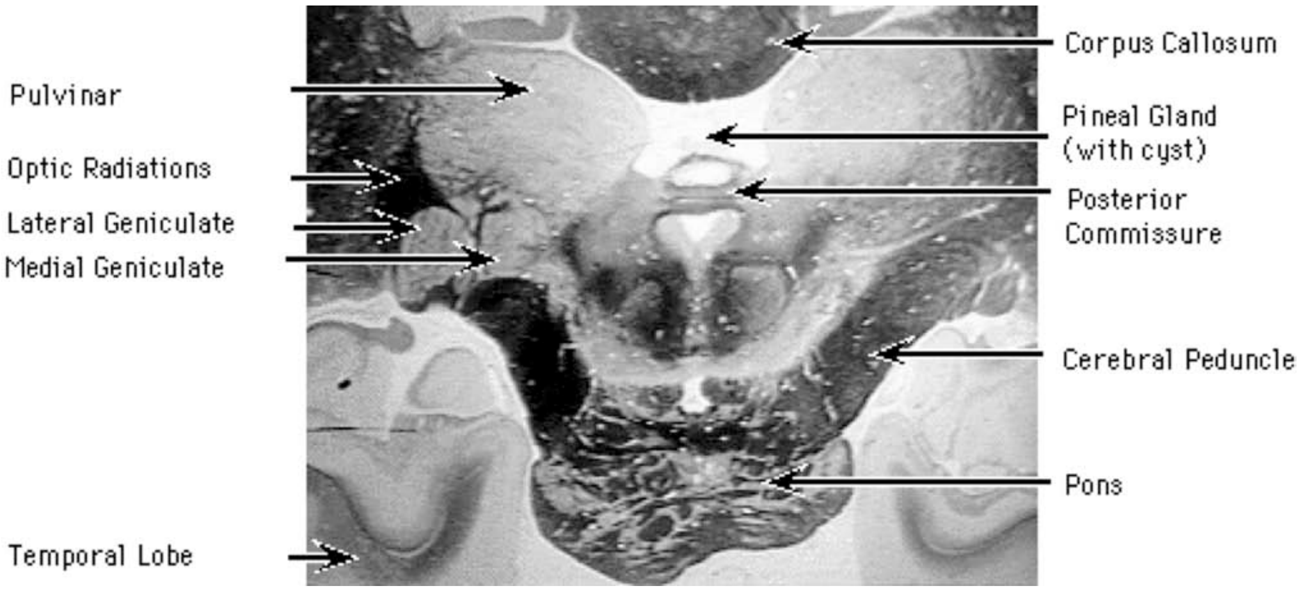

Figure 7F Midbrain and Thalamus, Courtesy of Dr. Diane E. Smith

Cortex: The optic radiation, like thalamic axons in general, ends in the cortex as a band of myelinated fibers in layer IV. However, only in the primary visual cortex (V1) can this band be seen with the naked eye as the line of Gennari (#6282, #8987). In fact, the term striate ("striped") cortex is another name for primary visual cortex.

Primary visual cortex is also referred to as either calcarine cortex or Brodmann's area 17. Although a small part of calcarine cortex is located on the lateral surface (#4217), most of it occurs on the medial surface of the occipital lobe (#4275). There is a point-to-point representation of the retina in the calcarine cortex. This is called the retinotopic organization of the cortex. What area of the retina is represented anteriorly (i.e., closer to the splenium) in the calcarine cortex? What retinal area is represented posteriorly (i.e., nearer the occipital pole) in the calcarine cortex? Are all areas of the retina equally represented? What cerebral artery supplies area 17 (#12519)? What is the origin of this artery (#5969)?

Adjacent to primary visual cortex (V1) are the visual association cortical areas, including V2 and V3 (= area 18, or 18 & 19, depending on the author) (#4350). Lesions of V1, V2 and V3 produce identical visual field defects.

Beyond V3, visual information is processed along two functionally different pathways. Injury isolated to the cortical areas in these two pathways does not disturb the visual fields; that is, visual sensation remains intact.

1. The occipitoparietal ("where") pathway processes position and motion. A person with a unilateral (mainly right) posterior parietal lesion (angular and supramarginal gyri) suffers from hemispatial neglect, ignoring the contralateral external world and the contralateral side of her own body.

2. The occipitotemporal ("what") pathway, to the undersurface of the temporal lobe (fusiform or occipitotemporal gyrus), identifies objects, symbols and colors. People with lesions of the **left** inferior occipitotemporal area cannot recognize objects by visual inspection alone. Such individuals can describe a key by palpation, but cannot identify and name it by sight. This condition is called associative visual agnosia for objects. Lesions in this vicinity can also cause inability to recognize words or to read despite intact spelling and writing (pure alexia, alexia without agraphia).

With a similar lesion on **right**, the patient cannot recognize familiar or famous faces (prosopagnosia) or may not recognize familiar places and streets. What artery supplies the inferior occipitotemporal area? What visual field deficit occurs if the lesion extends to the inferior bank of the calcarine cortex? Based on the above information, what findings might you expect with bilateral infarcts of this area?

Axial (Horizontal) Sections

A series of three axial (horizontal) sections are shown in fig 7g, fig 7h and fig 7i and help to visualize the visual pathway. The three sections are ordered from inferior to superior (toward the vertex, the top of the skull).

Beginning with the most inferior section at the level of the lateral geniculate nucleus (fig 7g), observe the relationship between the optic tract and cerebral peduncle (#6285). The tract can be followed into the lateral geniculate nucleus (#6286). The lateral geniculate nucleus gives rise to the optic radiation. The inferior axons of the optic radiation begin with an initial rostral loop (Meyer's loop) over the temporal horn to its lateral side (fig 7g) before proceeding to the inferior bank of the calcarine cortex. The superior axons of the optic radiation pass directly, without looping, to the superior bank of the calcarine cortex.

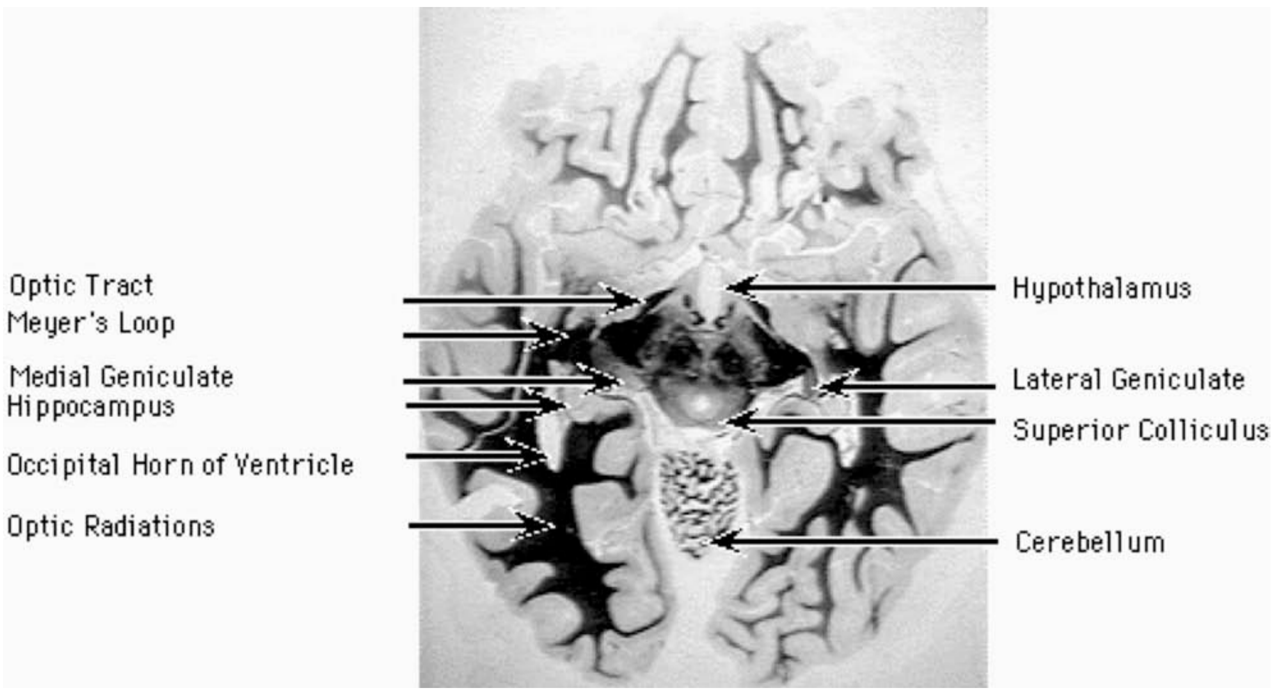

Figure 7G Axial (Horizontal) Section through Medial and Lateral Geniculate

The section for fig 7h, enlarged in fig 7j-b, is closer to the vertex than fig 7g. The cerebral peduncles are no longer present, but these same axons are now part of the internal capsule, which separates the thalamus from the putamen and globus pallidus of the basal ganglia. In fig 7j-b the medial and lateral geniculate nuclei and the pulvinar of the thalamus are labelled.

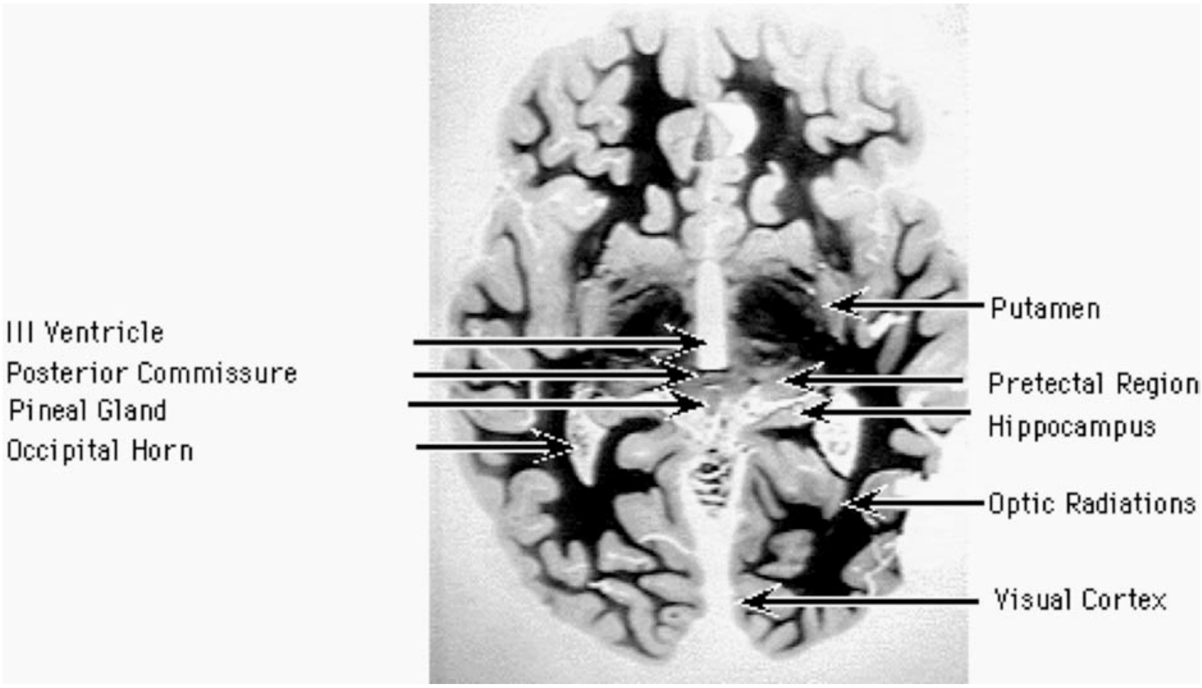

Figure 7H Axial (Horizontal) Section Through Posterior Commissure

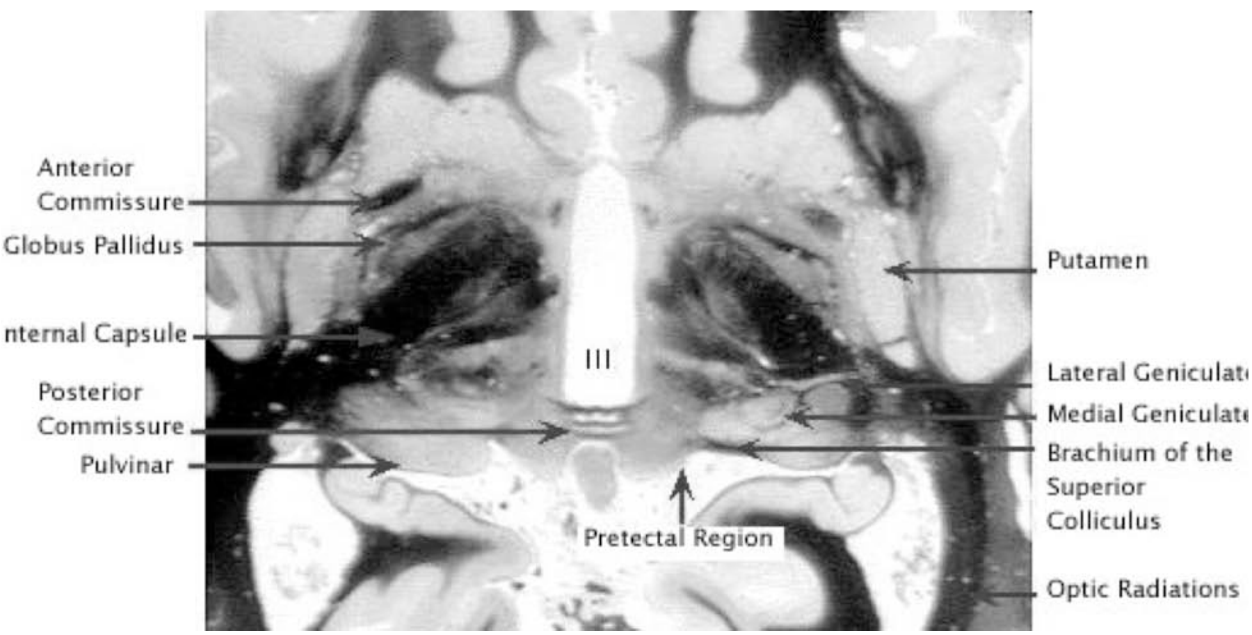

Figure 7J-b Enlargement of Figure 7H

Fig 7i is even closer to the vertex. The optic radiations are seen extending back from the internal capsule. Follow them as they course lateral to the occipital horn of the lateral ventricle and enter the occipital lobe.

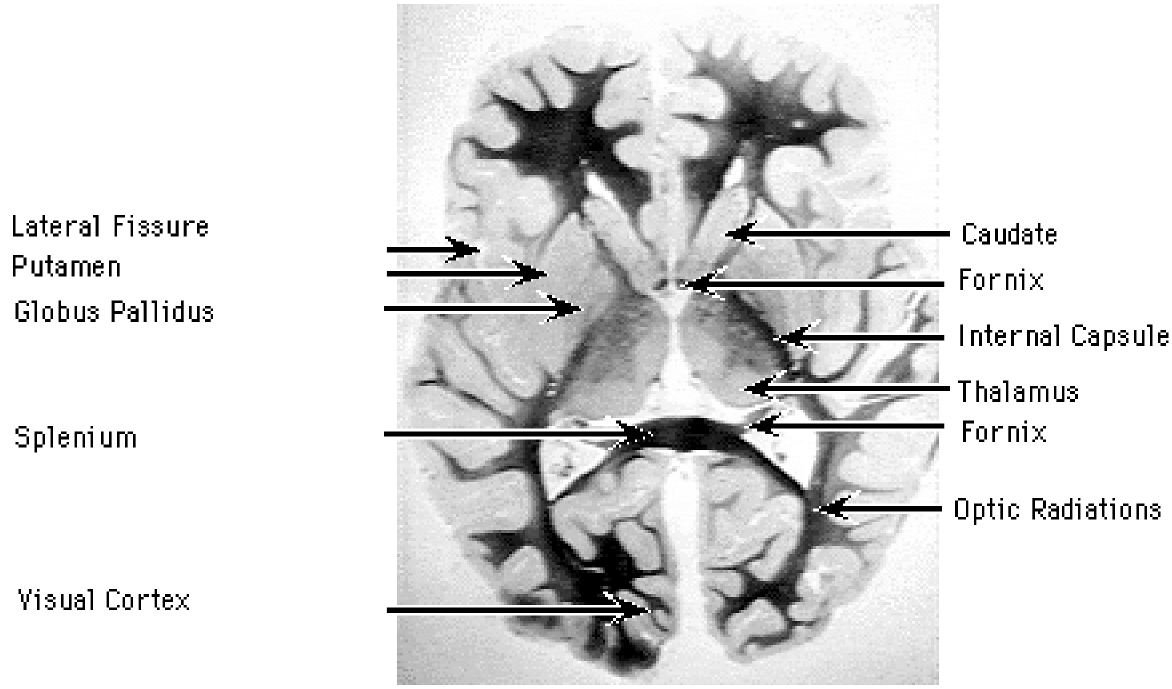

Figure 7I Axial (Horizontal) Section through Thalamus and Basal Ganglia

In axial (horizontal) sections, be able to locate the thalamus (#6298), the putamen and globus pallidus of the basal ganglia (#6297), and the posterior limb of the internal capsule that separates them. What cortical regions does the splenium of the corpus callosum (#4443) connect?

II. Visual Reflexes

There are two visual reflexes that are clinically important and whose reflex arcs must be understood.

1. Pupillary light reflex (This link plays an animation. Please enlarge the window.)
2. Near response (near-point reaction, near reflex), which has three components
   a. Accommodation of the lens
   b. Convergence of the eyes
   c. Constriction of the pupil

Inputs

1. Pupillary light reflex: This reflex depends on input to the pretectal region (fig 7j, fig 7k) from the retina. The pretectal region (pretectum) (#6307) is adjacent to the posterior commissure (#6305). Collaterals of ganglion cell axons leave the optic tract to go to the pretectum (and also to the superior colliculus) (#4359). As these collateral axons pass over the surface of the brain stem they are called the brachium of the superior colliculus. The relation of the pretectal region (#6307) to the corpus callosum, thalamus, and inferior temporal lobe can be seen in myelin (#6306) or gross coronal sections (fig 7l). What is the significance of the pretectal area in the light reflex? What is the direct light reflex? What is a consensual reflex?

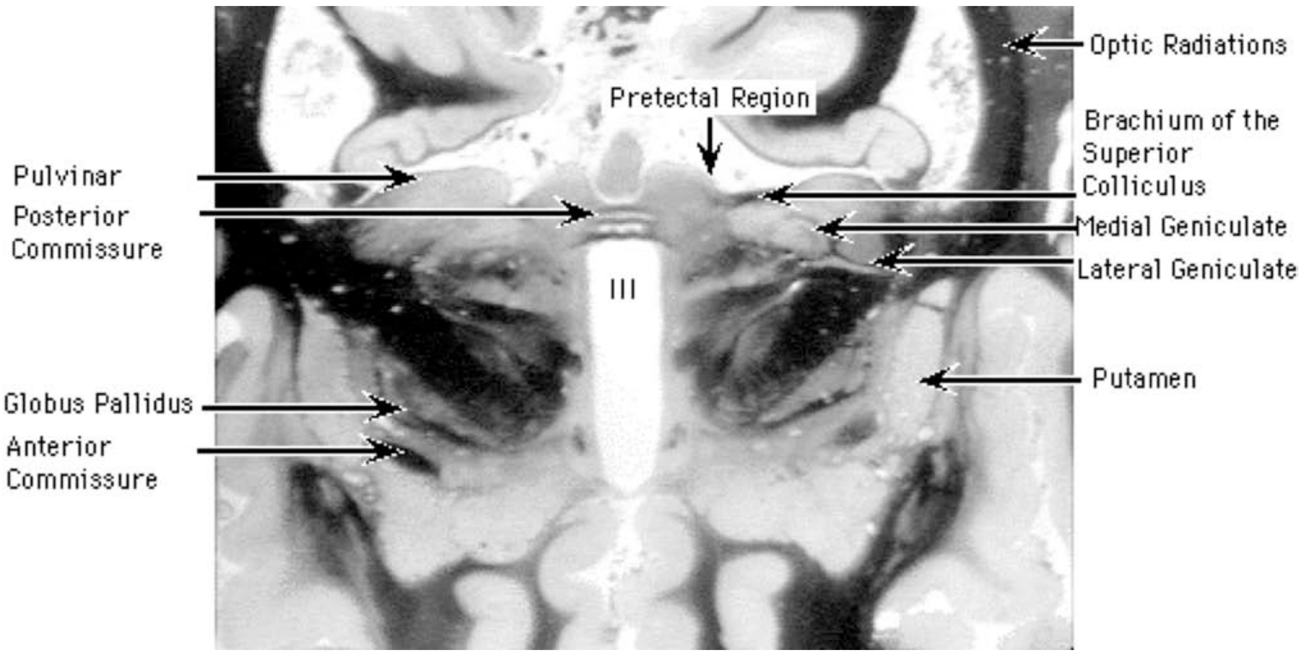

Figure 7J Axial (Horizontal) Section through Posterior Commissure
Same Image as Figure 7J-b but with Frontal Lobe Down

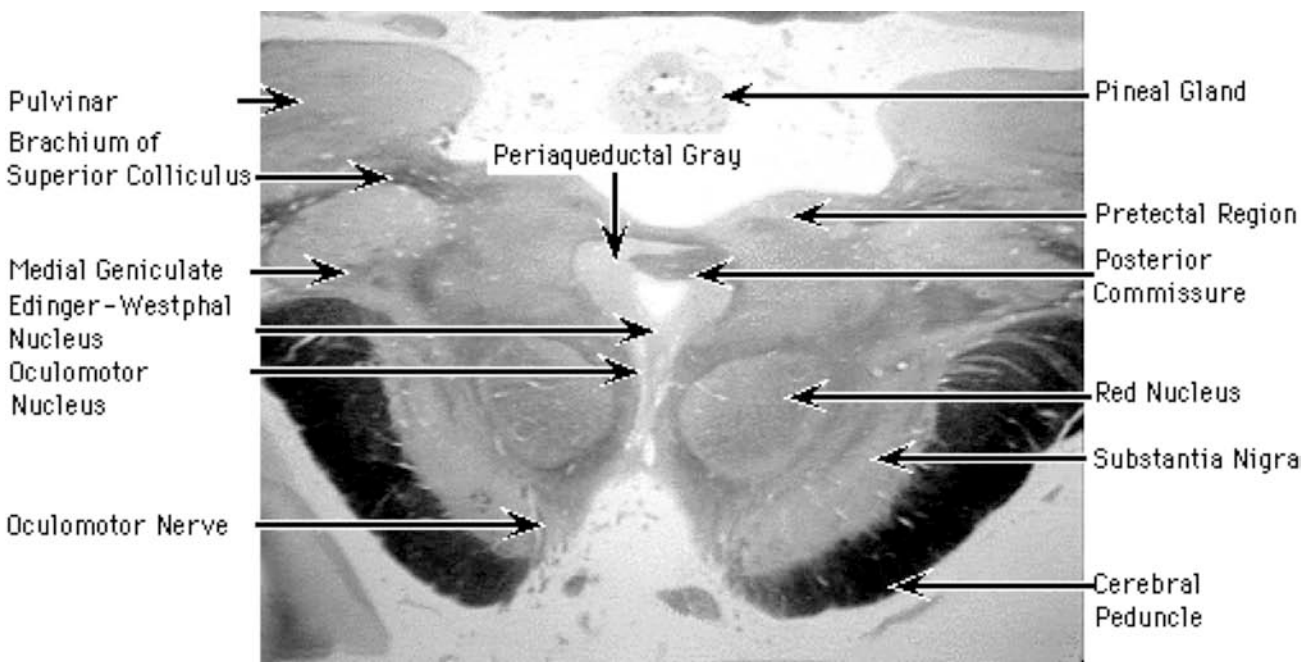

Figure 7K Midbrain in Pretectal Region

2. Near response: This reflex (see movie) depends on input to the near-response area of the midbrain from visual cortex pathways. The visual association cortex projects to parietal cortex and the frontal eye fields (#74245). These latter cortical areas project to the near-response area, which is dorsal and dorsolateral to the oculomotor nucleus.

