Medical Neuroscience | Tutorial Notes

Functional Microanatomy of Neurons

MAP TO NEUROSCIENCE CORE CONCEPTS[1]

NCC1. The brain is the body's most complex organ.

NCC2. Neurons communicate using both electrical and chemical signals.

LEARNING OBJECTIVES

After study of the assigned learning materials, the student will:

1. Differentiate the basic classes of cells found in the central nervous system (CNS).
2. Characterize the "functional microanatomy" of neurons (differentiate neuronal cell bodies, dendrites, axons and synapses).
3. Describe the microanatomical composition of gray matter and white matter in the CNS.

TUTORIAL OUTLINE

I. Functional microanatomy of neurons
  A. general features of neurons
    1. *Neurons are the fundamental unit of function in the CNS*
    2. possess all cellular and metabolic machinery common to all other somatic cells (see **Figure 1.3**[2])
    3. but they are distinguished from most other somatic cells by their:
      a. rich diversity in morphology (shape)
      b. bioelectrical properties (they generate electrical signals)
      c. specializations for intercellular communication
  B. survey of neuronal microanatomy (see **Figure 1.2**)
    1. **cell body**, also called a soma (= "body"; plural = *somata*)
      a. contains nucleus, nucleic