Common efferent arm – CN III: The pupillary light reflex and the near response have a common efferent path – the oculomotor nerve (cranial nerve III) (#4729). The efferent arm of these reflexes consists of pre- and postganglionic parasympathetic neurons. The Edinger-Westphal nucleus (#6310) contains the preganglionic cell bodies. Depending on the author, this nucleus is either part of the oculomotor nucleus (oculomotor nuclear complex) or an adjacent separate nucleus. The oculomotor nucleus is at the level of the superior colliculus near the midline ventral to the aqueduct and periaqueductal gray. The axons forming nerve III are seen in #6312. Note their relationship to the cerebral peduncle and the red nucleus (fig 7k). The postganglionic axons end in the sphincter pupillae of the iris and the ciliary muscle. Where are the postganglionic cell bodies located (#52066)? What is the action of the ciliary muscle? Which reflex (pupillary light reflex or near-response) also uses somatic motor neurons to extraocular muscles?

Where is the pineal body? What area of the brain stem is likely to be compressed by a tumor of the pineal body (#873)?

What is the role of the reticular formation, the intermediolateral cell column of the spinal cord, and the superior cervical ganglion in pupillary dilatation? Be sure you understand the anatomy of the pupillary light reflex and near response as well as pupillary dilatation. Can one reflex occur without the other?

HyperBrain Chapter 7. The Visual System
Review of Terms

Edited by Stephen C. Voron, M.D. Revised 2007

Structures to identify in lab are bolded.

I. THE VISUAL PATHWAY

A. EYEBALL: cornea, pupil, lens, vitreous

B. RETINA
- retina layers
  - retinal pigment epithelium
    - retinal detachment
  - neural retina
    - photoreceptors: rods and cones
    - bipolar cells
    - ganglion cells
- fovea
- optic disc, central retinal artery
- retinotopic organization, visual fields

C. GANGLION CELL AXONS:
1. **optic nerve (cranial nerve II)**
2. **optic chiasm**
3. **optic tract**
   at rostral border of **cerebral peduncle**

D. LATERAL GENICULATE NUCLEUS & AXONS
1. **lateral geniculate nucleus (body)**
2. **geniculocalcarine tract [optic (visual) radiation]** begins in most caudal part of the **posterior limb of the internal capsule**
   a. inferior axons: initial **Meyer's loop** to the lateral side of the **inferior horn** and on to occipital lobe lateral to the **occipital horn**
   b. superior axons: direct course to occipital lobe

E. CORTEX
1. **primary visual cortex (V1, calcarine cortex, striate cortex, Brodmann's area 17)**
   - **calcarine sulcus**
   - **line of Gennari** in cortical layer IV
2. visual association cortical areas (extrastriate visual cortex)
   a. V2 and V3 (= area 18, or 18 & 19)
   b. occipitoparietal (“where”) pathway and occipitotemporal (“what”) pathway

OTHER TERMS IN AXIAL (HORIZONTAL) SECTIONS
- **splenium of the corpus callosum**
- **medial and lateral geniculate nuclei, pulvinar**
- **thalamus, putamen** and **globus pallidus** of **basal ganglia**, and **posterior limb of the internal capsule** that separates them

II. VISUAL REFLEXES

A. VISUAL REFLEXES
1. Pupillary light reflex: direct, consensual
   a. **brachium of the superior colliculus**
   b. **pretectal area (pretectal region, pretectum)**
      at level of **posterior commissure**, which is inferior to **pineal body (pineal gland)**
2. Near response
   a. Accommodation of the lens
   b. Convergence of the eyes
   c. Constriction of the pupil

B. CN III PARASYMPATHETIC PATHWAY
1. preganglionic neurons:
   a. Edinger-Westphal nucleus
      oculomotor nucleus (oculomotor nuclear complex) at level of **superior colliculus**
   b. axons in **cranial nerve III**
      exit between the **cerebral peduncles**.
2. postganglionic neurons: ciliary ganglion
   a. sphincter pupillae
   b. ciliary muscle

C. PUPILLARY DILATATION
- *1° neuron*: hypothalamus, brainstem reticular formation, cervical spinal cord
- *2° neuron*: T1 lateral horn preganglionic sympathetic neurons, ventral root, sympathetic trunk
- *3° neuron*: superior cervical ganglion, postganglionic axons follow the internal carotid artery, dilator pupillae

8. The Vestibular System

Revised 2010

The learning objectives of this chapter are to:

Describe the organization of the vestibular system. In particular, be able to describe the

1. Vestibular receptors
2. Vestibular nerve and ganglion
3. Vestibular nuclei
4. Central connections of the vestibular nuclei

The **vestibular system** conveys sensory information about **head orientation and motion** from receptors in the inner ear. Its three main functions are

1. Coordination of head and eye movement
2. Helping to maintain upright posture and balance (equilibrium)
3. Conscious perception of spatial orientation and motion

Lesions of the vestibular system cause

1. **Vertigo:** the sensation of movement or that one's surroundings are moving, especially the sensation of whirling or that one's surrounding are whirling, often associated with **nausea and vomiting**
2. **Imbalance** (disequilibrium)
3. **Nystagmus:** rhythmic oscillation of the eyes

I. VESTIBULAR RECEPTORS

The inner (internal) ear contains the receptors for both the auditory system, discussed in Chapter 9, and the vestibular system.

Bony labyrinth. Within the petrous part of the temporal bone (#7270, #7271, #7272) lies the inner ear (#7348). It contains the bony labyrinth (fig 8a), a series of communicating bony cavities: the cochlea (part of the auditory system), the vestibule and the semicircular canals. The three semicircular canals are perpendicular to one another and correspond to the three planes of space (#7451). They are the lateral (horizontal) canal, and the superior (anterior) and posterior canals in the vertical plane.

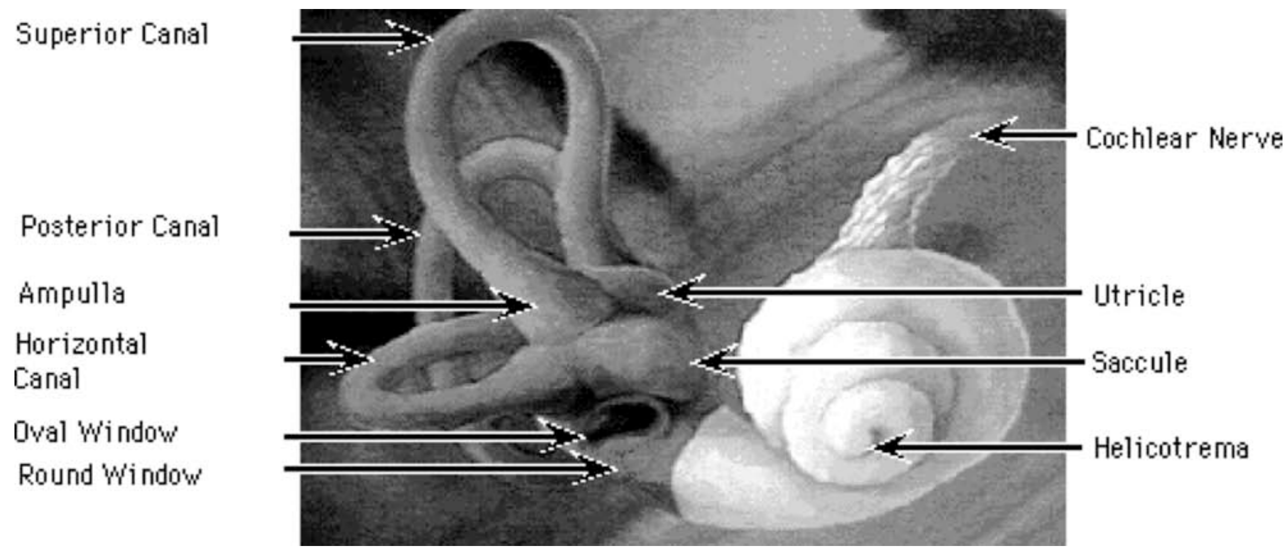

Figure 8A Outer Contours of Inner Ear

Membranous labyrinth. The bony labyrinth encloses the membranous labyrinth, a closed system of sacs and ducts filled with endolymph and bathed in perilymph. The membranous labyrinth includes two sacs, the utricle (#7354) and saccule (#7353, #7366), within the vestibule; and the semicircular ducts within the semicircular canals. The semicircular ducts, utricle and saccule contain the receptors of the vestibular system.

Semicircular ducts. Each semicircular duct has a dilated end, the ampulla, within a corresponding dilation of the semicircular canal (#7368). Each ampulla contains an ampullary crest (crista ampullaris) (#7444) with epithelium that contains mechanoreceptive hair cells. The hair cells are receptors whose stereocilia and kinocilium are embedded in a gelatinous mass called the cupula. Angular acceleration (#7452) sets up currents in the endolymph that cause the cupula to sway. This deflects the cilia and excites the hair cells (#7445). Consequently, the semicircular canals are sensitive to angular acceleration of the head and function in dynamic (or kinetic) equilibrium.

Utricle and saccule. Gravitational pull and linear acceleration, which represent static equilibrium, are detected by the utricle (#7367) and saccule (#7366). These structures also have collections of hair cells in the macula (#7446) of the utricle and the macula of the saccule. The hair cells have a gelatinous covering that contains rounded crystals of calcium carbonate called otoliths. Gravitational pull on the otoliths causes deflection (#7447) of the stereocilia and kinocilium of the hair cells in the maculae. The utricular macula lies horizontally when the head is upright and detects horizontal linear acceleration. The saccular macula is oriented vertically and is the major gravitational sensor.

What is the result of vigorous and excessive stimulation of these receptors? Carnival rides work their wonder through vestibular hair cells.

II. VESTIBULAR NERVE AND GANGLION

The primary sensory axons of the vestibular system comprise the vestibular nerve (#7448), a division of the vestibulocochlear nerve (VIII). The cell bodies of these bipolar neurons are located in the vestibular (Scarpa's) ganglion (#7449) in the lateral end of the internal auditory canal (internal acoustic meatus). The peripheral axonal processes of these cell bodies innervate the hair cells, and the central axonal processes enter the brain stem at the cerebellopontine angle. How do these axons enter the cranial cavity (#5440)? These axons enter which cranial fossa?

Vestibular schwannoma. Benign tumors of the Schwann cells in cranial nerve VIII generally arise from the vestibular part of VIII and are called vestibular schwannomas (old term, still used: acoustic neuromas) (#7966). This is one of the top three benign intracranial tumors (meningiomas, vestibular schwannomas, and pituitary adenomas) and by far the commonest tumor of the cerebellopontine angle.

The cochlear (auditory) nerve is generally affected first, causing **ipsilateral hearing loss**, often with tinnitus (ringing in the ear). Vestibular symptoms, imbalance or infrequently vertigo, are next most common. The adjacent facial nerve (VII) is resistant to gradual compression, and facial weakness is unusual. Instead, as the tumor gets quite large (#10866), the trigeminal nerve (V) is usually the next cranial nerve to be affected, with symptoms such as facial numbness and tingling.

III. VESTIBULAR NUCLEI

Instead of delineating each vestibular nucleus (there are four), understand where they are located in the brain stem. They extend from caudal medulla to mid-pons in the lateral floor of ventricle IV (#4608). Note their relationships with the inferior cerebellar peduncles (fig 8b), the solitary nucleus and tract, and the somatic and visceral motor nuclei.

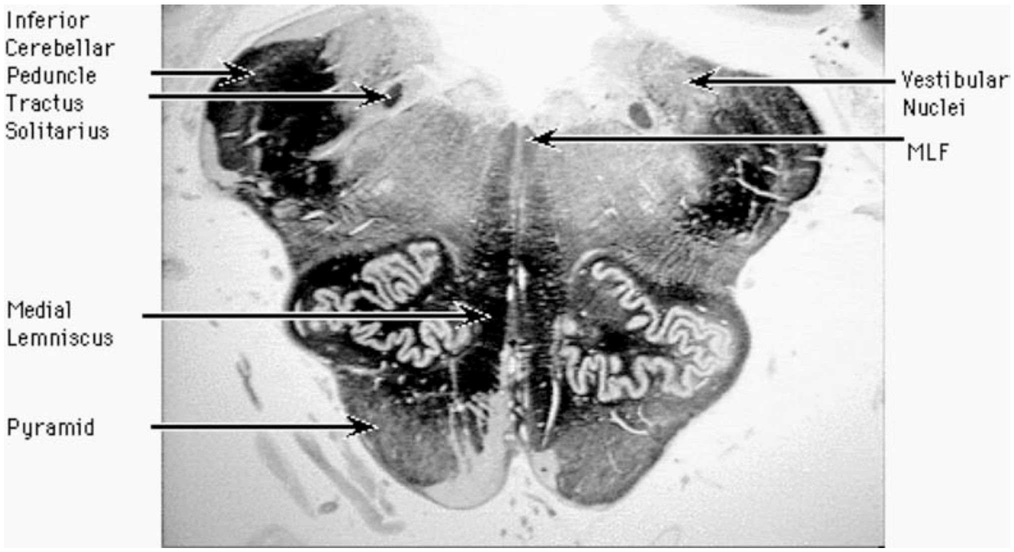

Figure 8B Mid-Medulla

IV. Central Connections of the Vestibular Nuclei

The vestibular nuclei have pathways to the

A. Extraocular muscles – to coordinate eye movements with head movements
B. Spinal cord – to maintain upright posture and balance
C. Cerebral cortex – to perceive spatial orientation and motion

(There are also connections with the cerebellum, especially cerebellar *efferents* from the vestibulocerebellum to the vestibular nuclei, discussed in Chapter 11: The Cerebellum.)

A. Vestibuloocular pathways: mlf

Medial longitudinal fasciculus (mlf). The central connections of the vestibular system are important in understanding conjugate eye movements. The medial longitudinal fasciculus (mlf) is a fairly complex fascicle that contains axons from the vestibular nuclei of both sides. The mlf runs longitudinally near the midline beneath ventricle IV and the periaqueductal gray matter of the midbrain (#6168, #6325, #6328, #6335, #6337, #4315). Secondary vestibular neurons project rostrally via the mlf to the motor neurons in the abducens nucleus (#6696), trochlear nucleus (#6702) and oculomotor nucleus (#6217).

Vestibuloocular reflex (VOR). The mlf is a vestibuloocular pathway important in mediating conjugate eye movements, especially the vestibuloocular reflex (VOR), which normally functions to keep the eyes fixed on a target, and hold images of the seen world steady on the retina, during brief head rotations. The integrity of the VOR is routinely tested in the comatose patient to help evaluate brain stem function. The two tests of the VOR in the comatose patient are the oculocephalic reflex (doll's eyes phenomenon) and caloric (thermal) testing.

B. Vestibulospinal tracts

The vestibular nuclei give rise to two vestibulospinal tracts.

The medial vestibulospinal tract projects bilaterally within the descending part of the mlf (#6339) to end in the ventral horns mainly in the upper cervical cord. It promotes stabilization of head position.

The lateral vestibulospinal tract projects ipsilaterally in the anterolateral white matter (#5505) to end in the ventral horns throughout the cord. It functions in reflex postural mechanisms to activate motor neurons of extensor (antigravity) muscles and promote upright posture and balance.

C. Vestibulothalamocortical pathway

Thalamus: VLp (Vim)

The vestibular nuclei project bilaterally to the thalamus, particularly its cerebellar territory: the posterior part of the ventral lateral nucleus (**VLp**) (#6592) (fig 11h), also called the ventral intermediate nucleus (**Vim**) in humans.

Lesions of this region cause transient vestibular signs and symptoms such as tilted perception of visual vertical and corresponding deviations of stance and gait.

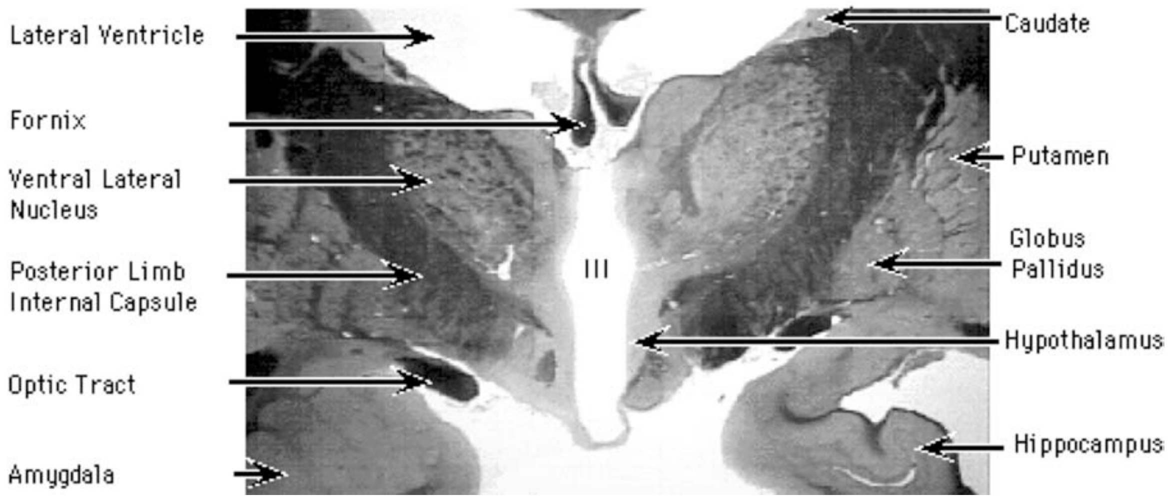

Figure 11H Thalamus

Vestibular cortex: the posterior insula

Thalamic vestibular neurons project to cerebral cortex. Unilateral stimulation of the vestibular labyrinth results in mainly ipsilateral activation of vestibular cortex. In contrast to the other sensory systems, there is no *unimodal* primary vestibular cortex. That is, there is no cortical area that receives only vestibular input. Instead, there are multiple *multisensory* vestibular cortical areas: their neurons also receive somatosensory and/or visual motion input.

The dominant vestibular area in humans is in the **posterior insula** (corresponding to the monkey parieto-insular vestibular cortex (PIVC), considered to be the core vestibular region in monkeys). Infarctions of this region cause subjective visual vertical tilt.

The vestibular system works in silence and does not usually intrude on consciousness except under extreme circumstances. We are, for example, conscious of vertigo. Primarily, we come to "experience" the vestibular system when it malfunctions.

What natural stimuli excite the vestibular system? The vestibular system can also be unnaturally stimulated, i.e., irritated, by inner ear infections, infections in the mastoid process (#5451) or by a tumor pressing on the vestibular nerve or nuclei (#15179). What sensations will irritative lesions evoke?

HyperBrain Chapter 8. The Vestibular System
Review of Terms

Stephen C. Voron, M.D. Revised 2010

Vestibular functional anatomy in a nutshell:
1. The vestibular apparatus contains mechanoreceptors for head orientation and motion: the ampullae and maculae.
2. The vestibular nerve synapses with the vestibular nuclei which have pathways to the
   a. Extraocular muscles – to coordinate eye movements with head movements
   b. Spinal cord – to maintain upright posture and balance (equilibrium)
   b. Cerebral cortex – to perceive spatial orientation and motion

Lesions of the vestibular system cause vertigo, imbalance and nystagmus.

Note: The only structure to identify in lab is CN VIII.

I. VESTIBULAR RECEPTORS
mechanoreceptors for
head orientation and motion

in inner ear in petrous part of temporal bone

A. bony labyrinth – perilymph
   1. semicircular canals
   2. vestibule

B. membranous labyrinth – endolymph

   1. semicircular ducts
      ampullae – for angular acceleration
      dynamic (kinetic) equilibrium
      ampullary crest (crista ampullaris)
      hair cells
      cupula

   2. utricle & saccule
      maculae – for gravitational pull & linear acceleration
      static equilibrium
      hair cells
      gelatinous covering containing otoliths

II. VESTIBULAR NERVE & GANGLION

primary sensory neuron
vestibular <u>(Scarpa's)</u> ganglion
vestibular nerve, a division of cranial nerve VIII
internal auditory canal (internal acoustic meatus)
cerebellopontine angle
vestibular schwannomas (acoustic neuromas)

III. VESTIBULAR NUCLEI – in floor of fourth ventricle

IV. CENTRAL CONNECTIONS of VESTIBULAR NUCLEI

A. VESTIBULO***OCULAR*** PATHWAYS
   to coordinate conjugate eye movements with head movements

   medial longitudinal fasciculus (mlf)
   ⇒ cranial nerve nuclei III, IV & VI

   vestibuloocular reflex (VOR)
   conjugate eye movements
   tests of brain stem function in comatose patient
   1. oculocephalic reflex (doll's eyes phenomenon)
   2. caloric (thermal) testing

B. VESTIBULO***SPINAL*** TRACTS

   1. medial vestibulospinal tract – bilateral
      to stabilize head position

      ⇒ ventral horns of cervical cord

   2. lateral vestibulospinal tract – ipsilateral
      to maintain upright posture and balance

      ⇒ ventral horns of entire cord
      motor neurons of extensor (antigravity) muscles

C. VESTUBULO***THALAMOCORTICAL*** PATHWAY
   to perceive spatial orientation & motion

   thalamus: VLp (Vim)
   multisensory vestibular cortex: the posterior insula

(There are also connections with the cerebellum, especially cerebellar *efferents* from the *vestibulocerebellum* to the vestibular nuclei. See Ch. 11: The Cerebellum)

9. The Auditory System

Revised 2010

The learning objectives of this chapter are to:

1. Describe the organization of the auditory system. In particular, be able to describe the
   a. Ear and auditory receptors
   b. Spiral ganglion and cochlear nerve
   c. Central auditory pathway
   d. Wernicke's area

2. Categorize hearing loss as conductive, sensorineural, or central according to the location of the causative lesion.

3. Describe where in the auditory system a unilateral lesion may cause ipsilateral hearing loss.

4. Explain hemisphere dominance and why inability to understand speech is only one type of aphasia.

Lesions of the auditory system cause

1. Tinnitus ("ringing" or "tinkling") (Pronounced TINN-ih-tuhs)
   Ringing in the ear: perception of noise in the absence of external sound. Examples are whistling like a teakettle and roaring like listening to a seashell.

2. Hearing loss (deafness)

I. EAR AND AUDITORY RECEPTORS

The auditory parts of the ear are the external ear, the middle ear, and the auditory portion of the inner ear, the cochlea, part of the bony labyrinth (#7348). (The vestibular parts of the bony labyrinth, the vestibule and the semicircular canals, are described in Chapter 8: The Vestibular System).

A. External ear and middle ear

Sound waves travel down the external auditory canal and cause the tympanic membrane to vibrate (#7371). Attached to the tympanic membrane is the malleus, the first of three ossicles in the middle ear (#7401): the malleus ("hammer"), incus ("anvil") and stapes ("stirrup"). The stapes is attached to the oval window of the vestibule (#7423), which is continuous with the base of the cochlea. Consequently, as the tympanic membrane vibrates so does the membrane of the oval window (#7408).

Conductive hearing loss is hearing loss due to a lesion of the external or middle ear.

B. Cochlea

The structure of the cochlea ("snail shell") can be appreciated by unwinding it as in #7430. A section through a turn of the cochlea shows three chambers (#7433). Two of these chambers, the scala vestibuli and the scala tympani (#7431), are filled with perilymph. They are continuous at the apex of the cochlea at a point called the helicotrema (#7435). The cochlear duct (scala media) (#7430) is a spiraled tube within the cochlea that contains endolymph and the organ of Corti, in which the auditory receptors are located.

Vibration of the membrane of the oval window produces waves in the perilymph of the bony labyrinth (#7424, #7974) that in turn create traveling waves along the basilar membrane. The organ of Corti (#6351) rests on the basilar membrane (#7432, #7927). The auditory receptors are hair cells (#7437, #6353, #3290) that are excited by the deflection of their stereocilia as the local part of the basilar membrane is displaced.

The cochlea is tonotopically organized along its length with high tones represented at the base and low tones at the apex. Tonotopic representation continues in the cochlear nerve and central auditory pathway to the auditory cortex.

II. Spiral Ganglion and Cochlear Nerve

At the base of each hair cell are terminals of the peripheral processes of the primary sensory neurons of the auditory system (#7438). The cell bodies of these bipolar neurons are in the spiral ganglion (#6342). The spiral ganglion is within the modiolus ("hub," pronounced moh-DYE-uh-luhs), the bony central pillar of the cochlea. The central axonal processes of these primary sensory neurons form the cochlear (auditory) nerve (#6341, #7439, #7975), a division of the vestibulocochlear nerve (VIII). The cochlear nerve leaves the inner ear and enters the posterior cranial fossa. It enters this fossa through what foramen (#7298)? What other cranial nerve passes through this foramen (#7297)?

The attachment of the vestibulocochlear nerve to the brain stem is seen in #5304. This general area, at the junction of the medulla, pons, and cerebellum, is known as the cerebellopontine angle. The cochlear nerve attaches to the brainstem at the rostralmost medulla (#5602), at the margin of the lateral recess, where its axons end in the ipsilateral dorsal cochlear nucleus (#4480) and ventral cochlear nucleus (#9752. Note also the dorsal cochlear nucleus and the lateral recess dorsal to the dorsal cochlear nucleus).

Sensorineural hearing loss is hearing loss due to a lesion of the cochlea (sensory), the cochlear nerve (neural), or both.

III. CENTRAL AUDITORY PATHWAY

The cochlear nuclei of each side give rise to *bilateral pathways to the primary auditory cortex*.

A. Brain stem auditory pathway

The main nuclei of the brain stem auditory pathway are located at each of the three levels of the brain stem: the medulla, the pons and the midbrain.

Medulla: cochlear nuclei. At the rostralmost medulla, the dorsal and ventral cochlear nuclei (fig 9a) look like saddle bags thrown over the inferior cerebellar peduncle. They contain the secondary sensory neurons of the auditory system. They give rise to the secondary sensory axons, which form the dorsal, intermediate and ventral acoustic striae. In humans, the secondary sensory axons project bilaterally to two main targets: the superior olivary complex and, via the lateral lemniscus (#6365, #6368), the inferior colliculus.

Figure 9A Rostral Medulla

Pons: superior olivary complex. The superior olivary complex (fig 9b, labelled Superior Olivary Nucleus) is in the pons. It processes sound localization. In addition, *efferent* olivocochlear axons to the organ of Corti enhance auditory selective attention and the processing of speech in the presence of noise. The superior olivary complex projects via the lateral lemniscus mainly to the inferior colliculus.

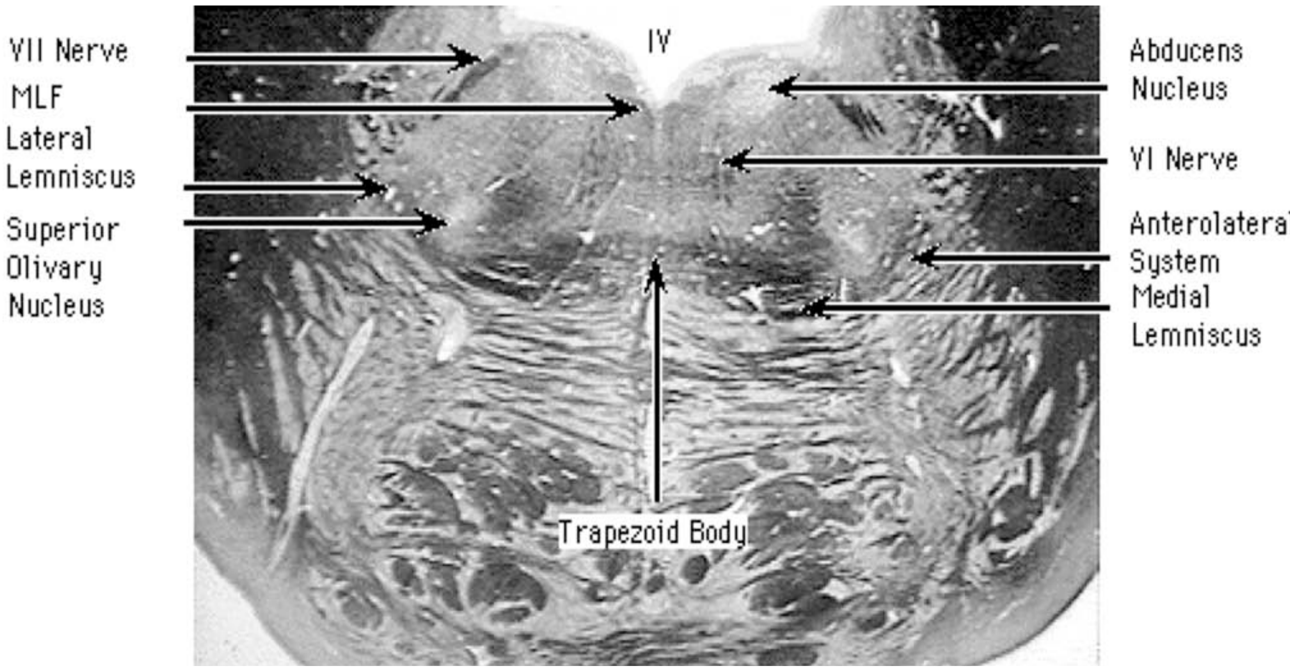

Figure 9B Pons

Midbrain: inferior colliculus. The lateral lemniscus terminates mainly in the central, or main, nucleus of the inferior colliculus (fig 9c), in the midbrain. Axons from the inferior colliculus form the brachium of the inferior colliculus (fig 9d), which can be seen on the surface of the brain stem. In cross section (#6374), the brachium is a band on the surface of the midbrain. The brachium of the inferior colliculus ends in the medial geniculate nucleus (#11716, #8291) of the thalamus.

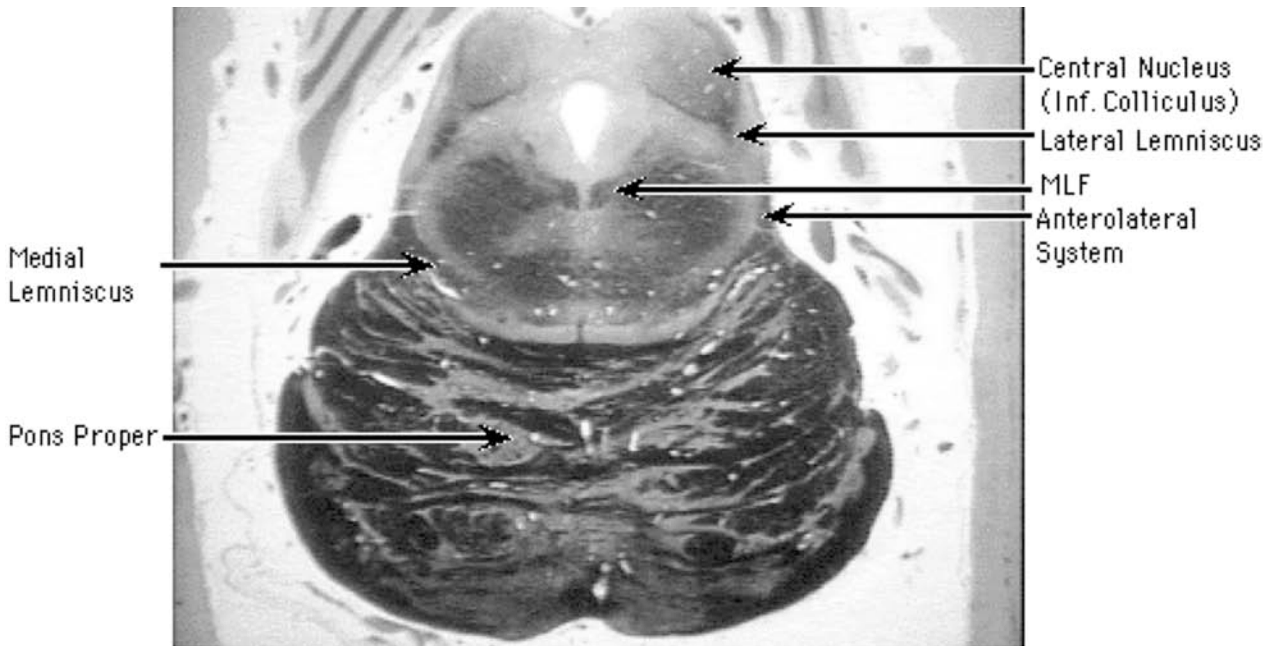

Figure 9C Midbrain at Level of Inferior Colliculus

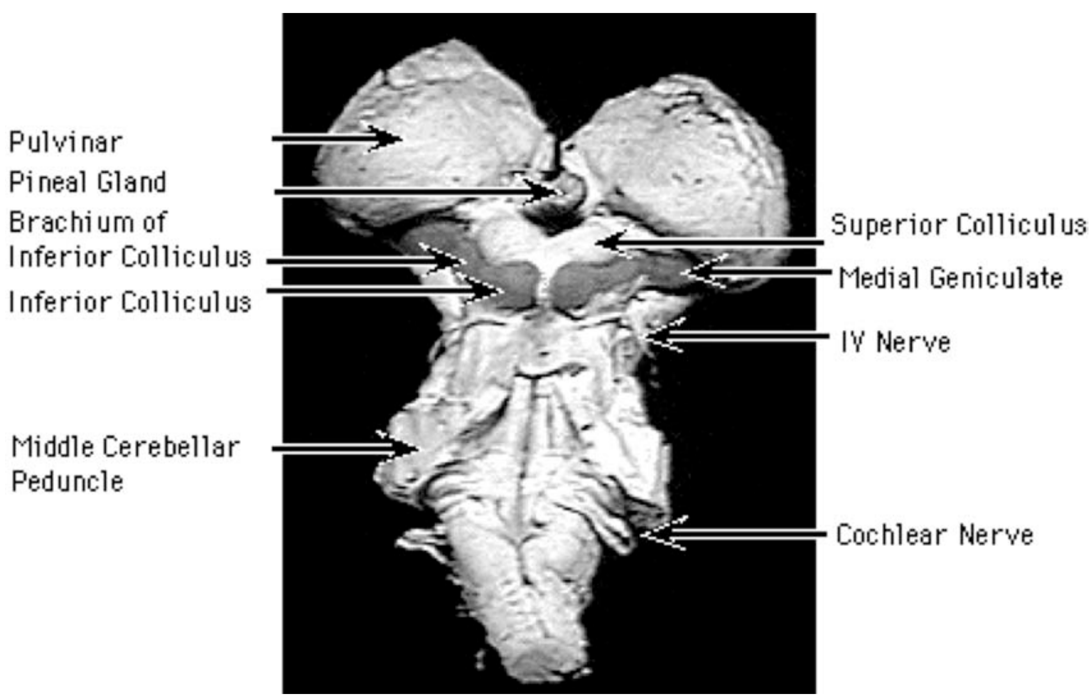

Figure 9D Dorsal Surface Isolated Brain Stem

B. Thalamus: medial geniculate nucleus

The medial geniculate nucleus (fig 9e) forms a surface elevation, the medial geniculate body. It is the relay nucleus of the thalamus for the auditory system. Axons of the medial geniculate nucleus project through the most caudal part of the posterior limb of the internal capsule (#6383) to end mainly in the primary auditory cortex. These thalamocortical axons constitute the auditory radiations (#6383).

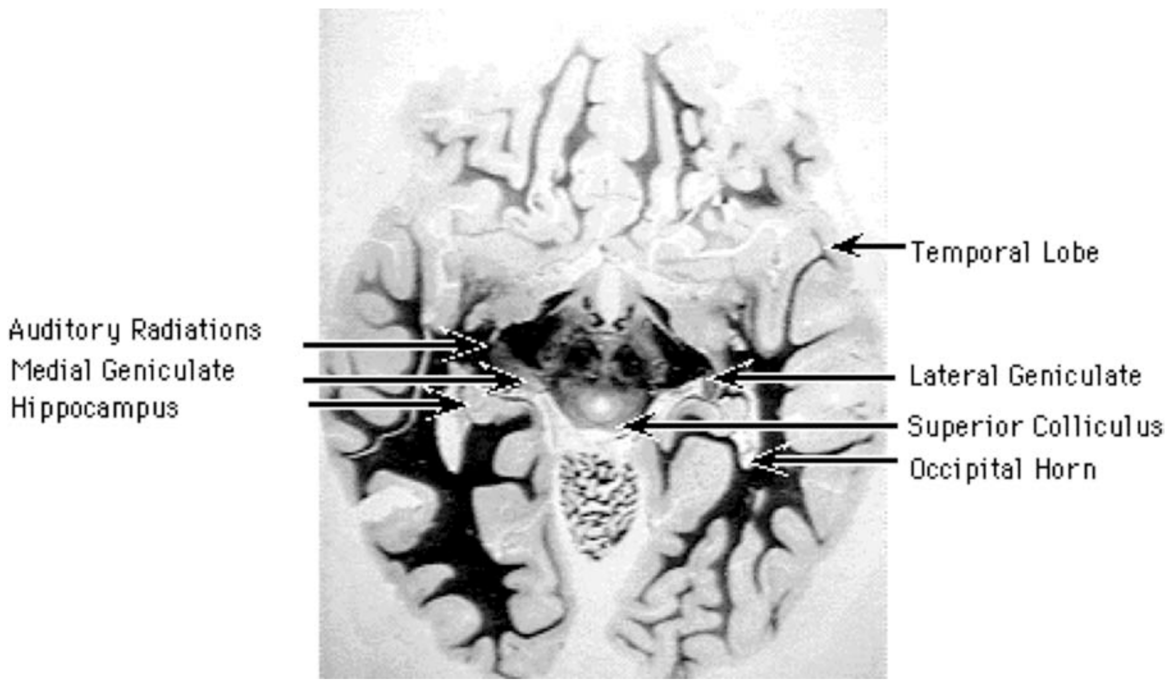

Figure 9E Horizontal Section Through Geniculate Bodies
Note: The frontal lobe is up as in radiology practice.

C. Auditory cortex

Primary auditory cortex. The transverse temporal gyrus (Heschl's gyrus) is on the superior surface of the superior temporal gyrus, so that it is hidden in the Sylvian (lateral) fissure (#8437, #5374). It is commonly two gyri (#5374), or bifid laterally. Only a small part of it extends onto the lateral surface of the temporal lobe (#4352). The primary auditory cortex (Brodmann's area 41) is on the medial two-thirds of Heschl's gyrus, corresponding approximately to the medial (anterior) Heschl's gyrus when there are two gyri. It represents perceived pitch, tonotopically organized with low tones laterally.

Secondary auditory cortex (Brodmann's area 42) forms a lateral crescent around the primary auditory cortex. **Further auditory areas** are on the anterior two-thirds of the superior temporal gyrus (anterior two-thirds of area 22) (#4340, superior temporal gyrus). These areas (42 and anterior two-thirds of 22) represent the phonological representation of words at a presemantic (pre-meaning) level.

Central hearing loss is hearing loss due to a lesion of the central auditory pathway and is rare.

- Bilateral lesions are generally necessary to produce central hearing loss.
- Patients with lesions of the central auditory pathway are usually not deaf in the usual sense. Pure tone audiometry is usually normal, and more sophisticated tests such as tests of speech reception threshold or word recognition are required for evaluation.
- Lesions of the CNS (except for the cochlear nuclei) do not result in unilateral hearing loss.

IV. Receptive Speech Region: Wernicke's area

Wernicke's area. Wernicke's area processes the understanding of speech. It is adjacent to the auditory cortex, mainly in the posterior third of the superior temporal gyrus, of the dominant, generally left, hemisphere (#4213. Ignore the included parietal area.).

> [The superior surface of the temporal lobe posterior to Heschl's gyrus is the planum temporale, which is usually larger on the left. The planum temporale behind the auditory cortex of the dominant hemisphere is also part of Wernicke's area (posterior third of area 22).]

Wernicke's aphasia. Aphasia means a *language deficit* caused by brain damage. This may include defective production or comprehension of spoken or written vocabulary or grammar (sentence structure). Aphasia occurs with lesions of the *dominant hemisphere*, which, by definition, is the cerebral hemisphere that is dominant for *language*.

Lesions of Wernicke's area result in Wernicke's (fluent, sensory, receptive) aphasia. These patients are *unable to understand speech* or repeat words. Yet, they speak fluently, although with many incorrect words.

Branches of what cerebral artery vascularize auditory cortex and Wernicke's area?

HyperBrain Chapter 9. The Auditory System
Review of Terms

Stephen C. Voron, M.D. Revised 2010

Auditory functional anatomy in a nutshell:

1. **Conduction:** The *external and middle ear* conduct sound to the inner ear.
2. **Sensorineural:**
   Sensory: The *inner ear* contains mechanoreceptors for sound in the organ of Corti.
   Neural: The *cochlear nerve* synapses with the cochlear nuclei.
3. **Central:** The cochlear nuclei of each side give rise to *bilateral pathways to the primary auditory cortex*.
4. **Language:** The auditory cortex of each side provides input to the left-sided *Wernicke's area*.

Structures to identify in lab are **bolded.**

Tinnitus
Hearing Loss
- Conductive hearing loss
- Sensorineural hearing loss
- Central hearing loss

I. EAR and AUDITORY RECEPTORS

A. EXTERNAL EAR
- external auditory canal
- tympanic membrane

B. MIDDLE EAR
- ossicles: malleus, incus, stapes
- oval window of the vestibule

C. INNER EAR (auditory portion)

- bony labyrinth – perilymph
  - cochlea
    - scala vestibuli
    - scala tympani
    - helicotrema

- membranous labyrinth – endolymph
  - cochlear duct (scala media)
    - basilar membrane
    - organ of Corti
      - hair cells – stereocilia
    - tonotopic organization

II. SPIRAL GANGLION & COCHLEAR NERVE

primary sensory neuron
spiral ganglion
cochlear (auditory) nerve
- **vestibulocochlear nerve (VIII)**
- internal auditory canal (internal acoustic meatus)
- **cerebellopontine angle**

III. CENTRAL AUDITORY PATHWAY

A. BRAIN STEM AUDITORY PATHWAY

- cochlear nuclei – dorsal and ventral
  - secondary sensory neurons
    - acoustic striae
  - lateral lemniscus

- superior olivary complex

- **inferior colliculus**
  - brachium of the inferior colliculus

B. THALAMUS

- **medial geniculate nucleus**
  - **medial geniculate body**
- **most caudal part of posterior limb of internal capsule**
- auditory radiations

C. AUDITORY CORTEX

- primary auditory cortex
  - **transverse temporal gyrus (Heschl's gyrus)**
  - **Sylvian (lateral) fissure**
- secondary auditory cortex
- further auditory areas
  - **anterior ⅔ of superior temporal gyrus**

IV. WERNICKE'S AREA

Wernicke's area
- posterior third of superior temporal gyrus
- dominant hemisphere (generally left)

Wernicke's (fluent, sensory, receptive) aphasia

10. Lower and Upper Motor Neurons and the Internal Capsule

Revised 2007

The objectives of this chapter are to:

1. Describe the anatomy of lower and upper motor neurons.
2. Describe the organization of the internal capsule.

I. Lower and Upper Motor Neurons

Lower motor neurons are neurons that directly innervate skeletal muscle. The cell bodies of these neurons are located within the ventral horns of the spinal cord and within brainstem motor nuclei.

Upper motor neurons, as defined clinically, **are cortical neurons that innervate lower motor neurons** (either directly or via local interneurons). The axons of upper motor neurons are contained within the pyramidal system, which is composed of the corticospinal (pyramidal) and corticobulbar tracts.

A. The corticospinal (pyramidal) tract

Primary motor cortex: The corticospinal tract (pyramidal tract) originates from several frontal and parietal cortical areas. The focus here is on its origin from the primary motor cortex (Brodmann's area 4) (#74246) of the precentral gyrus (#4321) and the anterior part of the adjacent paracentral lobule (#74248). The precentral gyrus, similar to the postcentral gyrus, is somatotopically organized. The foot and lower limb are represented on the medial surface of the hemisphere and the trunk, upper limb, hand and face, on the lateral surface. What cerebral arteries supply the primary motor cortex? What part of the somatotopic representation does each cerebral artery supply?

Pyramidal cells: Two types of neurons occur in the cerebral cortex, pyramidal (#6131) and stellate cells (#8319). Stellate ("star-shaped") neurons are local interneurons. Their axons remain within the cerebral cortex. Pyramidal cells are the output neurons of the cortex. Their axons end in other areas of the cortex on the same or opposite side, or they project to the basal ganglia, thalamus, brain stem, and spinal cord. The name pyramidal is derived from the shape of their cell bodies, "pyramid-like" (#5799). The fact that the term "pyramidal" is applied both to this category of cortical cell and to the corticospinal tract is coincidental. The tract is named after the pyramids in the medulla (#6411).

Corona radiata and internal capsule: Pyramidal tract axons leave the cerebral cortex and go through the subcortical white matter. Within the subcortical white matter, the pyramidal system fibers converging from all parts of the cerebral cortex into the internal capsule (fig 10a, #6390) form part of the corona radiata.

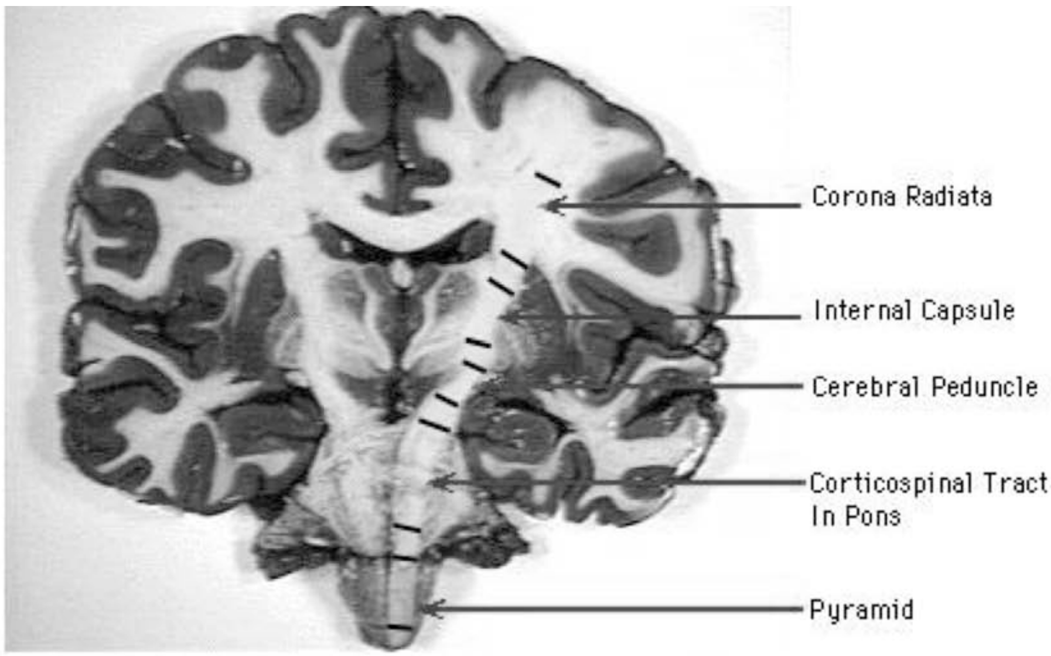

Figure 10A Coronal Section through Brain, Courtesy of Dr. Diane E. Smith

Remember, though, that the subcortical white matter contains three kinds of fibers:

1. **Commissural fibers** that travel to the opposite hemisphere through the corpus callosum and anterior commissure.
2. **Association fibers** that travel to other parts of the same cerebral hemisphere.
3. **Projection fibers,** which include
   - All fibers projecting (in the corona radiata) from the cerebral cortex to noncortical areas.
   - All fibers from the thalamus projecting (in the corona radiata) to the cerebral cortex.

Thus, the subcortical white matter is composed of these three kinds of fibers (commissural, association and projection fibers) traveling at roughly right angles to each other. The focus here is on the corona radiata fibers.

Brainstem: The pyramidal fibers descend through the internal capsule into the middle three-fifths of each cerebral peduncle (#6461, #6397). The cerebral peduncle fibers become incorporated into basilar pons (pons proper) (#4020). In transverse sections through the pons, the corticospinal fibers are the large fascicles in the center of basilar pons (#10144, #6403). As these axons continue caudally, they come to the surface of the medulla as the pyramids (#6411).

Pyramidal decussation and spinal cord: The corticospinal axons decussate (#5306) at the junction of the medulla spinal cord (#6414), which is at the level of the foramen magnum. The axons move laterally (#6213) into the lateral funiculus (#6416). Consequently, the axons that originate in the left cerebral cortex become located on the right side of the spinal cord. In the spinal cord, these axons form the lateral corticospinal tract. Some of the axons in the pyramids do not decussate but continue directly into the spinal cord as the ventral (anterior) corticospinal tract (#6417), but most of these fibers eventually cross and the ventral corticospinal tract is of little clinical significance. There are considerably fewer corticospinal fibers in lumbar than in cervical segments (#6420). Why?

In summary, the upper motor neurons of the **left** motor cortex innervate the lower motor neurons of the **right** body. A stroke or other lesion involving all of the corticospinal fibers from the left cerebral cortex produces weakness of the right upper and lower limbs (right hemiparesis).

Lower motor neurons: The corticospinal fibers terminate in the ventral horn on lower motor neurons, either directly or via local interneurons. Of course, these motor neurons receive input from several other sources. In fact, their dendrites and cell bodies are literally outlined by synaptic buttons. The axons of these motor neurons leave the cord via the ventral roots (#4497). The axons of the large ventral horn neurons (alpha motor neurons) terminate as motor endplates on skeletal muscle (#52178). Alpha motor neurons are also designated as "final common path neurons." What deficits result from the interruption of upper motor neurons? Compare these deficits with those that occur after lower motor neuron disease or damage.

B. The Corticobulbar Tract

Axons that are homologous to corticospinal fibers, but terminate in the motor nuclei of cranial nerves in the brain stem [e.g., nuclei V (#6198), VII (#6695), IX, X, XI and XII (#4311)], form the corticobulbar tract. Thus, they are the axons of the upper motor neurons that synapse on the lower motor neurons of the cranial nerves. The corticobulbar fibers accompany the corticospinal axons through the internal capsule (#6430) and cerebral peduncle (#6463) and then gradually leave the corticospinal tract to enter the tegmentum of the pons and medulla to terminate in the different nuclei.

A clinically important point is that the lower motor neurons of the brain stem receive bilateral corticobulbar input. Therefore, unilateral corticobulbar tract lesions usually produce no clinical effect on head and neck muscles with **two exceptions**:

- Facial nucleus (VII): The neurons that innervate the muscles of the lower face (below the forehead) receive mainly crossed input from the opposite motor cortex. Therefore, a stroke or other lesion involving the **left** motor cortex or internal capsule causes weakness of the **right** facial muscles below the forehead, but the patient can still wrinkle her right forehead. This is demonstrated with an animation where you can compare an upper and lower motor neuron lesion and its effect on facial expression.

- Hypoglossal nucleus (XII): The neurons that innervate the genioglossus muscle receive mainly crossed input from the opposite motor cortex. Therefore, a stroke or other lesion involving the **left** motor cortex or internal capsule causes weakness of the **right** genioglossus muscle. When the patient protrudes his tongue, the normal left genioglossus muscle pushes the tongue to the right. However, this deficit is generally transient, lasting a few days.

In summary, a lesion involving all of the corticospinal and corticobulbar fibers from the **left** cerebral cortex produces

1. **Right** hemiparesis (weakness of the right upper and lower limbs).
2. Weakness of the **right** face below the forehead.
3. Deviation of the tongue to the **right** upon protrusion (transient).

C. Control of voluntary eye movements

Voluntary control of eye movements is not executed through the corticobulbar tract. There are discrete cortical areas subserving the control of eye movements. One of these is called the frontal eye field (FEF). The FEF has recently been localized in humans to the junction of the superior frontal sulcus with the precentral sulcus (#74245) in area 6, not in area 8 as in the monkey (#4351). Electrical stimulation of the FEF produces conjugate horizontal gaze to the opposite side. Thus, the **left** hemisphere controls horizontal gaze to the **right**. A **left** FEF lesion impairs ability to voluntarily look to the **right** (and the patient looks toward the left for the first few days).

FEF cortical cells send axons through the internal capsule and cerebral peduncle into the pons. In the case of horizontal gaze, these axons decussate and terminate in an area of the opposite reticular formation near the abducens nucleus called the paramedian pontine reticular formation (PPRF). The PPRF, in turn, connects with the abducens nucleus of the same side, thus exciting the motor neurons of cranial nerve VI (#6174). The abducens nucleus also has interneurons whose axons ascend in the opposite medial longitudinal fasciculus (MLF) (#6333) to the oculomotor nucleus to cause concurrent activation of the medial rectus muscle of the opposite side. A **right** PPRF lesion impairs ability to voluntarily look to the **right.**

The PPRF is the pontine center for horizontal gaze. Similarly, there is a center for vertical gaze located in the midbrain near the posterior commissure and pretectal area (fig 7k, #6302). This center connects directly with the oculomotor (#6217) and trochlear nuclei. Upward gaze depends on the posterior commissure, and a lesion affecting the posterior commissure causing loss of upward gaze (dorsal midbrain or Parinaud's syndrome) does not affect horizontal gaze. Likewise, patients with impaired horizontal gaze may have no difficulty with upward gaze. Why? Predict what gaze problem would occur with a tumor of the pineal gland (#2397).

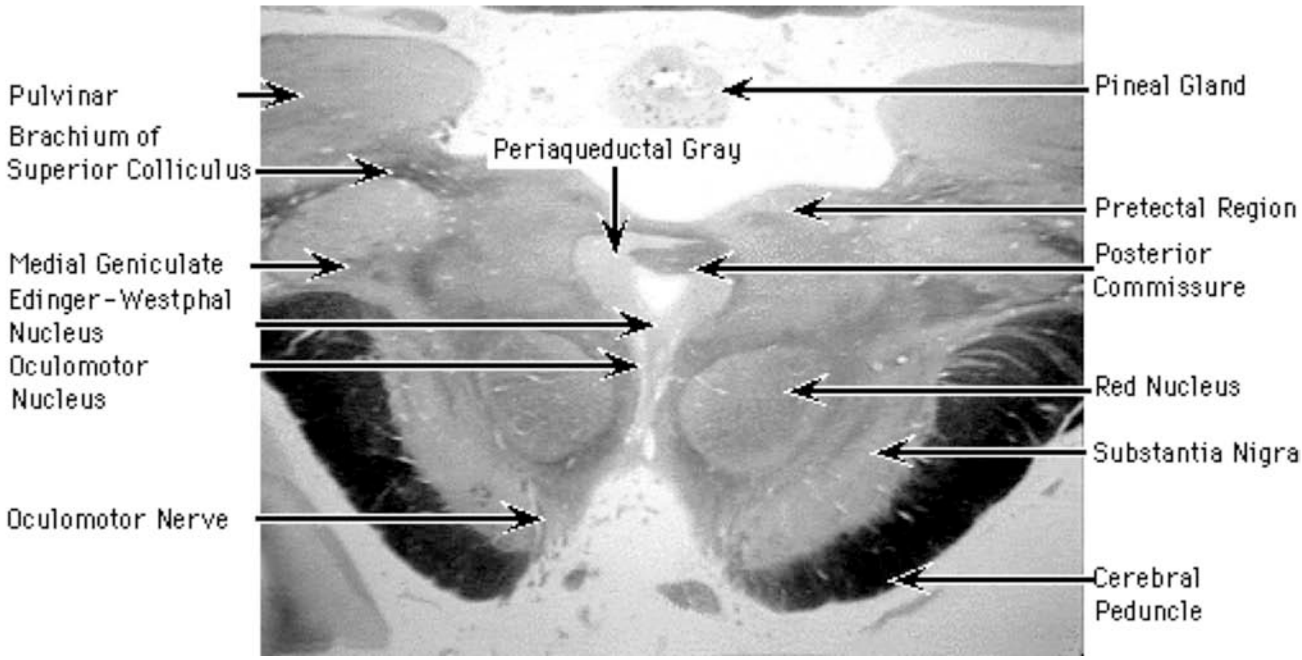

Figure 7K Midbrain in Pretectal Region

II. The Internal Capsule

The internal capsule is the fibrous expressway that connects the cerebral cortex to the basal ganglia, thalamus, brain stem (motor nuclei, pontine nuclei and reticular formation) and spinal cord. In addition, it carries the fibers connecting the thalamus to the cerebral cortex.

The internal capsule is divided into three regions: the anterior limb, genu, and posterior limb. These three regions are best seen in an axial (horizontal) section (fig 10b).

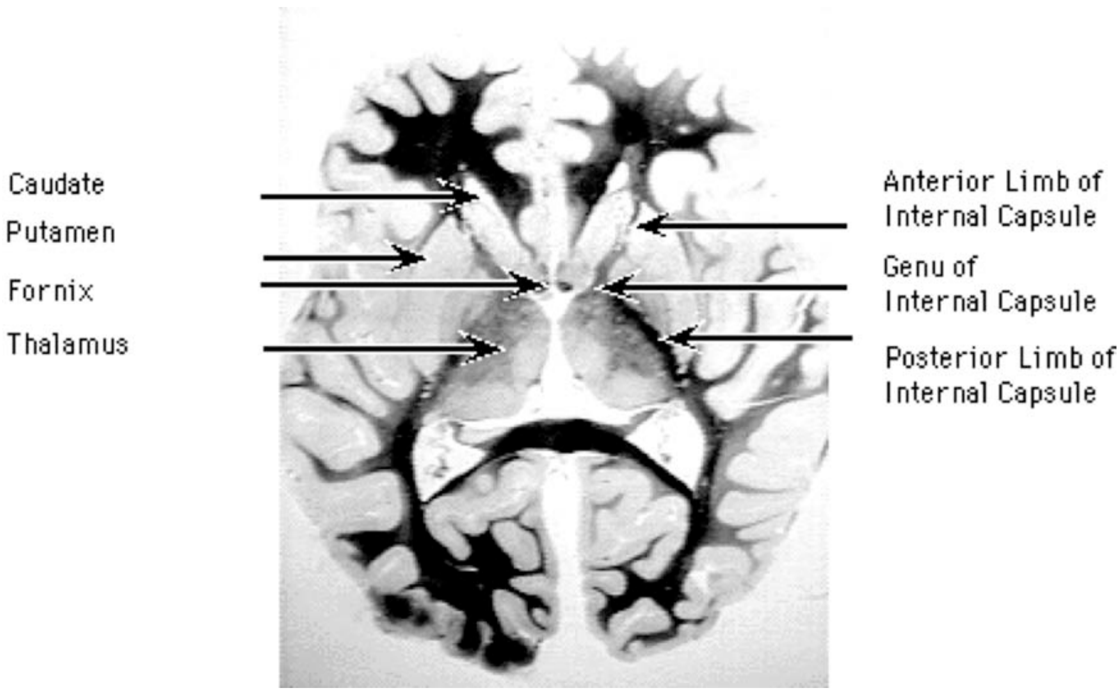

Figure 10B Horizontal Section of the Internal Capsule

1. **Anterior limb:** The anterior limb (#6446 horizontal, #6426 coronal) is located between the putamen and the caudate nucleus. It does not contain any pyramidal system axons and it does not contain any thalamic axons to primary sensory cortex. It is of relatively little clinical significance.
2. **Genu:** The genu (#6447 horizontal, #15106 coronal) is located where the anterior and posterior limbs meet at the rostral end of the thalamus, at the level of the foramen of Monro and the anterior commissure on coronal section. The genu contains corticobulbar fibers.
3. **Posterior limb:** The posterior limb (#6448 horizontal, #6390 coronal) is located between the thalamus medially and the basal ganglia laterally. It contains corticobulbar fibers, corticospinal fibers, and the thalamocortical somatosensory radiations. The corticobulbar fibers are closest to the genu. Caudal to them are the corticospinal fibers, which are grouped in a somatotopic manner. The thalamic somatosensory radiation partly interdigitates with the corticospinal axons but is also caudal to the upper motor neuron axons. The optic (visual) radiations and auditory radiations are in the most caudal part of the posterior

limb. Where are the cell bodies for the somatosensory, auditory, and optic radiations located?

It has frequently been observed that a small lesion in the internal capsule causes more damage than many large lesions of the cortex. Why? Contrast the clinical results of hemorrhage into the anterior limb with hemorrhage into the posterior limb.

The course of the corticospinal tract can be followed from the internal capsule as far caudally as the pyramid in fig 10c, a sagittal section from a monkey brain and fig 10a, a coronal section from a human.

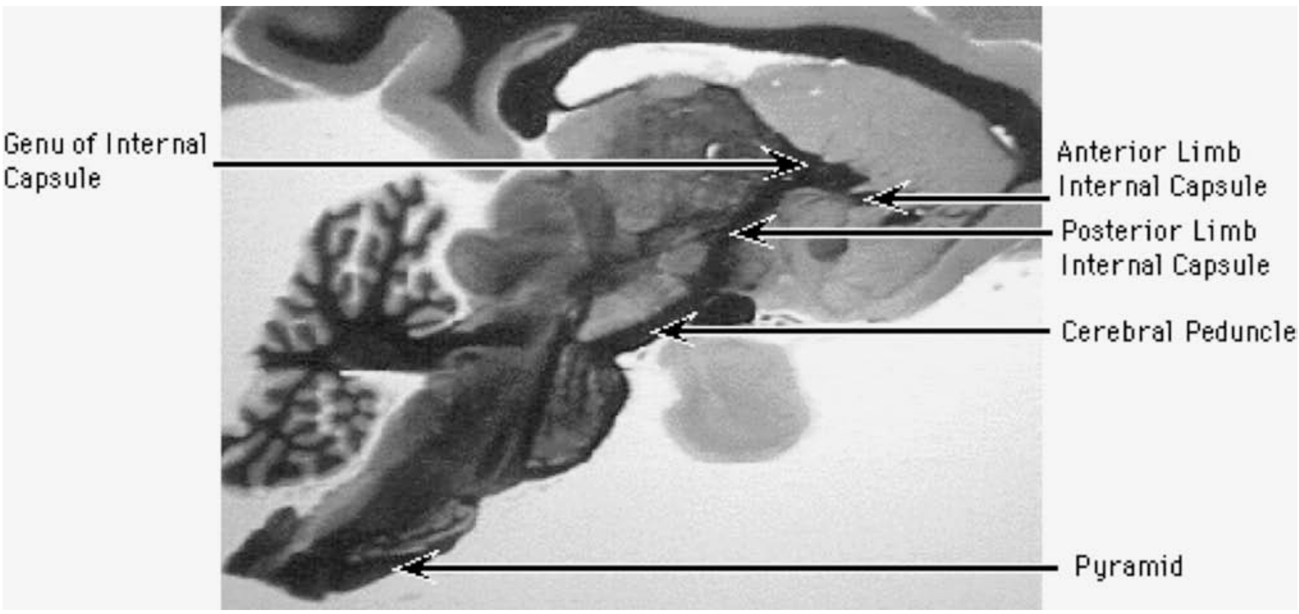

Figure 10C Parasagittal Section through Monkey Brain

HyperBrain Chapter 10. The Corticospinal Tract and the Internal Capsule
Review of Terms

Edited by Stephen C. Voron, M.D. Revised 2007

I. LOWER AND UPPER MOTOR NEURONS

Lower motor neurons: neurons that directly innervate skeletal muscle

- ventral horn neurons and brain stem motor nuclei
  - alpha motor neurons (final common path neurons)
- ventral roots, and cranial nerve motor roots
- motor endplates

Upper motor neurons: cortical neurons that innervate lower motor neurons (either directly or via local interneurons)

- primary motor cortex (Brodmann's area 4): precentral gyrus and anterior paracentral lobule
  - pyramidal cells
- corticospinal (pyramidal) tract and corticobulbar tract
  - corona radiata – projection fibers
  - internal capsule
  - cerebral peduncle
  - basilar pons (pons proper)
  - pyramid
    - pyramidal decussation: lateral corticospinal tract
    - ventral (anterior) corticospinal tract

[Control of voluntary eye movements: covered later in the course.]

- Frontal eye field (FEF) in area 6 in humans
- Brainstem gaze centers
  - Horizontal gaze – paramedian pontine reticular formation (PPRF)
  - Vertical gaze – in pretectal area
    - Upward gaze – depends on posterior commissure – dorsal midbrain (Parinaud's) syndrome

II. THE INTERNAL CAPSULE

Look at the axial (horizontal) section and the appropriate coronal section:

A. anterior limb

B. genu: corticobulbar fibers.

C. posterior limb

- corticobulbar fibers, corticospinal fibers
- thalamocortical somatosensory radiations
- optic (visual) radiations, auditory radiations

11. The Cerebellum

Revised 2007

The objectives of this chapter are to:

1. Describe cerebellar anatomy, afferents, internal circuitry, efferents and blood supply
2. Compare the effects of lesions of the hemisphere, vermis and vestibulocerebellum (flocculonodular lobe).

I. Cerebellar Anatomy

A. Anatomic Divisions of the Cerebellum: Like the Balkans, the cerebellum has been divided, redivided, and parcelled into various divisions and regions. In this section we will talk about the two kinds of ***anatomic*** divisions: 1) vermis and hemispheres, and 2) three lobes.

Vermis and hemispheres: The midline area is called the vermis (#5300), because it resembles a worm. Spreading out on either side from the vermis are the cerebellar hemispheres (#5299).

Three lobes: The cerebellum is divided into three lobes by two fissures (fig 11a). The posterolateral fissure separates the flocculonodular lobe from the rest of the cerebellum. The flocculonodular lobe is composed of the small nodulus (#15111), which is part of the midline vermis, and the left and right flocculi (#5260, #5283), which are small lobules of the hemispheres. This lobe is functionally related to the vestibular system, especially via its efferents.

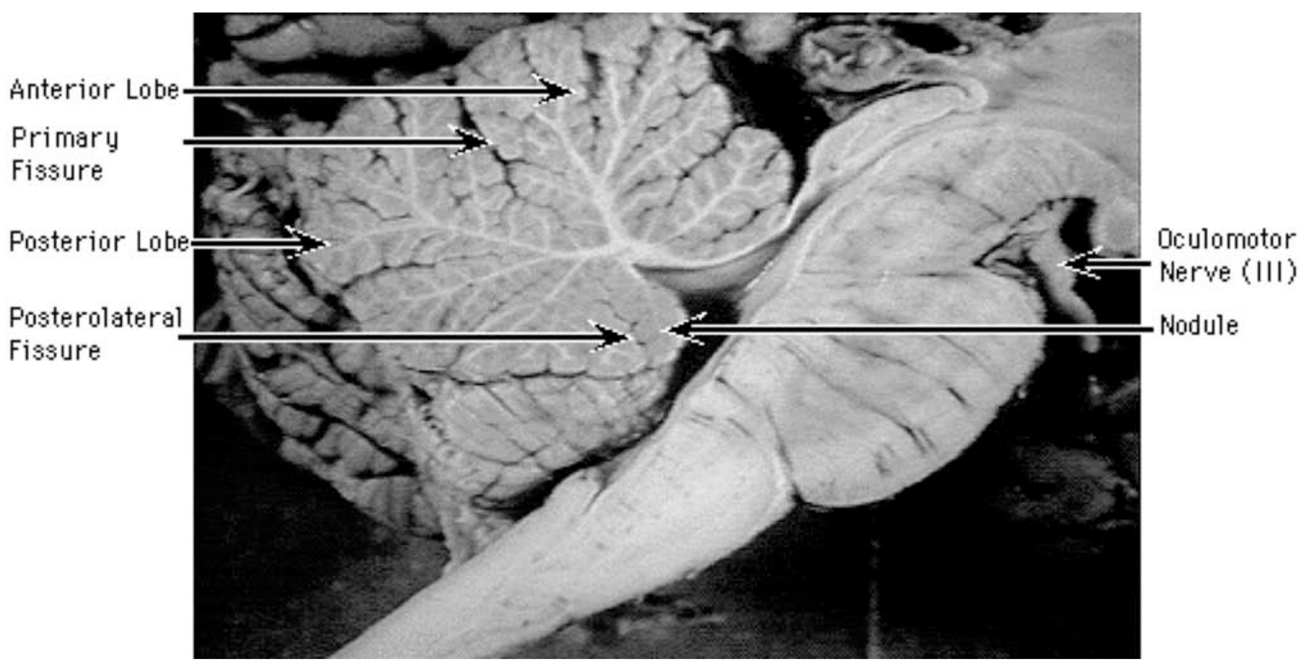

Figure 11A Midsagittal Section of Brain Stem and Cerebellum, Courtesy of Dr. Bruce Updyke

The rest of the cerebellum is further divided by the primary fissure into an anterior lobe and a posterior lobe. The anterior lobe is rostral to the primary fissure (#11721). The primary fissure is hard to find by examining the surface of the cerebellum (#5585), but it is the deepest fissure that is seen in midsagittal sections of the cerebellum (#11721). The posterior lobe, the largest cerebellar lobe, is caudal to the primary fissure (#5317). What are the cerebellar tonsils?

The anterior lobe just might be of some interest because it degenerates in alcoholics (#5335). It atrophies, leaving the individual with ataxia. What are some other indications of cerebellar disturbance?

Many textbooks mistakenly try to *functionally* equate *anatomic* divisions with *afferent* regions and with *evolutionary* divisions. E.g., posterior lobe = pontocerebellum = neocerebellum. However, 1) Afferent regions overlap. **Afferent regions are not discrete divisions and do not correspond to anatomic divisions.** 2) Evolutionary terms do not refect current knowledge of the comparative anatomy and evolution of the cerebellum. **Evolutionary terms (neocerebellum, paleocerebellum and pontocerebellum) are outdated** despite their continued frequent use in textbooks and even journal articles.

B. Cerebellar peduncles: The cerebellar peduncles have been referred to incidentally in previous chapters. Now they are to be studied. There are three on each side: the inferior cerebellar peduncle (#4025, #6172), the middle cerebellar peduncle (brachium pontis) (#8361, #6553), and the superior cerebellar peduncle (brachium conjunctivum) (#6554). The middle and inferior cerebellar peduncles contain most of the cerebellar afferents. The superior cerebellar peduncle contains the majority of the cerebellar efferent fibers. What attaches the cerebellum to the brain stem (#4629)?

II. Cerebellar Afferents

A. Afferents via the inferior cerebellar peduncle: Proprioceptive information from muscle spindles (#7606) in the trunk and lower limb travels to the nucleus dorsalis (Clarke's column, Clarke's nucleus) (fig 11b). This nucleus extends from T1 to L2. Axons from this nucleus form the ipsilateral dorsal spinocerebellar tract (fig 11b, #6525), which ascends in the lateral funiculus of the spinal cord to the medulla (#6530 #4369). The dorsal spinocerebellar fibers enter the cerebellum via the inferior cerebellar peduncle (#6172) and end as mossy fibers in the cerebellar cortex.

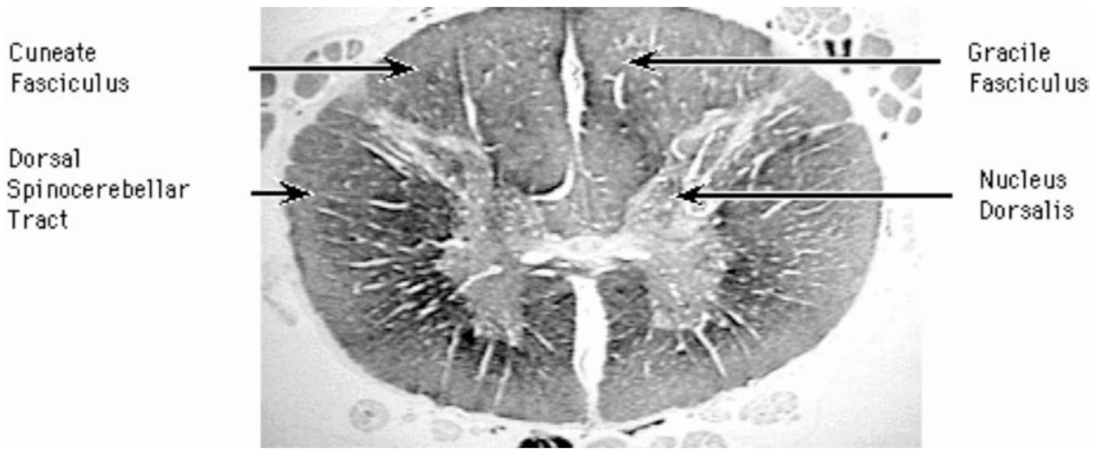

Figure 11B Thoracic Spinal Cord

[The lateral cuneate nucleus, also called the accessory or external cuneate nucleus (fig 11c), is rarely mentioned clinically or pathologically. It is similar to the nucleus dorsalis, and serves as a relay nucleus for proprioceptive information entering the spinal cord from the neck and upper limb. Axons of this nucleus, the cuneocerebellar fibers, join the dorsal spinocerebellar tract and enter the inferior cerebellar peduncle.]

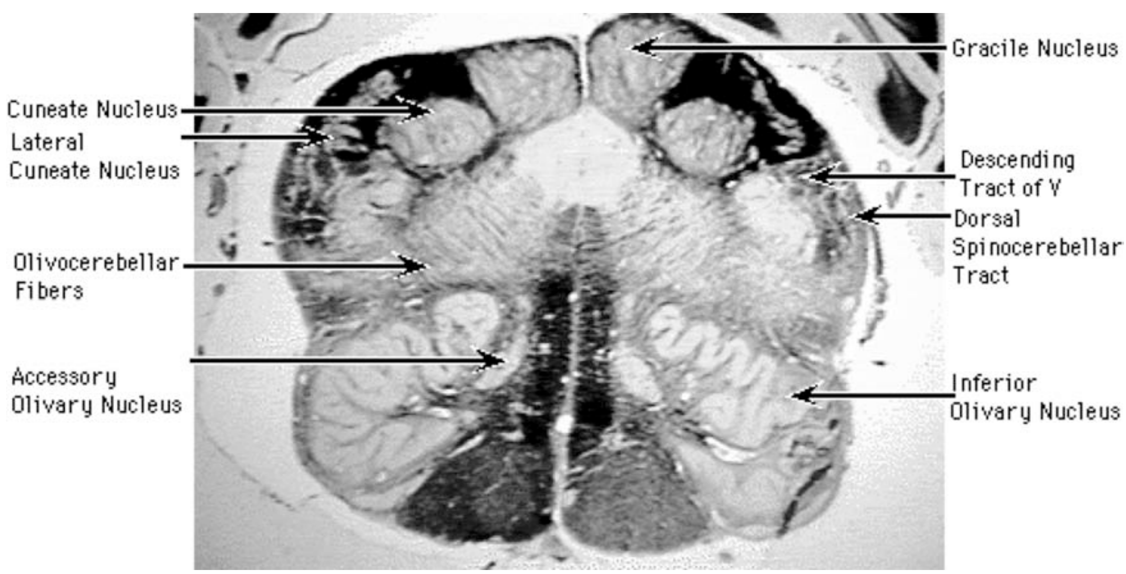

Figure 11C Caudal Medulla

It is now time to introduce the inferior olivary nucleus (#6541). The cells of the inferior olivary nucleus send their axons across the midline (#6542). These olivocerebellar axons (#6540, #7977) travel in the inferior cerebellar peduncle (#6317) to terminate as climbing fibers in the cerebellar cortex.

> [Other axons in the inferior cerebellar peduncle come from the vestibular nerve and nuclei, reticular formation and trigeminal nuclei.]

B. Afferents via the middle cerebellar peduncle: The middle cerebellar peduncle is by far the largest peduncle (#5599) and contains only afferents. The axons in this peduncle come from the pontine nuclei of the opposite side (#6545). What is the afferent supply of the pontine nuclei? What course do the afferent axons follow in reaching the pons? What is the vascular supply of the pons? Pontocerebellar (transverse pontine) axons terminate as mossy fiber endings.

The cerebellum receives sensory information of all modalities, not just proprioception. Indirect pathways bring auditory, visual, somatosensory, and cortical information to the cerebellum.

III. Cerebellar Internal Circuitry

A. Cerebellar cortex: The surface of the cerebellum is a sheet of gray matter that is folded quite regularly into folia (#4959). The structure of the cerebellar cortex is uniform throughout and it is difficult to distinguish – even histologically – one region from another. This is not true for the cerebral cortex.

Study fig 11e. Identify the molecular layer (#8321) and granular layer (#8323). Cell bodies of the Purkinje cells occur along the boundary between these layers (#8322). The complex dendrites (#4486) of the Purkinje cells radiate into the molecular layer. What is the orientation of these dendrites with respect to the granule cell axons (parallel fibers)?

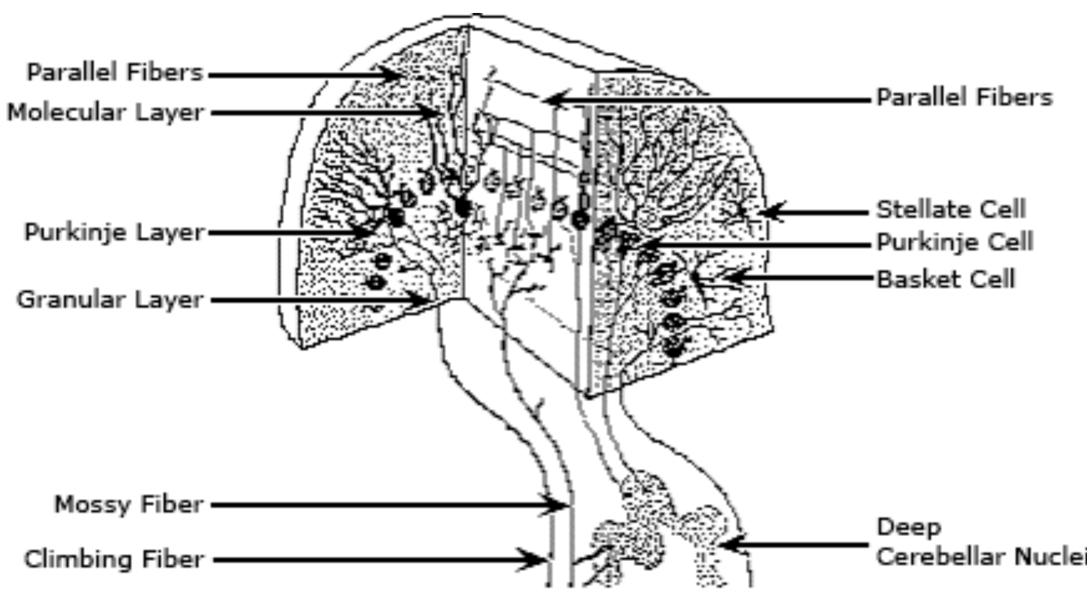

Figure 11E Cerebellar Cortex

B. Cerebellar Nuclei: The cerebellar nuclei are located deep in the white matter adjacent to the roof of the fourth ventricle (fig 11f) and receive axons from Purkinje cells as well as collaterals from all climbing fibers and some mossy fibers. The nuclei are the main source of cerebellar efferent fibers. The largest is the dentate nucleus (#6567). The Purkinje cells of the lateral part of the hemisphere project to the dentate nucleus. The medial part of the hemisphere projects to the emboliform (#6566) and globose (#7926) nuclei (together called the interposed nuclei).The fastigial nucleus (#6565) receives axons from Purkinje cells of the vermis.

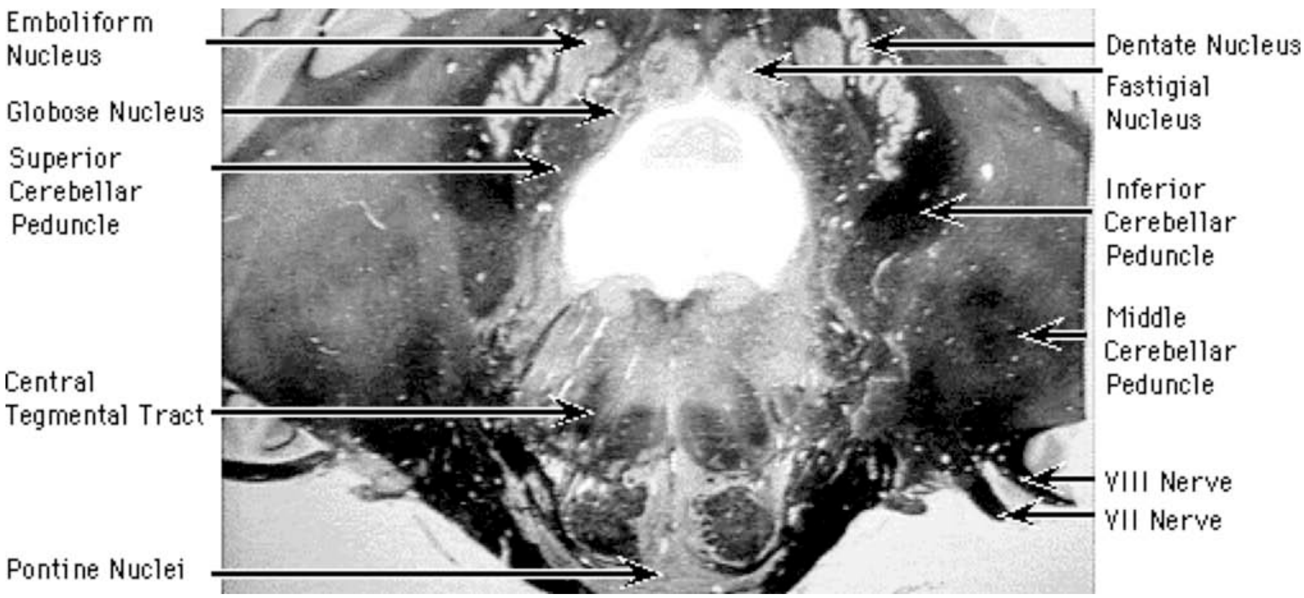

Figure 11F Pons and Deep Cerebellar Nuclei

IV. Cerebellar Efferents

A. Hemisphere efferents: The superior cerebellar peduncle (#15178) originates from the nuclei of the cerebellar hemisphere (#8438), and carries most of the cerebellar efferent fibers. It begins on the medial side of the dentate nucleus (#6575) and forms the lateral wall of the rostral part of the fourth ventricle (fig 11d, #6578). The superior cerebellar peduncles converge (#6544) to cross the midline in the decussation of the superior cerebellar peduncles (#6336) in the tegmentum of the midbrain (fig 11g) at the level of the inferior colliculus. (In Fig. 11g, the superior colliculus is seen rather than the inferior colliculus because the slice is oriented coronally.)

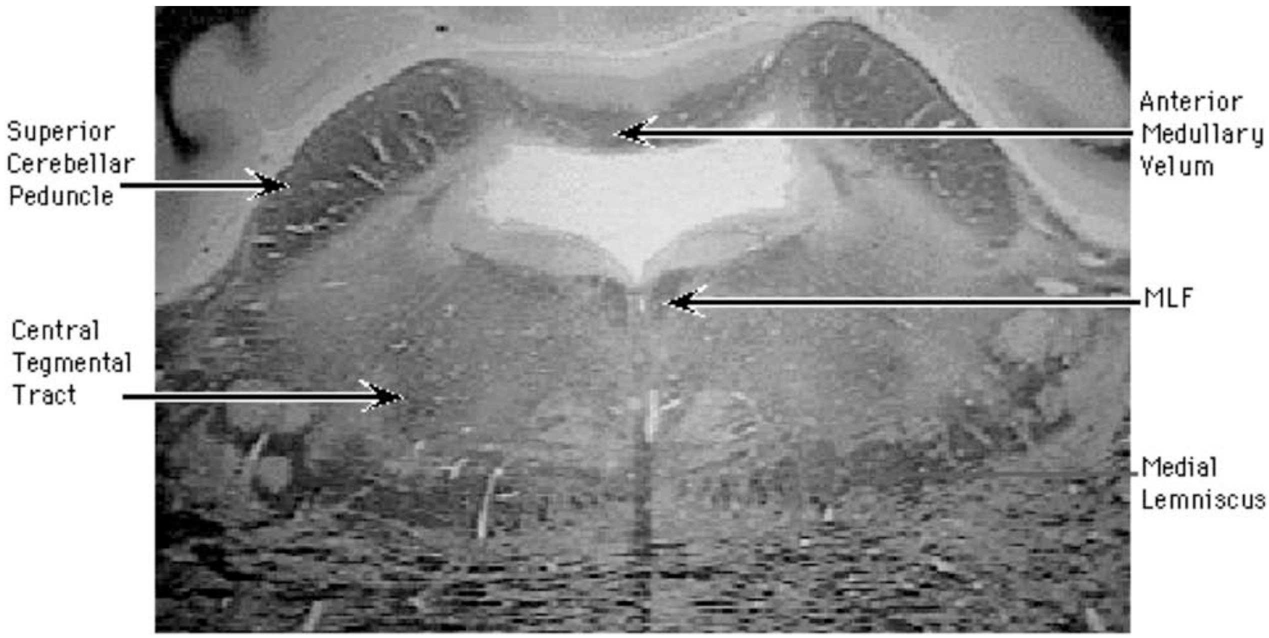

Figure 11D Rostral Pons, Tegmentum

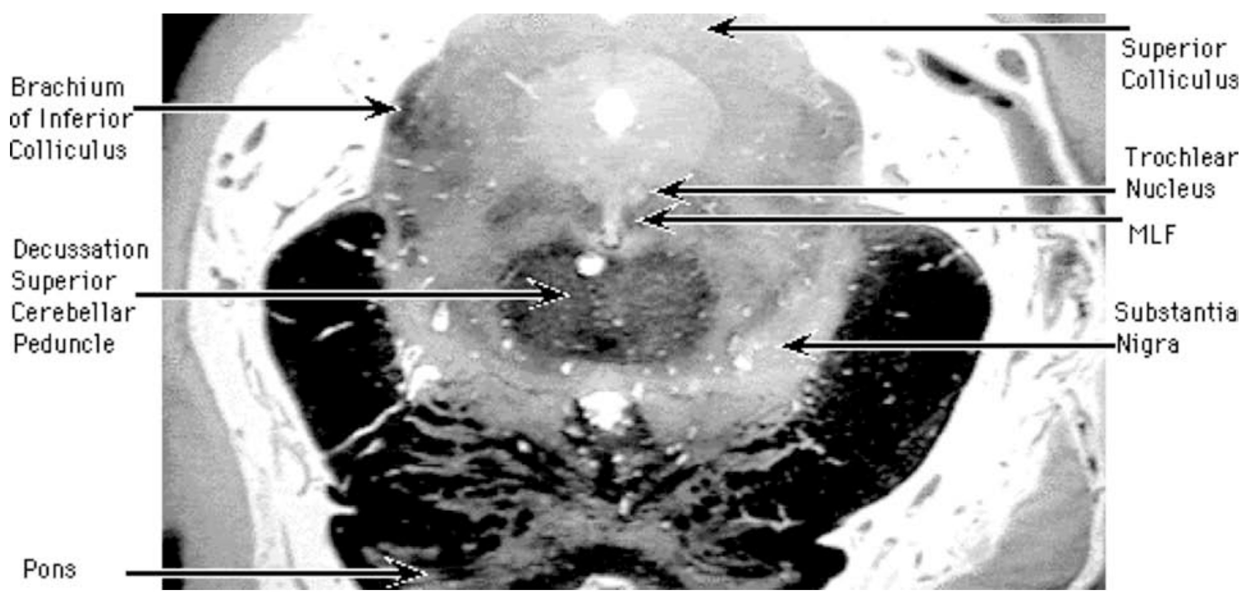

Figure 11G Mesencephalon

Axons of the superior cerebellar peduncle project to the red nucleus and the thalamus, but there is little clinical correlation for the fibers to the red nucleus. Axons of the cerebellothalamic tract (or dentatothalamic tract) pass through and around the red nucleus to the thalamus. They terminate in the posterior part of the ventral lateral nucleus (VLp) of the thalamus (#6592), also called the ventral intermediate nucleus (Vim) in humans. This thalamic nucleus (fig 11h) projects mainly to the primary motor cortex (#4321) and the premotor cortex (#4322) of the frontal lobe to **affect limb coordination**. What is the route of these thalamocortical fibers? A constellation of findings, sometimes called the cerebellar hemisphere syndrome, occurs with disease of the cerebellar hemisphere.

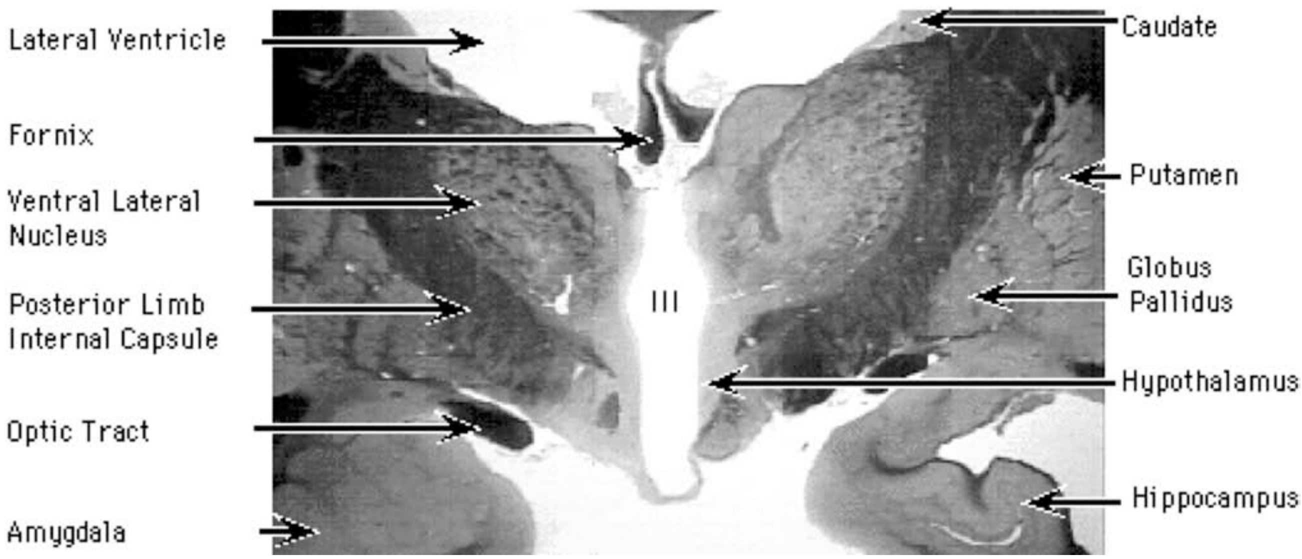

Figure 11H Thalamus

B. Vermis efferents: Other cerebellar efferents arise in the vermis and its fastigial nuclei and leave the cerebellum in the inferior cerebellar peduncle. They end in the vestibular nuclei and reticular formation, which give rise to vestibulospinal and reticulospinal tracts. These projections all **affect axial muscles.** Disease of the vermis is associated with 1) truncal ataxia: impaired equilibrium (balance) with unsteady stance and gait (though these also occur with hemisphere disease) and unsteadiness while sitting, 2) titubation, and 3) inaccurate (dysmetric) saccades.

C. Vestibulocerebellum (≈ flocculonodular lobe) efferents: Finally, other cerebellar efferents arise from the Purkinje cells in the vestibulocerebellum**,** which is almost equivalent to the flocculonodular lobe. These projections again leave the cerebellum in the inferior cerebellar peduncle. They end in ipsilateral vestibular nuclei that project via the medial longitudinal fasciculus **(**fig 11d**)** to the nuclei of cranial nerves III, IV and VI to **affect eye movements**. Vestibulocerebellar (flocculonodular lobe) disease causes many eye movement disorders, especially gaze-evoked nystagmus, impaired smooth pursuit (eyes following a moving object), and downbeat nystagmus.

Think about the functional differentiation of each region as deduced from its connections, particularly its efferents. From what has been studied, you should now know if the influence of the cerebellum on skeletal muscle is ipsilateral or contralateral. Is the right cerebral cortex "working" with the right or left cerebellar cortex? Do the clinical signs of cerebellar disease generally occur on the same side or opposite side of the lesion? Does isolated cerebellar disease cause loss of strength? Loss of sensation? A positive Romberg sign?

V. Blood Supply to the Cerebellum

The blood supply to the cerebellum comes from branches of the vertebral and basilar arteries. The three cerebellar arteries are the posterior inferior cerebellar artery (#8469), anterior inferior cerebellar artery (#8453), and the superior cerebellar artery (#8455). What is the relationship of the superior cerebellar artery to cranial nerve III?

As these arteries go around the circumference of the brain stem, they give off branches that vascularize discrete portions of the tegmentum. For example, branches of the posterior inferior cerebellar artery nourish the dorsolateral quadrant of the medulla. The constellation of findings resulting from a lesion here is called the lateral medullary syndrome. What sensory pathways will be interrupted if this artery is occluded as in (#2826)? Here the right side of the medulla is affected. On which side(s) will the sensory deficits occur? What other neurologic impairments will be found on examination of the patient? What area of the brain stem is vascularized by the anterior inferior cerebellar artery? By the superior cerebellar artery?

HyperBrain Chapter 11. The Cerebellum
Review of Terms

Stephen C. Voron, M.D. Revised 2010

I. CEREBELLAR ANATOMY

A. Anatomic divisions of the cerebellum

lobules

1. vermis and hemispheres
2. three lobes
   - anterior lobe
   - posterior lobe
   - flocculonodular lobe: nodulus, flocculi

B. Cerebellar peduncles

superior cerebellar peduncle (brachium conjunctivum)
middle cerebellar peduncle (brachium pontis)
inferior cerebellar peduncle

II. CEREBELLAR AFFERENTS

A. Afferents via the inferior cerebellar peduncle

1. DORSAL SPINOCEREBELLAR TRACT
   - nucleus dorsalis (Clarke's column, nucleus),
     - mossy fiber endings
2. OLIVOCEREBELLAR FIBERS
   - inferior olivary nucleus, climbing fibers

B. Afferents via the middle cerebellar peduncle

CORTICOPONTOCEREBELLAR PATHWAY
- cerebral cortex: corticopontine fibers
- → pontine nuclei: pontocerebellar (transverse pontine) fibers, mossy fiber endings

III. CEREBELLAR INTERNAL CIRCUITRY

A. Cerebellar cortex

folia
layers

1. molecular layer
2. Purkinje cell layer – Purkinje cells
3. granular layer – granule cells

B. Cerebellar nuclei

dentate, emboliform, globose, fastigial

IV. CEREBELLAR EFFERENTS

A. Hemisphere efferents: ipsilat limb coordination

superior cerebellar peduncle

1. PATHWAY
   - → Dentate, emboliform and globose nuclei
     - cerebellothalamic (dentatothalamic) tract
       - superior cerebellar peduncle (SCP)
       - decussation of the SCP
   - → thalamus
     - ventral lateral nucleus, posterior part (VLp) / ventral intermediate nucleus (Vim)
   - → premotor cortex and primary motor cortex
2. SIGNS: ataxia, intention tremor, hypotonia

B. Vermis efferents: axial muscles

inferior cerebellar peduncle

1. PATHWAY
   - → vestibular nuclei and reticular formation
   - → vestibulospinal and reticulospinal tracts
2. SIGNS:
   truncal ataxia, titubation, saccadic dysmetria

C. Vestibulocerebellum (≈ flocculonodular lobe) efferents: eye movements

inferior cerebellar peduncle.

1. PATHWAY
   - → vest nuclei → mlf → CN nuclei III, IV, VI
2. SIGNS: gaze-evoked nystagmus,
   impaired smooth pursuit
   downbeat nystagmus

V. BLOOD SUPPLY TO THE CEREBELLUM

vertebral artery
- posterior inferior cerebellar artery

basilar artery
- anterior inferior cerebellar artery
- superior cerebellar artery

12. The Basal Ganglia

Revised 2007

The objectives of this chapter are to:

1. Describe basal ganglia anatomy and blood supply.
2. Describe the pathways through which the basal ganglia affect motor function.

I. BASAL GANGLIA ANATOMY

A group of brain nuclei are known collectively as the basal ganglia (fig 12a). The basal ganglia that are studied in this chapter are the caudate nucleus (#4766), the putamen (#4752), the globus pallidus (#4753), the subthalamic nucleus (#4809), and the substantia nigra (#4810). The motor components of the basal ganglia make up the extrapyramidal motor system, a term that is sometimes still used clinically.

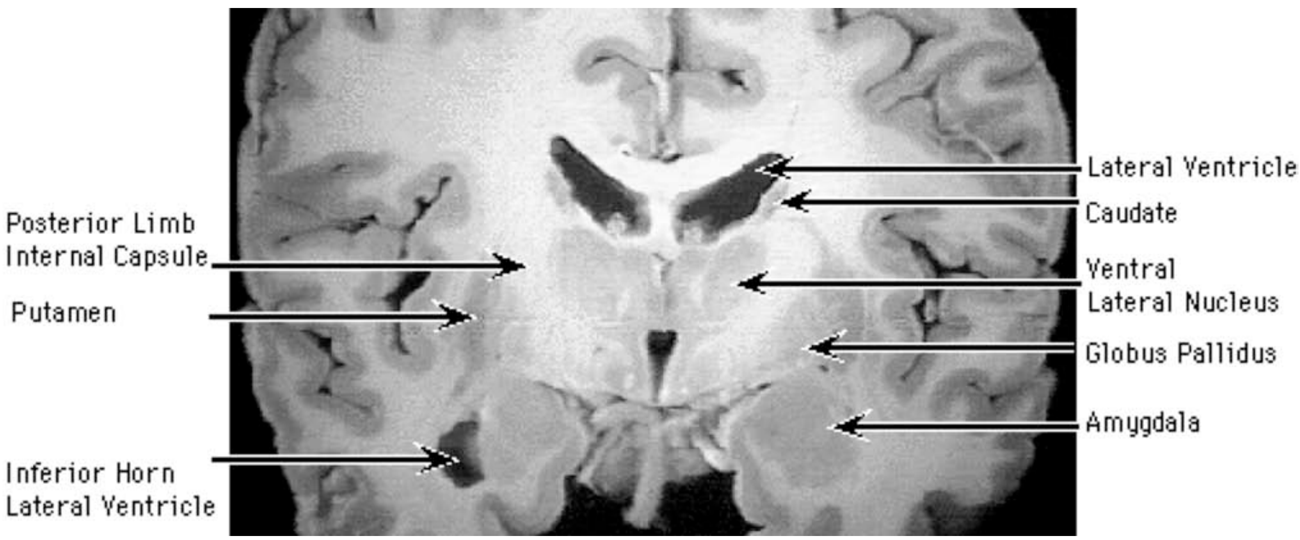

Figure 12A Coronal Section through the Thalamus

Diseases of the basal ganglia cause movement disorders. Movement disorders are diseases characterized by hypokinesia (inhibition of intentional movement) and/or hyperkinesia (abnormal involuntary movements such as tremor and writhing movements). Basal ganglia diseases include such well-known diseases as Parkinson's disease (hypokinetic) (video) and Huntington's disease (hyperkinetic) (video). However, not all movement disorders are due to dysfunction of the basal ganglia.

An axial (horizontal) section offers a panoramic view of the general shapes and relations of the caudate nucleus, putamen, and globus pallidus with each other and with the lateral ventricle and internal capsule (fig 12b). A coronal view through the frontal horn shows the relationships of the head of the caudate (#6475) and the anterior part of the putamen (#6474) to the anterior limb of the internal capsule and the frontal horn. Note that the head of the caudate nucleus bulges into the frontal horn of the lateral ventricle (#6475).

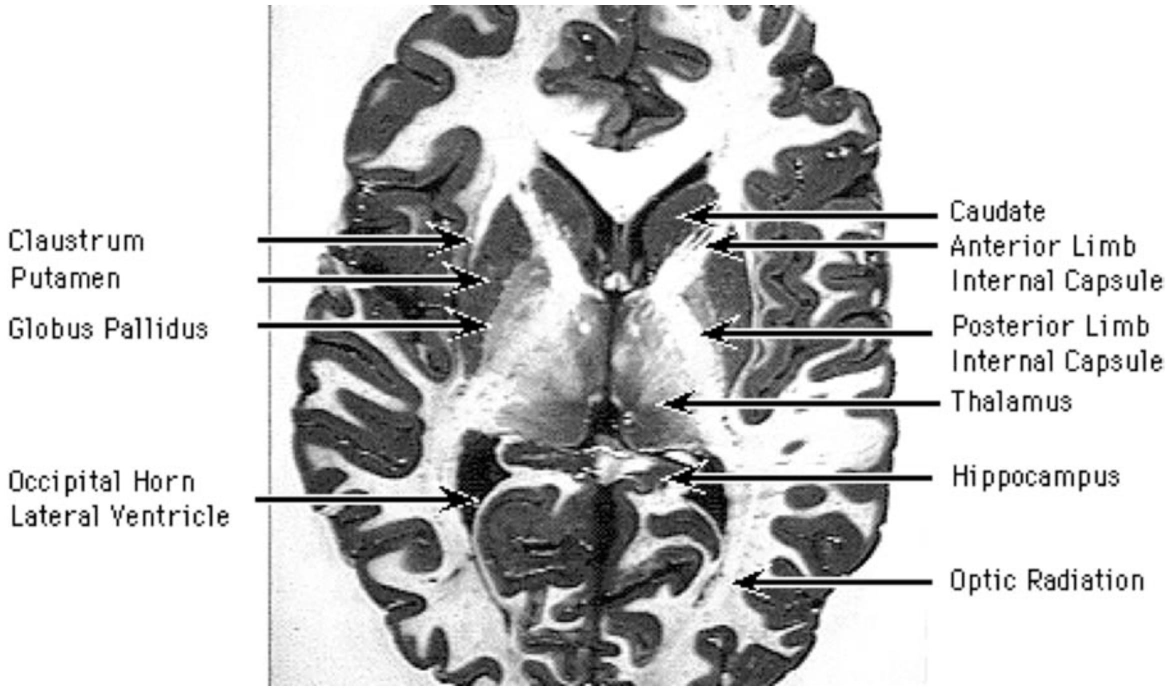

Figure 12B Axial (Horizontal) Section Through the Thalamus, Courtesy of Dr. Diane E. Smith

The putamen and caudate nucleus are developmentally a single nuclear mass that is divided by the internal capsule, but with gray matter bridges still connecting them (#6428, fig 12d). Because of this appearance, the putamen and caudate nucleus together are known as the dorsal striatum ("striped"). In Huntington's disease, atrophy of the striatum causes flattening of the caudate nucleus where it bulges into the lateral ventricle (#5686).

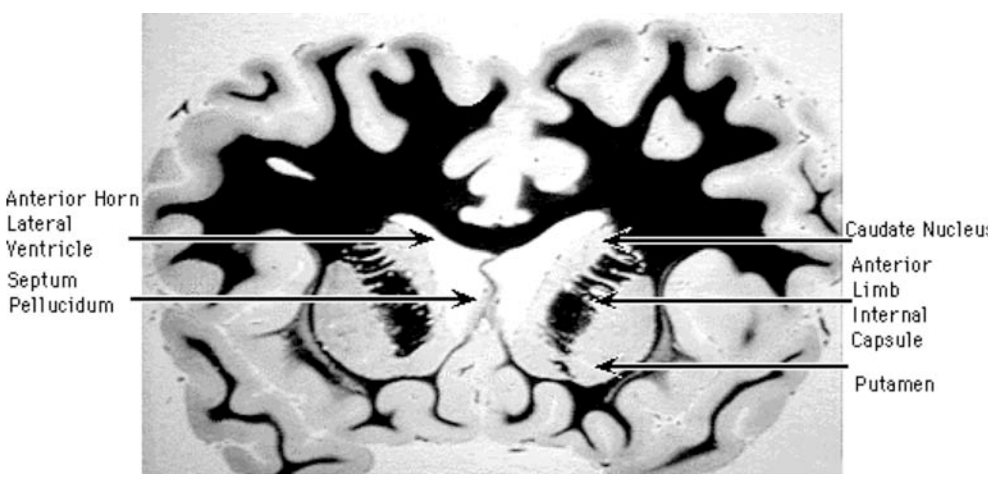

Figure 12D Coronal Section, Basal Ganglia

The putamen and globus pallidus together are known as the lentiform nucleus (lenticular nucleus) (#6297). This name was given to them because of their lens shape as seen in axial (horizontal) sections.

To review previously studied figures with basal ganglia structures, go to fig 3g, fig 3h, fig 3k, and fig 7i.

II. BASAL GANGLIA PATHWAYS

The principal source of striatal afferents is the cerebral cortex. The sensorimotor cortex (#4323) projects primarily to the putamen. What is the course of these ipsilateral corticostriate fibers? Other significant striatal afferents come from the substantia nigra, pars compacta, which is the pigmented part of the substantia nigra (#5256). Degeneration of these of these dopamine-containing nigrostriatal axons is linked to the genesis of Parkinson's disease (#5523), in which degeneration of the cell bodies leads to loss of pigmentation of the substantia nigra (#41958).

The putamen and the caudate nucleus send most of their axons, respectively, to the globus pallidus (dorsal pallidum) and the substantia nigra, pars reticulata (the non-pigmented part of the substantia nigra). The globus pallidus has an internal segment and an external segment, fig 12e, and focuses its activity on two areas: (A) It projects to the thalamus (#6594), and (B) It has reciprocal connections with the subthalamic nucleus (#6496).

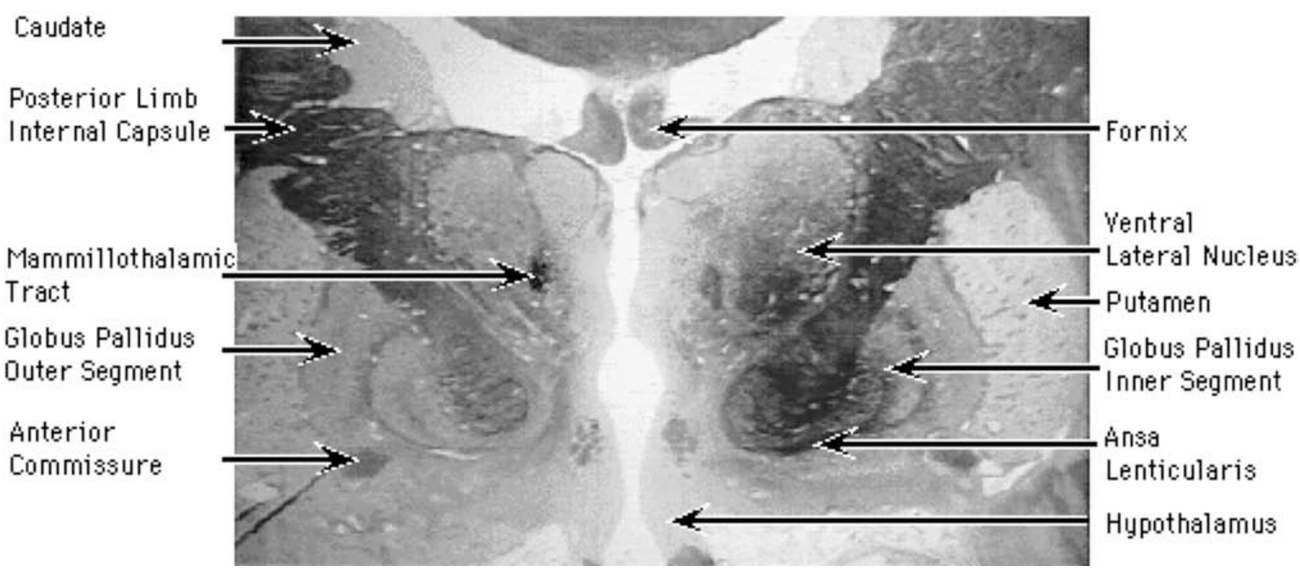

Figure 12E Thalamus, Courtesy of Dr. Diane E. Smith

A. Pallidal projections to the thalamus

To reach the thalamus, the pallidothalamic fibers have to get from one side of the internal capsule to the other.

> [They either go directly across the capsule or swing under it. The axons that penetrate the capsule form the fasciculus lenticularis (#8310). The axons that go around it are known as the ansa lenticularis (#4639, fig 12e). These axons are named "lenticularis" because the pallidum and putamen together are known as the lentiform nucleus as noted above.]

The chief destination of the pallidothalamic fibers that influence movement is the anterior part of the ventral lateral nucleus (VLa) of the thalamus (#6491), also called the ventral oral nucleus (VO) in humans. The pallidal efferents end in a different (anterior) part of VL than the fibers from the cerebellum.

VLa sends axons through the internal capsule primarily to the supplementary motor area (fig 12f), which is on the medial surface of the frontal lobe rostral (anterior) to the paracentral lobule. The supplementary motor area is interconnected with Brodmann's area 4 (the precentral gyrus, (#4321) and the adjacent anterior part of the paracentral lobule). In this way, the basal ganglia affect the activity of the corticospinal tract (#42050). Surgical lesions of the thalamus are sometimes made to ameliorate movement disorders. If the movement disorder is on the right side of the body, which side of the thalamus would be the surgical target?

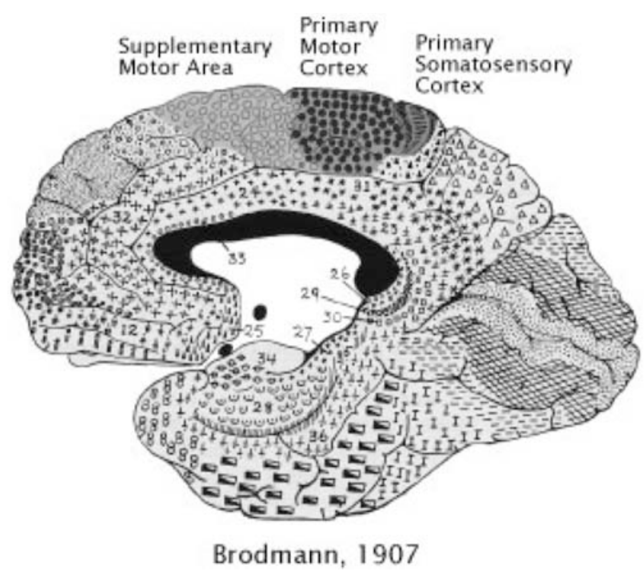

Figure 12F Midsagittal Section

B. Pallidal connections with the subthalamic nucleus

The globus pallidus (#8395) and subthalamic nucleus (#8405) are reciprocally connected. Lesions of the subthalamic nucleus, usually due to vascular disease, produce rapid, ballistic movements of the opposite side of the body (hemiballismus). Why is the opposite side affected? What is meant by the term "disinhibition"?

III. BLOOD SUPPLY TO THE BASAL GANGLIA

The blood supply to the basal ganglia comes primarily from the middle cerebral artery (#4796), in particular, the lenticulostriate branches, seen on a postmortem frontal angiogram in #9811, and as small holes in a gross horizontal specimen in #5631. These narrow lenticulostriate vessels are a frequent site of cerebral hemorrhage in people with uncontrolled hypertension. Such events can be fatal (#10865). Small infarcts produced by occlusion of these small vessels are called lacunar infarcts (lacunes) and may be asymptomatic, discovered incidentally at autopsy (#11219) or on CT or MRI. However, lacunes in the basal ganglia may cause movement disorders.

HyperBrain Chapter 12. The Basal Ganglia
Review of Terms

Edited by Stephen C. Voron, M.D. Revised 2007

I. BASAL GANGLIA ANATOMY

Major components of the basal ganglia

- dorsal striatum = caudate nucleus + putamen – **Huntington's disease**
- dorsal pallidum = globus pallidus: internal and external segments
- subthalamic nucleus – **hemiballismus**
- substantia nigra:
  - pars compacta – **Parkinson's disease**
  - pars reticulata

- lentiform (lenticular) nucleus = putamen + globus pallidus

Movement disorders

- basal ganglia diseases
  - hypokinesias – **Parkinson's disease**
  - hyperkinesias – disinhibition
    - **Huntington's disease, hemiballismus**

II. BASAL GANGLIA PATHWAYS

Striatal afferents

- sensorimotor cortex: corticostriatal fibers
- substantia nigra, pars compacta: nigrostriatal fibers

Striatum

Globus pallidus

- projections to the thalamus: pallidothalamic fibers
- reciprocal connections with subthalamic nucleus

Substantia nigra, pars reticulata

Thalamus: anterior part of the ventral lateral nucleus (VLa) / ventral oral nucleus (VO)

Supplementary motor area (SMA)

III. BLOOD SUPPLY TO THE BASAL GANGLIA

Middle cerebral artery: lenticulostriate branches

13. The Hypothalamus

Revised 2008

The objectives of this chapter are to:

1. Describe and identify the anatomic features of the hypothalamus
2. Describe the efferent connections of the hypothalamus with the autonomic nervous system.
3. Compare neuroendocrine secretion and control in the anterior and posterior pituitary.

The hypothalamus, occupying just 4 grams of the adult human brain, regulates many functional systems that support life, including energy metabolism, food intake and body weight; fluid and electrolyte balance, thirst, and water intake; body temperature; immune response; circadian (24-hour) rhythms and sleep-wake cycles; and reproduction. Most of this regulation is achieved via hypothalamic control of the autonomic and endocrine systems, to be discussed below.

As described earlier, in chapters 1 and 2, the only parts of the hypothalamus that appear on the surface of the brain are the tuber cinereum and the paired mammillary bodies (#4737). This ventral area is outlined by the optic chiasm, optic tract, and interpeduncular fossa.

As seen in midsagittal sections, (fig 13a) the hypothalamic sulcus separates the hypothalamus from the thalamus. The rostral boundary of the hypothalamus is indicated by a line drawn between the anterior commissure (#4835) and the optic chiasm. Actually, this line corresponds to a thin wall of neural tissue called the lamina terminalis (#4525), which is the anterior wall of the third ventricle. The caudal boundary of the hypothalamus is approximated by a line extending from the posterior margin of the mammillary bodies to the posterior commissure.

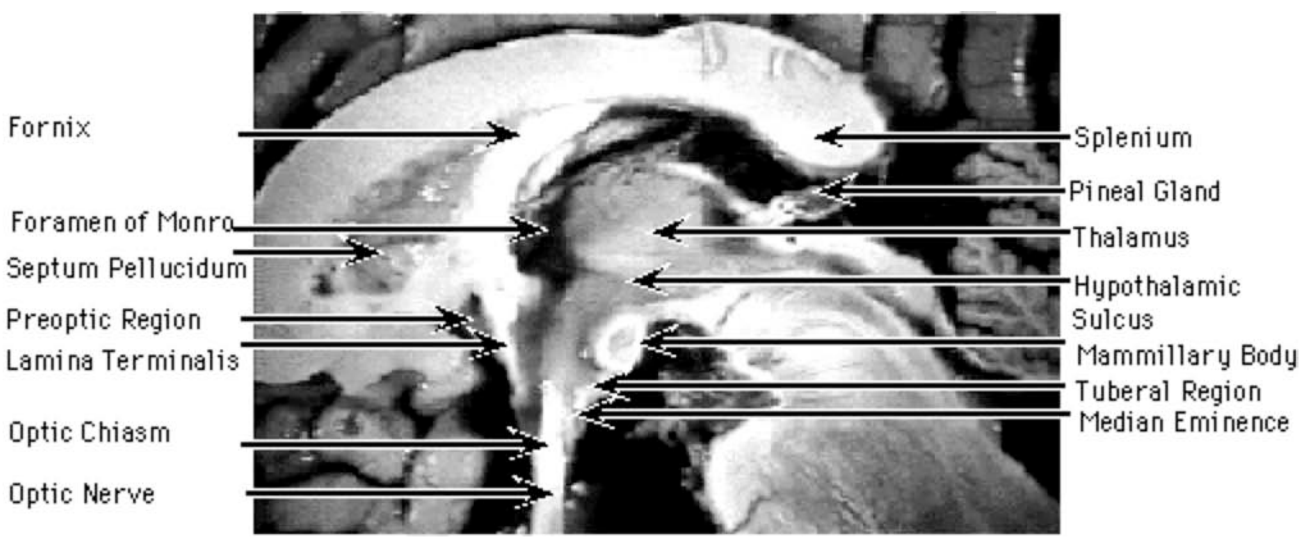

Figure 13A Midsagittal Section of Hypothalamus

On coronal sections (fig 13b), the fornix divides the hypothalamus into medial and lateral zones. The medial forebrain bundle (#11857) runs longitudinally through the lateral zone. This complex fiber group is a bidirectional pathway that connects the forebrain, hypothalamus, and brain stem. Transverse sections through the caudal hypothalamus show the mammillary bodies (#11860).

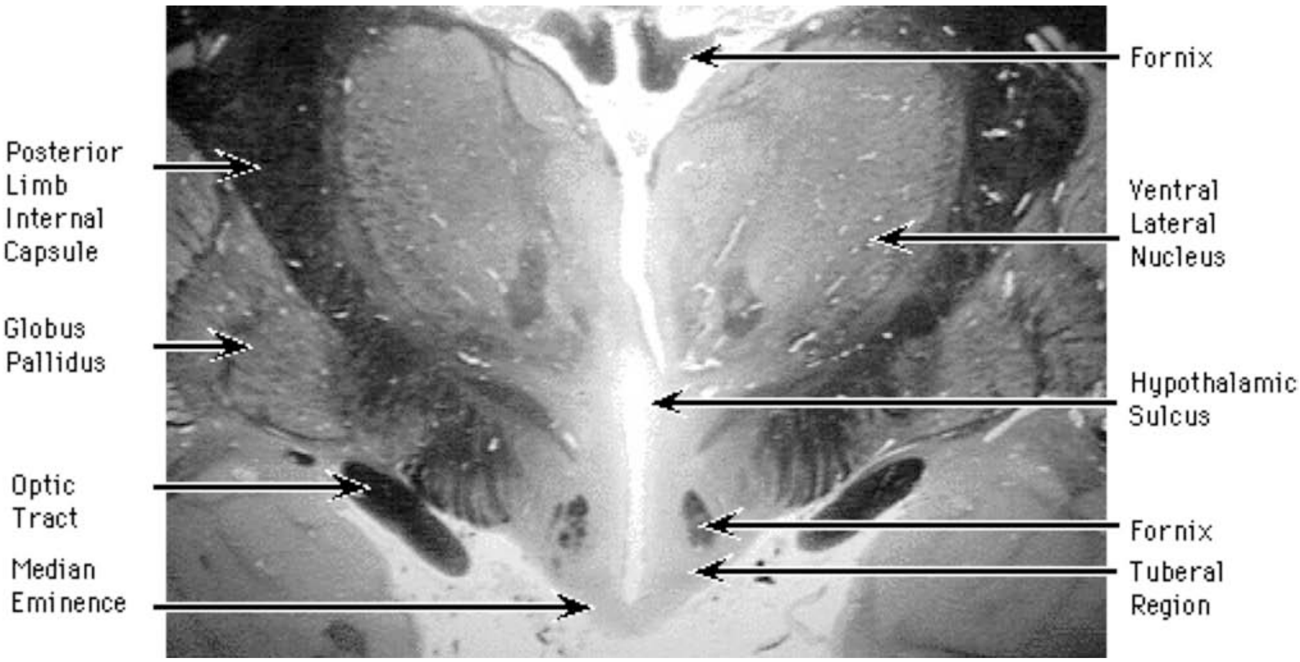

Figure 13B Coronal Section, Diencephalon

Most of the functions of the hypothalamus are achieved via autonomic regulation and endocrine regulation.

I. Autonomic Regulation

The hypothalamus receives information from visceral sensory systems, especially via the vagus nerve and solitary nucleus.

Attention will be directed to how the hypothalamus, through its connections with preganglionic neurons, affects the autonomic nervous system. The paraventricular nucleus and adjacent lateral hypothalamus project to autonomic preganglionic neurons in the brain stem and spinal cord. This pathway begins in the medial forebrain bundle and continues into the lateral brain stem tegmentum (#6609). The axons to spinal preganglionic neurons form the hypothalamospinal tract, a central autonomic pathway. It descends through the cord in the dorsal part of the lateral funiculus.

Recall that the preganglionic cell bodies are located in specific cell groups in the CNS and that postganglionic cell bodies are located in autonomic ganglia in the PNS. The preganglionic cell bodies of the parasympathetic (craniosacral) division are in the Edinger-Westphal nucleus, superior salivatory nucleus, inferior salivatory nucleus, the dorsal motor nucleus of X, and in the intermediolateral cell column of sacral segments S-2, 3, and 4. Where are each of these nuclei located? Engrave on your heart that cranial nerves

III, VII, IX, and X (#4184) contain preganglionic parasympathetic axons. Where are the preganglionic neurons of the sympathetic division located (fig 13d)?

Figure 13D Thoracic Spinal Cord

Lesions affecting the hypothalamospinal tract in the brain stem or cervical cord cause Horner's syndrome. What is this syndrome and why is it caused by interruption of these fibers? One classical location for such a lesion is the dorsolateral aspect of the rostral medulla. Name the resultant syndrome. What other tracts and nuclei are affected in this syndrome, and what signs and symptoms occur?

II. Endocrine Regulation

A. The Hypothalamus and Anterior Pituitary

The hypothalamus controls the release of anterior pituitary hormones. Small neurons in the arcuate nucleus (in the tuber cinereum), periventricular zone and paraventricular nucleus produce releasing hormones and release-inhibiting hormones, e.g., growth hormone-releasing hormone and somatostatin, which inhibits release of growth hormone. These hormones are transported from the cell bodies down the axons in the short tuberoinfundibular tract into the median eminence (#11861) in the infundibulum ("funnel") at the junction of the tuber cinereum with the pituitary stalk.

The tuberoinfundibular tract axons end on the fenestrated capillaries in the median eminence (fig 13e). The hypophysial portal system connects the fenestrated capillaries of the median eminence with the fenestrated capillaries of the anterior pituitary (#9904 a, #6618). Therefore, releasing and release-inhibiting hormones discharged from axon terminals in the median eminence flow through the hypophysial portal system into the anterior pituitary. They stimulate or inhibit the release of the corresponding anterior pituitary hormones. The blood supply to this region can be seen in fig 13f.

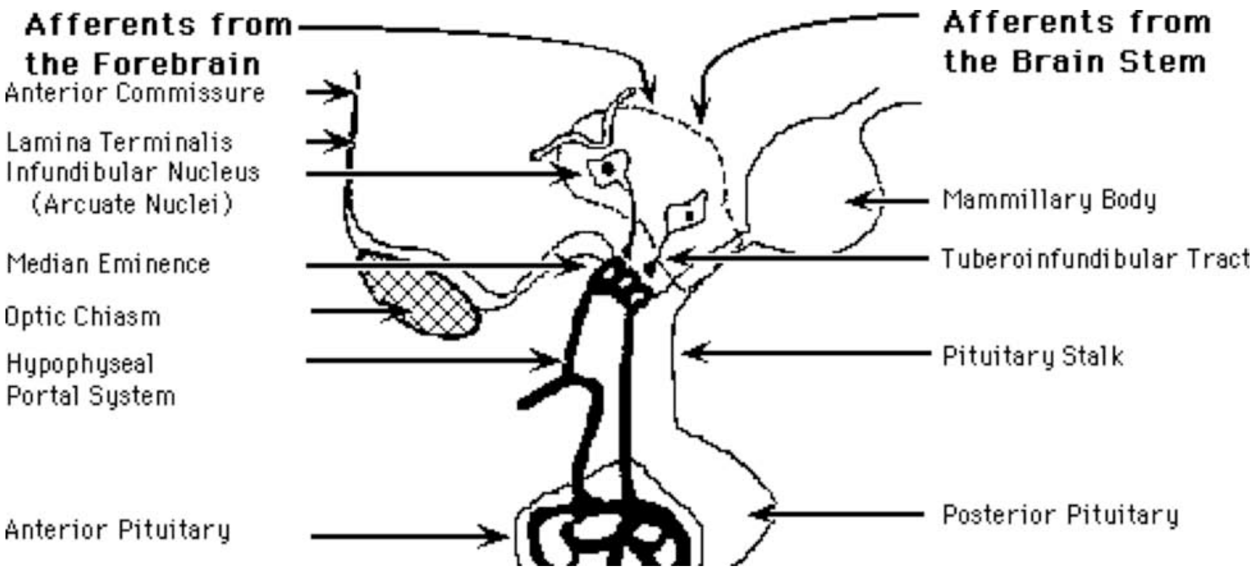

Figure 13E Hypothalamic-Anterior Pituitary Relationship

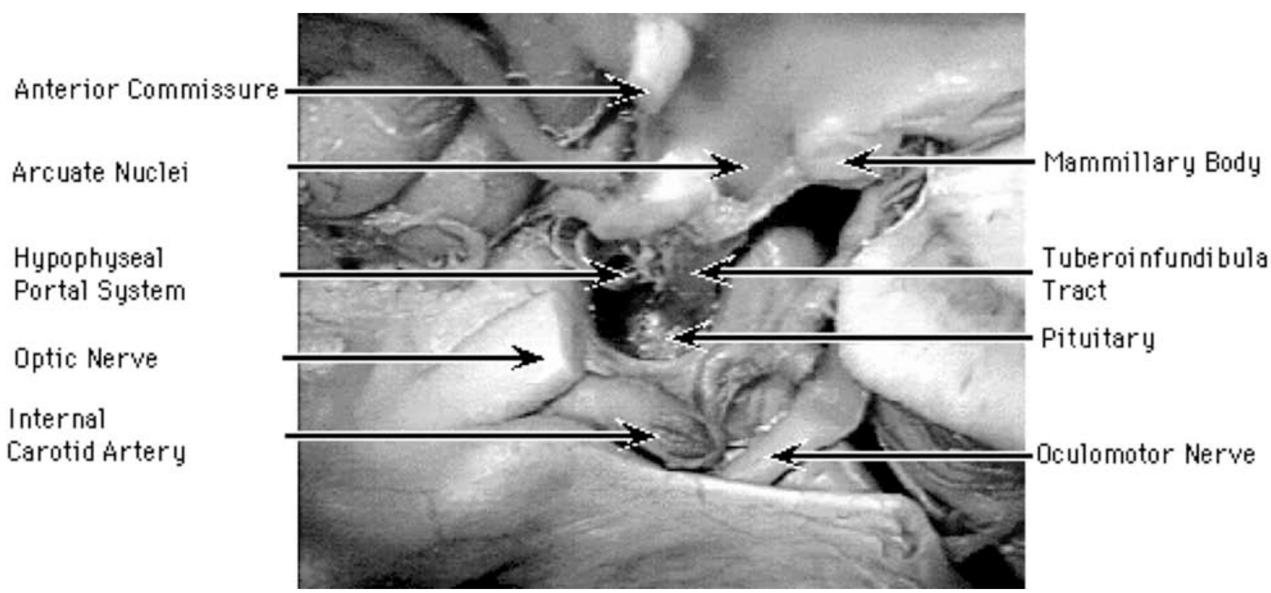

Figure 13F Blood Supply For Anterior Pituitary
Courtesy of Dr. Robert Chase, Curator of the David Bassett Collection

B. The Hypothalamus and Posterior Pituitary.

Fig 13g shows the supraoptic nucleus (#11863) and the paraventricular nucleus (#11918) in the anterior hypothalamus. They stand out because their cell bodies are relatively large and deeply stained (#41909, as seen in the rat). The supraoptic nuclei are named for their location above the optic tract. The paraventricular nuclei are also named for their location, which is near the wall of the third ventricle. These neurons manufacture vasopressin (antidiuretic hormone, ADH) and oxytocin. The hormones are transported down the axons of the hypothalamo-neurohypophysial tract to the posterior pituitary (#9904 b, #5770) where the axons end on fenestrated capillaries (Fig 13h). Vasopressin and oxytocin are stored in the axon terminals and, in response to nerve impulses are released and enter the capillaries and, thus, the systemic circulation.

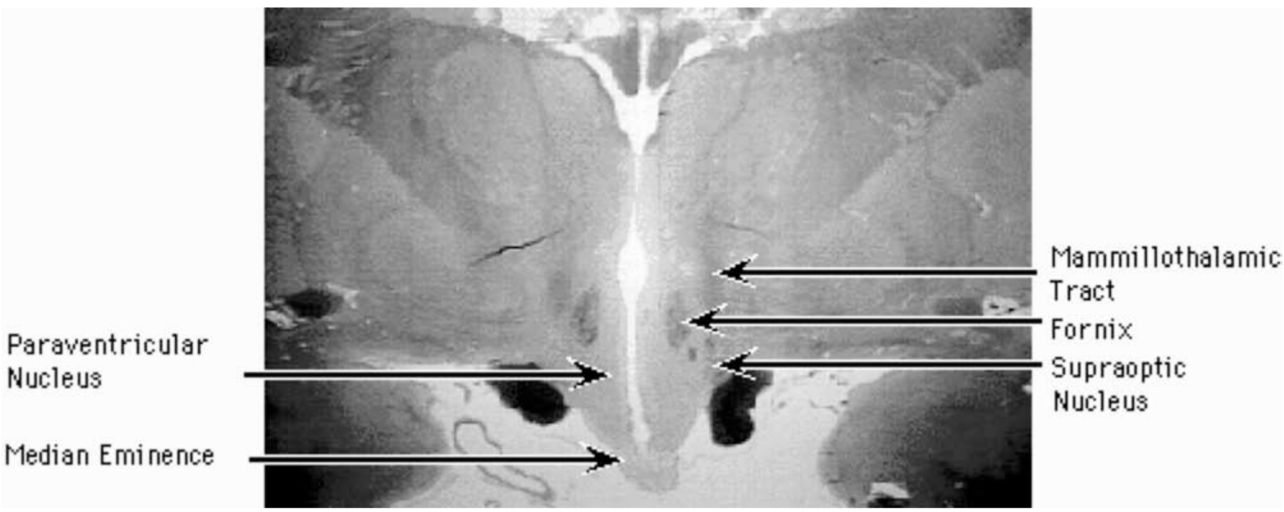

Figure 13G Thalamus And Hypothalamus

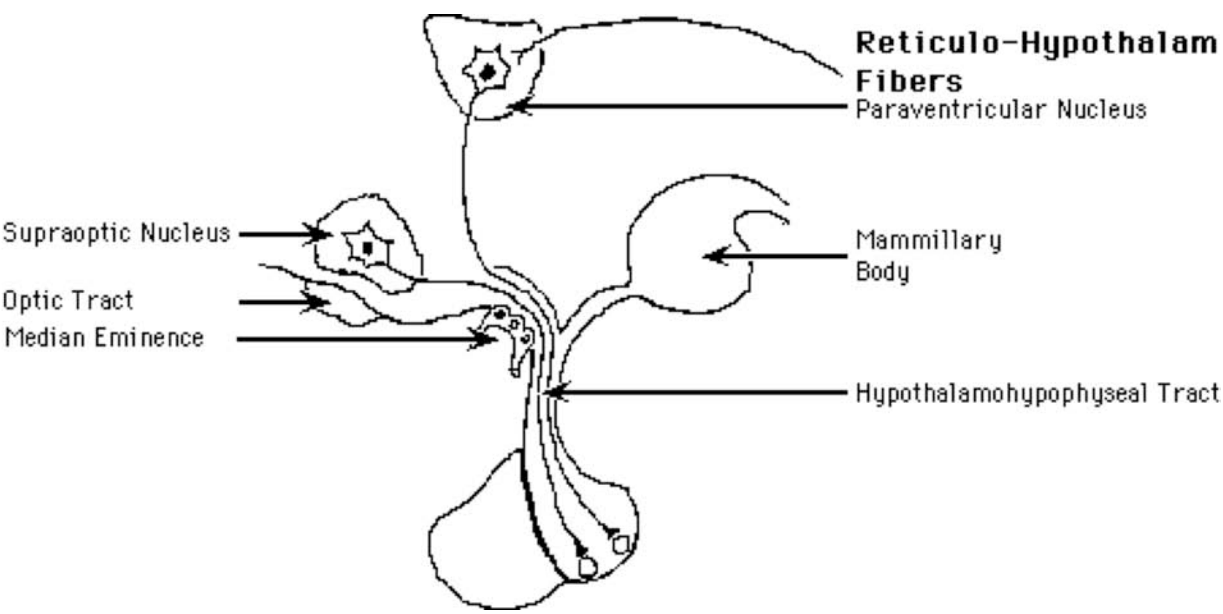

Figure 13H Hypothalamic-Posterior Pituitary Relationship

The supraoptic and paraventricular nuclei receive afferents directly and indirectly from several areas of the CNS that influence the neurosecretion of vasopressin and oxytocin. For example, near the supraoptic nuclei are neurons that act as osmoreceptors and detect change in the osmolality of the blood. Hyperosmolality leads to release of vasopressin, resulting in increased water retention in the kidney. Low vasopressin secretion results in increased output of dilute urine (polyuria), severe thirst, and increased drinking (polydipsia). This condition is called diabetes insipidus.

Stimulation of mechanoreceptors in the breast of a lactating mother reflexly causes the release of oxytocin, which causes contraction of the myoepithelial cells in the breast resulting in milk ejection. How does information from the mechanoreceptors in the nipple reach the supraoptic and paraventricular nuclei (#11913)?

HyperBrain Chapter 13: The Hypothalamus
Review of Terms

Edited by Stephen C. Voron, M.D. 8/4/08

HYPOTHALAMIC ANATOMY

Ventral surface of brain

- tuber cinereum
- mammillary bodies

Midsagittal section

- hypothalamic sulcus
- anterior commissure
- optic chiasm
- lamina terminalis
- mammillary bodies
- posterior commissure

Coronal sections

- fornix
  - medial & lateral zones of the hypothalamus
- medial forebrain bundle
- mammillary bodies

I. AUTONOMIC REGULATION

- paraventricular nucleus & adjacent lateral hypothalamus
- medial forebrain bundle, hypothalamospinal tract
- autonomic preganglionic neurons in brain stem & cord
  - parasympathetic (craniosacral) division
    - Edinger-Westphal nucleus
    - superior salivatory nucleus
    - inferior salivatory nucleus
    - dorsal motor nucleus of X
    - intermediolateral cell column of S-2, 3, 4
  - sympathetic division
- Horner's syndrome

II. ENDOCRINE REGULATION

A. The Hypothalamus and Anterior Pituitary

- arcuate nucleus, periventricular zone, paraventricular nucleus
- releasing hormones and release-inhibiting hormones
  - e.g., growth hormone-releasing hormone and somatostatin
- tuberoinfundibular tract
- median eminence in infundibulum ("funnel")
- pituitary stalk
- hypophysial portal system
  - fenestrated capillaries in the median eminence
  - fenestrated capillaries of the anterior pituitary
- anterior pituitary hormones

B. The Hypothalamus and Posterior Pituitary

- supraoptic nucleus and paraventricular nucleus
- vasopressin (antidiuretic hormone, ADH) and oxytocin
- hypothalamo-neurohypophysial tract
- fenestrated capillaries of the posterior pituitary

- osmoreceptors
- diabetes insipidus: polyuria, severe thirst, polydipsia

- myoepithelial cells in the breast
- milk ejection

14. Olfaction and the Limbic System

Revised 2007

The objectives of this chapter are to:

1. Describe the structure of the olfactory system.
2. Describe the organization of the limbic system and the input and output connections of the hippocampus, amygdala and septal nuclei.

I. Olfaction

Olfaction is not currently considered to be part of the limbic system but is discussed here for convenience.

Olfactory receptors and cranial nerve I: The olfactory receptors are neurons within the olfactory epithelium (#15100) located in the upper nasal cavity. Axons leave the olfactory receptors and synapse in the olfactory bulb. These axons are called the olfactory fila (#11847), which collectively make up cranial nerve I (olfactory nerve). They enter the anterior cranial fossa through the cribriform plate (#4477) of the ethmoid bone (#5186). The fila that make up the olfactory nerve are torn from their insertions into the olfactory bulb when the brain is removed from the skull.

Olfactory bulb and tract: Neurons in the olfactory bulb (#4965) called mitral cells are secondary sensory neurons of the olfactory system. Their axons leave the olfactory bulb and enter the olfactory tract (#4963). The **olfactory tract** is not a peripheral nerve. It is part of the central nervous system. The olfactory bulb and tract are parts of which major brain division? Anosmia (loss of smell) may result from traumatic shearing of the olfactory fila from the bulb, or from traumatic contusion, tumor or other lesion affecting the olfactory bulbs or tracts.

Lateral olfactory stria and olfactory cortex: Some fibers of the olfactory tract (fig 14a) turn laterally at the junction between the frontal cortex and anterior perforated substance to form the lateral olfactory stria (fig 14a, #6616), which projects to olfactory cortex. All gray matter areas that receive output from the olfactory bulb are called olfactory cortex, which is mainly on or near the dorsal surface of the uncus. The uncus (#6079)) is the rostral tip of the parahippocampal gyrus and the most medial part of the temporal lobe. Deep to the uncal cortex is the **amygdala** (#4860). In humans, the main areas of olfactory cortex are

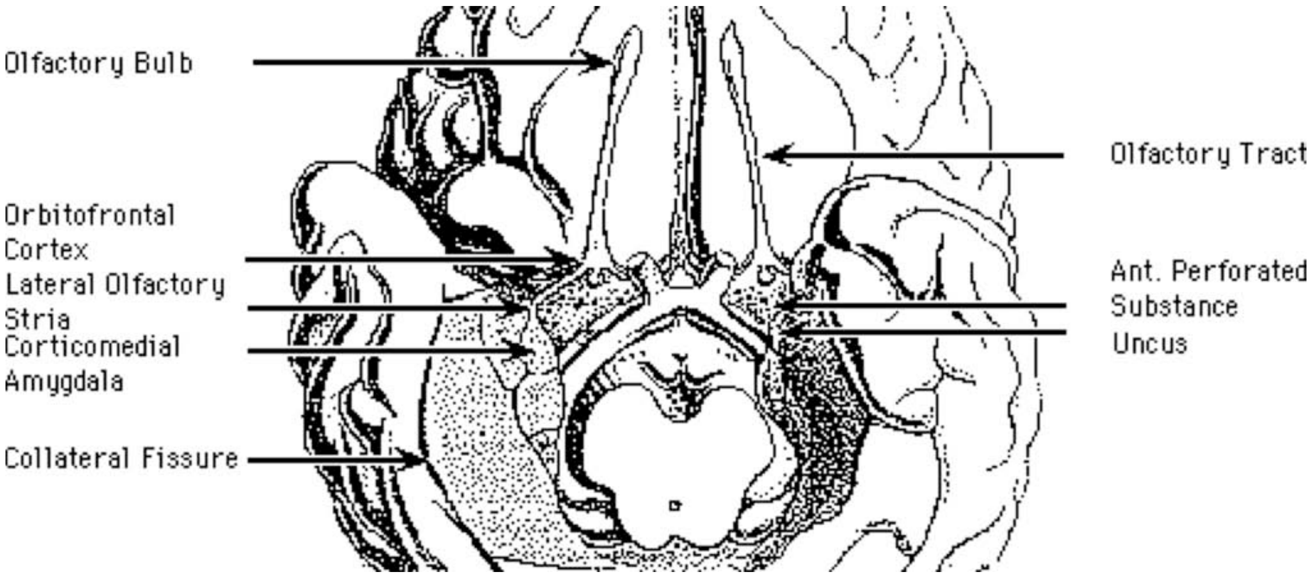

Figure 14A Orbital Surface of Frontal Lobe, (Modified from William and Warwick)

* **Piriform cortex:** The most posterior part of the orbitofrontal cortex (fig 14a), lateral to the lateral olfactory stria, and extending to the adjacent sulcus dorsal to the uncus (#6624).

* **Cortical Amygdala:** The dorsal surface of the uncus. This is the superficial ("cortical") part of the amygdala (#4860).

Both of these cortical areas are referred to as olfactory cortex (#4404).

Hypothalamus: Olfactory cortex projects to the hypothalamus. The hypothalamus (#6602) is thought to use olfactory information to affect feeding, reproductive activity, and autonomic reflexes triggered by olfactory signals ("the smell of fear"). How, then, do odors affect the output of the salivatory nuclei? Through what pathways can foul odors produce vomiting? Or, better, how can alluring odors affect autonomic neurons in the spinal cord involved in sexual function?

Orbital prefrontal cortex: Olfactory cortex and gustatory (taste) cortex project to orbital prefrontal cortex (the inferior surface of the frontal lobe), where information from both sensory modalities can be combined for the sensation of flavor.

II. The Limbic System

The limbic system consists of the limbic lobe and other cortical areas and nuclei that have connections with the limbic lobe. This group of structures is associated with learning, memory, emotion and motivation.

A. The Limbic Lobe

The limbic lobe (from *limbus* "border") is the cerebral cortex that forms the inferior medial border of the cerebral hemisphere. Its main components are the cingulate gyrus, the parahippocampal gyrus, and the hippocampal formation (hippocampus).

1. The cingulate gyrus: The cortex adjacent to the corpus callosum is the cingulate gyrus (#4274, #4749). Deep to this cortex is a bundle of axons called the cingulum (#4898). The cingulate gyrus and cingulum curve around behind the splenium of the corpus callosum into the parahippocampal gyrus.

2. The parahippocampal gyrus: The parahippocampal gyrus is the most medial gyrus on the ventral surface of the temporal lobe (fig 14d). Its anterior half consists of a transitional cortex called entorhinal cortex (#4519), which is one of the four components of the hippocampal formation (hippocampus). Thus, the entorhinal cortex is part of both the parahippocampal gyrus and the hippocampal formation.

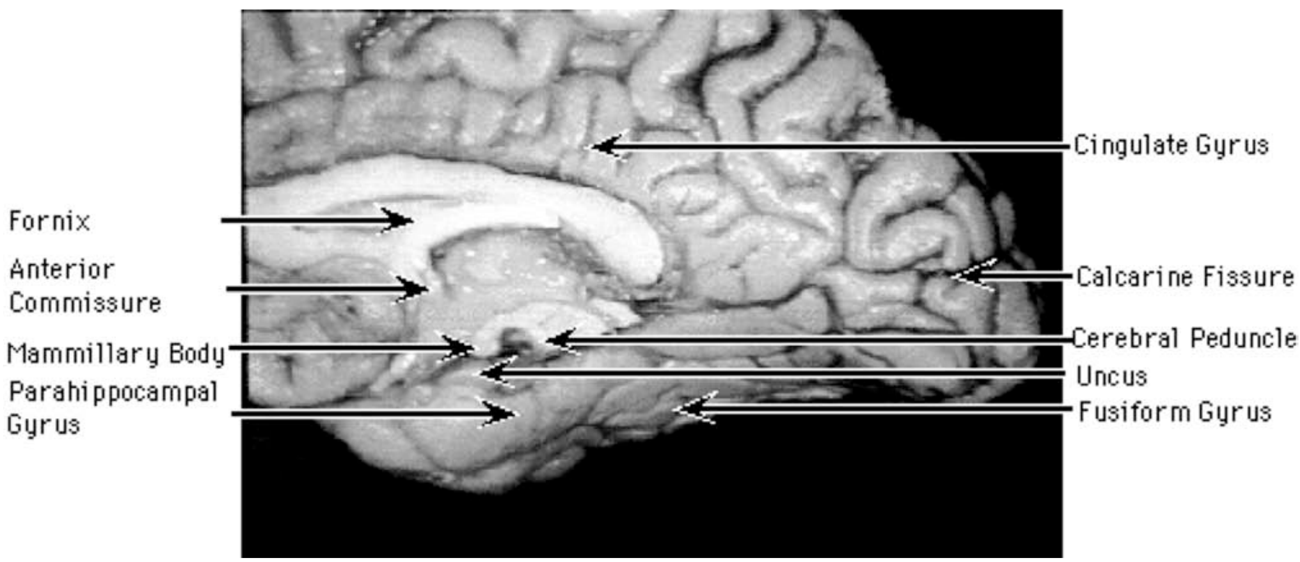

Figure 14D Midsagittal Section, Brain Stem Removed

3. The hippocampal formation (hippocampus): The parahippocampal gyrus turns in upon itself along its medial margin and becomes the other three components of the hippocampal formation (hippocampus). Since this part of the hippocampal formation is rolled in upon itself, it cannot be seen from the surface of the brain. This rolled-in part of the hippocampus is an elongated structure located in the floor of the inferior horn of the lateral ventricle (#4885, #7939, monkey brain, and #5234).

Thus, there are four components of the hippocampal formation (fig 14f, fig 14e): the entorhinal cortex and the three components of the rolled-in part of the hippocampus – the dentate gyrus, Ammon's horn (Cornu Ammonis, hippocampus proper) and the subiculum.

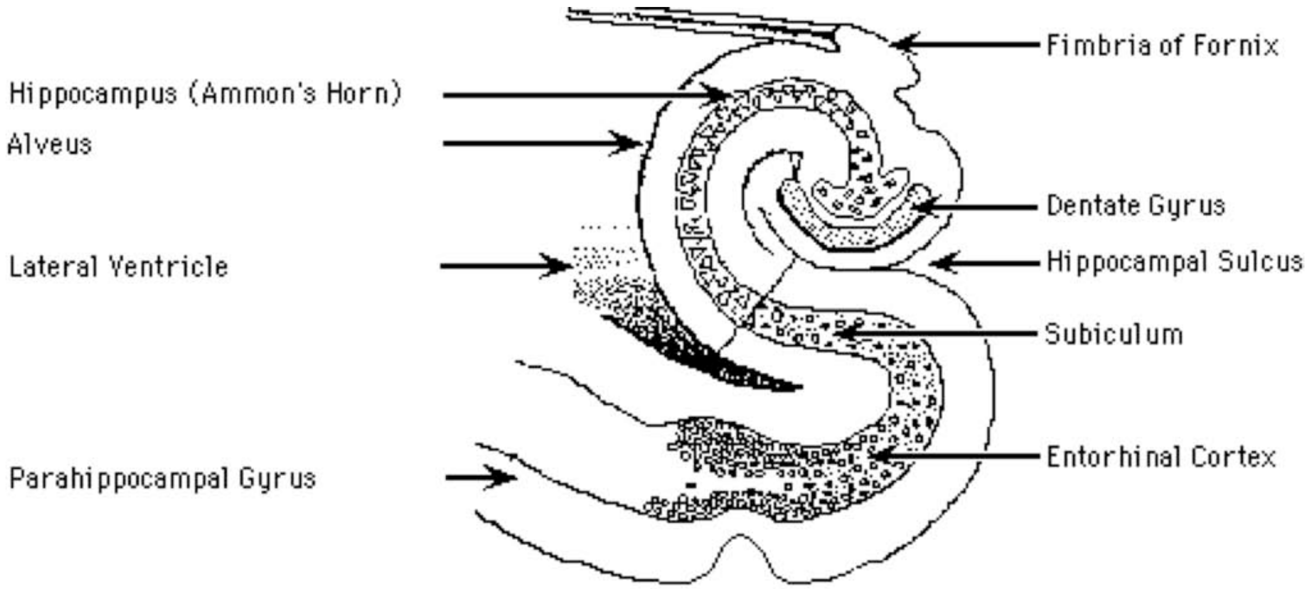

Figure 14F The Hippocampus and Related Structures, (Modified from William and Warwick, 1975)

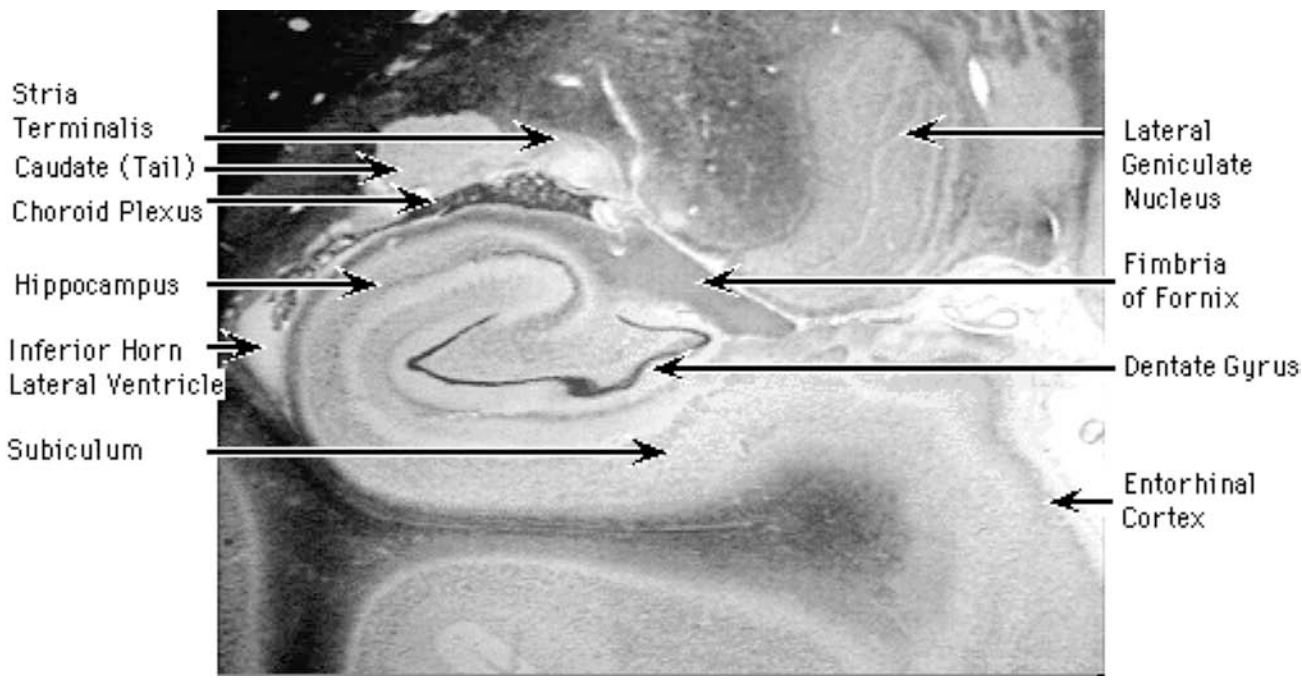

Figure 14E Hippocampal Region, Microscopic View, High Power

[The entorhinal axons synapse on the granule cells in the dentate gyrus (#4682). The granule cell axons synapse on the pyramidal cells of Ammon's horn (fig 14f), which synapse on the pyramidal cells of the subiculum.]

Recent explicit memory: The hippocampus is necessary for storing recent memories of facts and events – explicit (declarative) memory. It receives information from many cortical areas. For example, processed information from all sensory cortices projects to the inferior temporal cortex, which in turn sends axons to the entorhinal cortex. Through these connections, the hippocampus is informed about sensory processing in all cortical areas. This is undoubtedly important in forming memories.

> **Amnestic syndrome:** Bilateral hippocampal damage causes the amnestic syndrome, a profound loss of recent explicit memory and ***inability to form new memories (anterograde amnesia)***, but with preserved immediate (working) memory, preserved remote memory for long-known information, such as where you grew up, and preserved implicit (nondeclarative) memory for motor skills and habits.
>
> **Alzheimer's disease** is the most common dementia. Its pathologic changes are most severe in the hippocampal formation, and its most prominent symptom is loss of recent explicit memory.

B. The Circuit of Papez

A circle of connections from the hippocampus to the mammillary body, to anterior thalamus, to cingulate cortex, and back to the hippocampus through the cingulum and parahippocampal gyrus is known as the Papez circuit (fig 14g). Historically, it was the anatomic basis of the concept of the limbic system. Currently, it is not associated with any specific function, but it illustrates many of the connections of the limbic system.

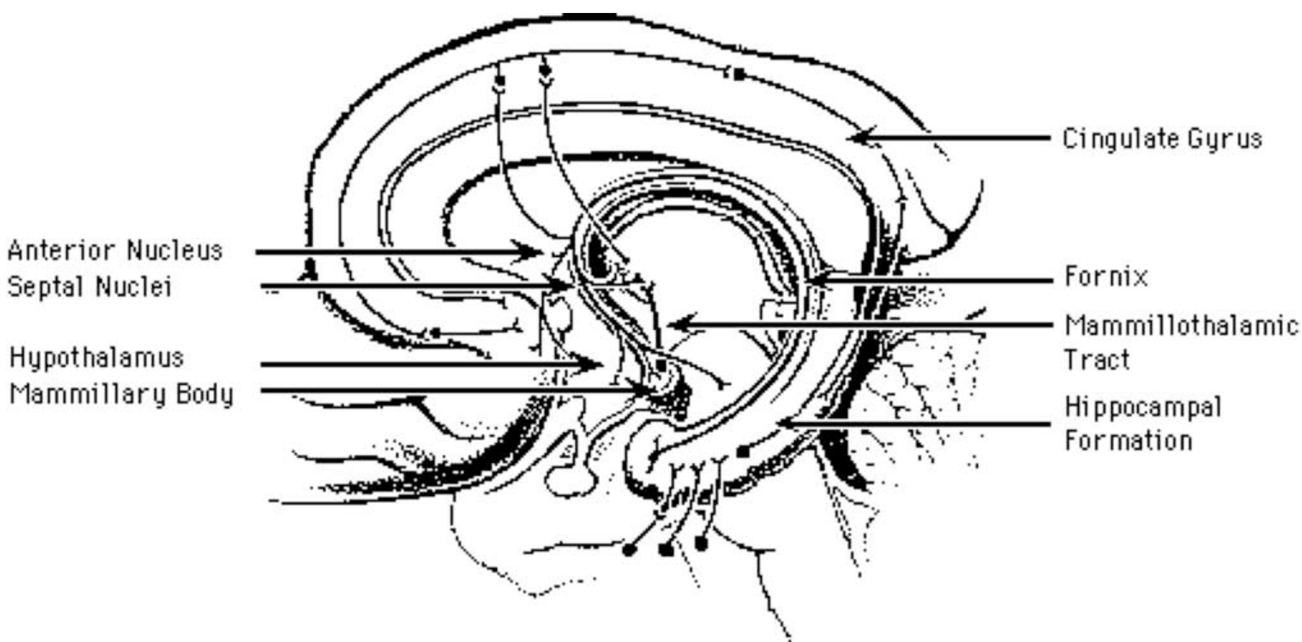

Figure 14G Papez Circuit (Modified from Noback, Strominger, and Demarest, 1991)

Axons of cells in the hippocampal formation (mainly the subiculum, but also Ammon's horn) collect on the surface of the hippocampus in the floor of the temporal horn to form a layer of white matter called the alveus (#4679). These axons gather into a bundle known as the fimbria (#4681). Posteriorly, as this bundle leaves the hippocampal formation, it is called the fornix (#5239).

The fornix is the major projection from the hippocampus. The fornix goes forward under the splenium and body of the corpus callosum and above the third ventricle (#5390, #8404, #6260). This portion of the course of the fornix is seen on the medial surface of the hemisphere (fig 14d). The fornix (#8499) bends to form the anterior margin of the foramen of Monro and courses posterior to the anterior commissure. It then dives into the hypothalamus and divides the hypothalamus into medial and lateral zones (#11864). It terminates in the mammillary body (#8506, #8311).

The mammillary body projects to the anterior nucleus of the thalamus through the mammillothalamic tract (#6640). The anterior nucleus (#8314) sends thalamocortical axons via the internal capsule to the cingulate gyrus (#4749). Axons from the cingulate gyrus form the cingulum (#4898, #4751), which goes to the parahippocampal gyrus and the entorhinal cortex, completing the circuit back to hippocampal formation.

Click for the Pathway Quiz: Papez Circuit.

C. Other Cortical Areas and Nuclei

The main other cortical area of the limbic system is the orbitomedial prefrontal cortex, which is composed of

* The orbital prefrontal cortex, on the inferior surface of the frontal lobe
* The medial prefrontal cortex, which is roughly equivalent to the anterior cingulate gyrus

The main nuclei of the limbic system are

* The basolateral amygdala
* The septal nuclei
* The nucleus accumbens (ventral striatum) and the ventral pallidum
* The hypothalamus, especially the mammillary bodies
* The anterior nucleus of the thalamus and the dorsomedial (mediodorsal) nucleus of the thalamus

Some of these structures were described with the Papez circuit above. Here, we will describe the amygdala and the septal nuclei, with references to some other limbic system structures.

1. The amygdala: The amygdala is a nuclear complex that is rostral to the hippocampus (#4709, monkey). It is more typically seen in a coronal section, (fig 14h). Notice on #4709 that the amygdala is located at the rostral superior tip of the temporal horn. Therefore, in contrast to the hippocampal formation, which can be seen on any coronal slice that includes the temporal horn, the amygdala will only be seen on a coronal slice that goes through the very anterior tip of the temporal horn or just in front of it (fig 14h).

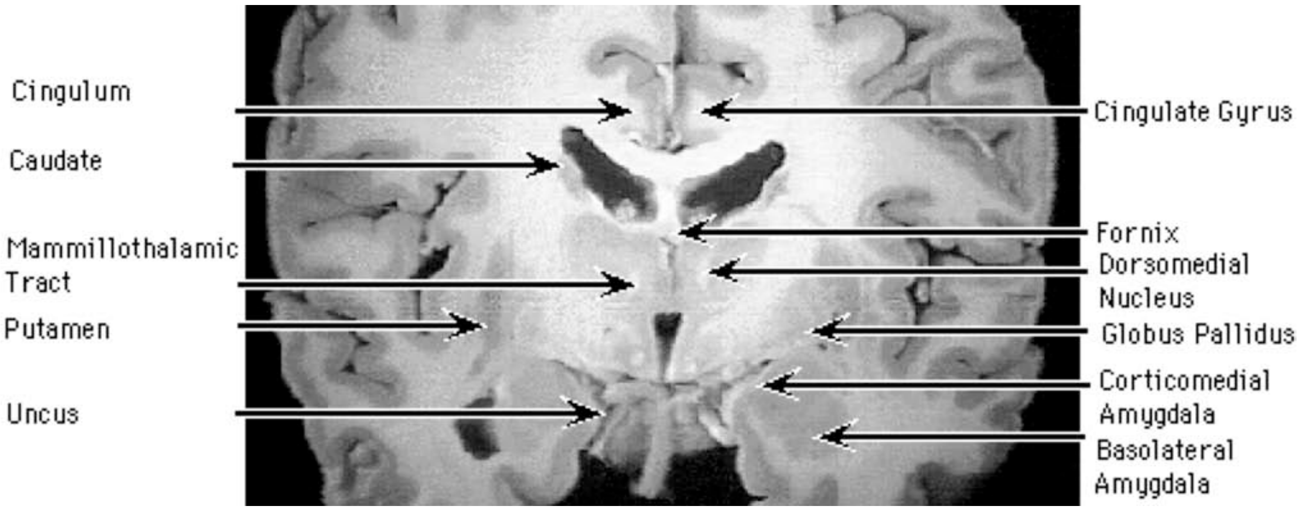

Figure 14H Coronal Section through The Amygdala

The three main nuclear groups of the amygdala are the cortical amygdala ("cortical" nuclei), the basolateral amygdala (basolateral nuclei), and the centromedial extended amygdala (central nucleus, medial nucleus and other nuclei):

a. The cortical amygdala has been considered above in relation to the olfactory system. Notice on fig 14h that the amygdala extends medially to the dorsal surface of the uncus. This superficial part of the amygdala is the cortical amygdala, an area of olfactory cortex as described above.

b. The basolateral amygdala: The basolateral amygdala (#6262) is considered part of the limbic system. It receives information from all sensory modalities. It assigns emotional significance (especially fear) to sensory information, and it produces fear-related "fright, fight and flight" autonomic responses via pathways to the hypothalamus and brainstem (see below). In contrast, human amygdala activity is decreased – consistent with decreased monitoring of environmental stimuli – during romantic love, sexual stimulation and orgasm.

The basolateral amygdala is involved in enhancing our memories of emotionally significant experiences, either pleasant or unpleasant. In this regard, it has receptors for adrenergic and corticosteroid adrenal stress hormones, and connections to regions such as the hippocampal formation, the nucleus accumbens (ventral striatum), dorsomedial nucleus (#6457) of the thalamus, and the orbitomedial prefrontal cortex.

c. The centromedial extended amygdala receives input from the cortical amygdala and the basolateral amygdala and projects to the hypothalamus and brainstem autonomic nuclei. Two pathways connect the amygdala and the hypothalamus: the ventral amygdalofugal pathway (#6644) and the stria terminalis.

[The stria terminalis leaves the posterior amygdala to accompany the tail of the caudate nucleus in the roof of the temporal horn. It has a semicircular course, immediately medial to the C-shaped caudate nucleus. In the body of the lateral ventricle, this tract lies in the groove between the caudate nucleus and the thalamus, next to the thalamostriate vein (vena terminalis) (fig 14b) and can be seen in coronal sections through the thalamus (#5956). In humans, axons of the stria terminalis mainly descend behind the anterior commissure to reach the preoptic area and the hypothalamus (fig 14c).]

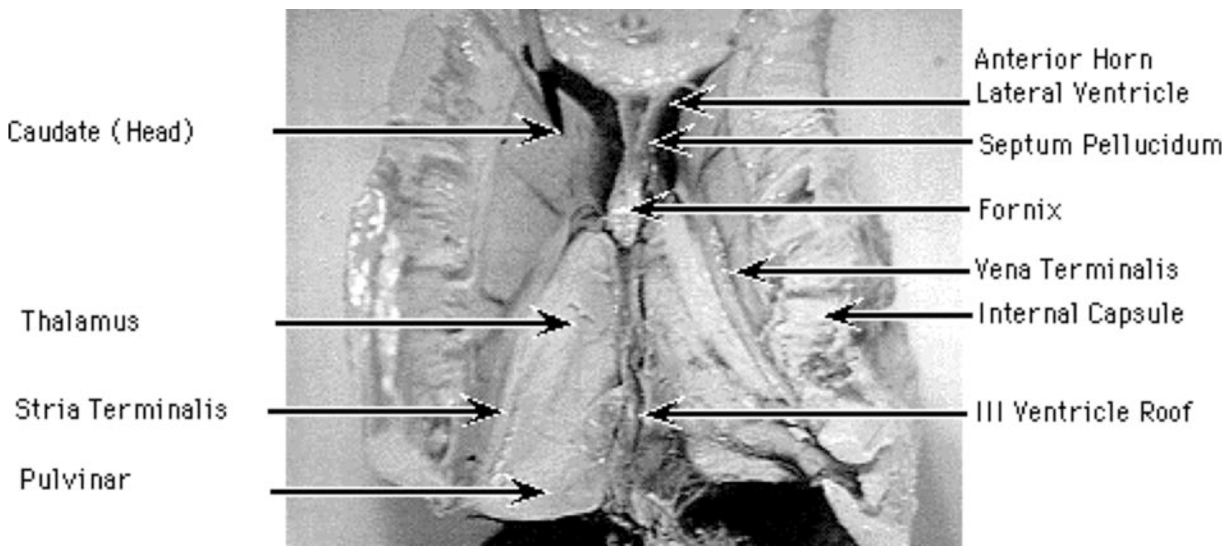

Figure 14B Dissection of Thalamus and Basal Ganglia, Dorsal View, Courtesy of Dr. Diane E. Smith

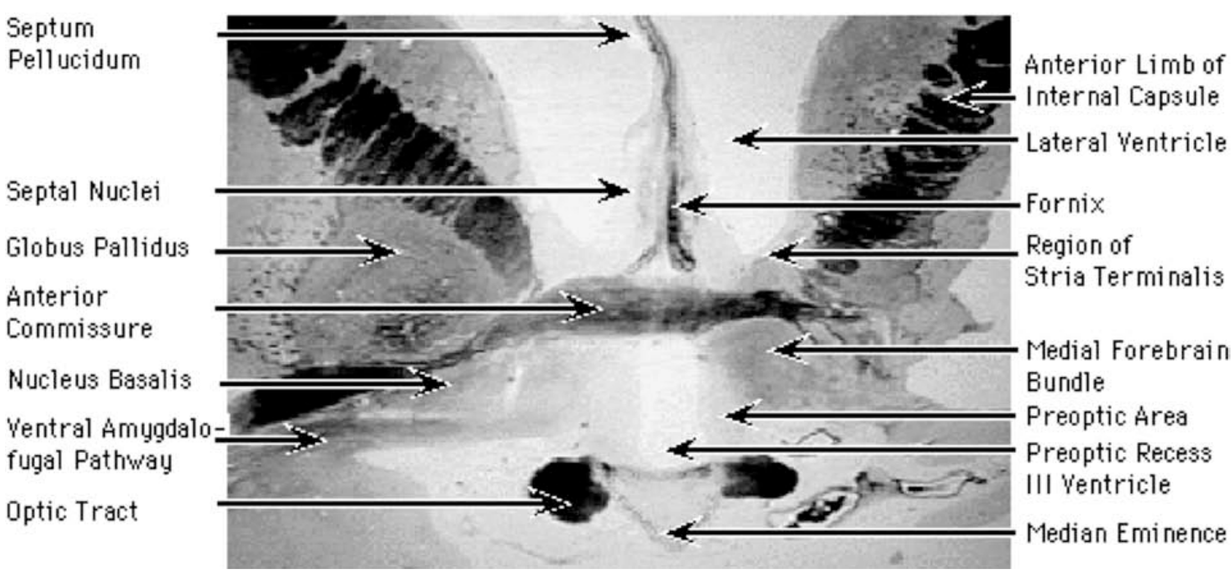

Figure 14C Coronal Section at Level of Anterior Commissure

Amygdala clinical correlations: fear

* The human amygdala is involved in recognizing fear-related stimuli such as fear in facial expressions, voice, or body posture. Lesions of the amygdala in humans cause impaired recognition of the facial expression of emotional states, especially fear.

* The aura of fear that may accompany complex partial seizures (temporal lobe epilepsy) is most likely due to involvement of the amygdala. Another type of aura that may occur is olfactory hallucinations (e.g., foul odors), probably due to involvement of the cortical amygdala or the adjacent piriform cortex.

* In human brains, the basolateral amygdala has the highest concentration of benzodiazepine receptors and thus is probably the critical site for the anxiety-relieving action of benzodiazepines (e.g., Valium®).

* The amygdala is central to theories of pathophysiology of some anxiety disorders, particularly posttraumatic stress disorder and social phobia (social anxiety disorder).

2. The septal nuclei: The septum pellucidum (#4800) is a thin sheet located between the right and left lateral ventricles. Rostrally, near the anterior commissure, the sheet is considerably thicker and houses the septal nuclei (#6600). These nuclei receive afferents from the hypothalamus and hippocampus. The hippocampal input is through the fornix (#6652), which courses through the septal nuclei (#6653). The septal nuclei project to the hypothalamus.

[Information on the role of the septal nuclei in humans is limited. Hypersexuality has been reported following septal damage in humans. Temporary hyperemotionality and increased rage reactions have also been reported.]

HyperBrain Chapter 14. Olfaction and the Limbic System
Review of Terms

Stephen C. Voron, M.D. Revised 2007

Structures to identify in lab are bolded.

I. OLFACTION

A. Peripheral Nervous System

1. olfactory receptors, olfactory epithelium
2. olfactory fila, cranial nerve I (olfactory nerve) cribriform plate of the ethmoid bone

B. Central Nervous System

1. **olfactory bulb**, mitral cells
2. **olfactory tract**
3. **lateral olfactory stria** (lateral to **anterior perforated substance**)
4. **olfactory cortex** is mainly on or near the dorsal surface of the **uncus**
   a. **piriform cortex:** most caudal part of **orbitofrontal cortex** (lateral to lateral olfactory stria) and adjacent sulcus dorsal to the uncus
   b. **cortical amygdala:** dorsal surface of uncus

II. LIMBIC SYSTEM

A. Components
1. **limbic lobe**
   a. **cingulate gyrus**
   b. **parahippocampal gyrus**
   c. **hippocampal formation** (**hippocampus**)
      1) **entorhinal cortex** (anterior half of the parahippocampal gyrus)
      2) dentate gyrus
      3) Ammon's horn (Cornu Ammonis; CA 1,2,3; hippocampus proper)
      4) subiculum
2. **orbitomedial prefrontal cortex**, including the **anterior cingulate gyrus**
3. nuclei
   a. **basolateral amygdala**
   b. **septal nuclei**
   c. **nucleus accumbens (ventral striatum)**
   d. **hypothalamus** especially the **mammillary bodies**
   e. **anterior nucleus of the thalamus**
      dorsomedial nucleus of thalamus

B. The Papez Circuit

hippocampal formation
  entorhinal cortex ⇒
  dentate gyrus ⇒
  Ammon's horn CA3 ⇒ CA1 ⇒
  subiculum ⇒
alveus ⇒ **fimbria** ("fringe") ⇒ **fornix** ("arch") ⇒
mammillary body ⇒ mammillothalamic tract⇒
anterior nucleus of the thalamus ⇒
  thalamocortical axons in **internal capsule** ⇒
cingulate gyrus ⇒ cingulum ⇒
parahippocampal gyrus ⇒
hippocampal formation

C. Miscellaneous Terms

granule cells in the dentate gyrus
pyramidal cells of Ammon's horn and subiculum
recent memory, explicit (declarative) memory
amnestic syndrome
Alzheimer's disease
stria terminalis
thalamostriate vein (vena terminalis)
ventral amygdalofugal pathway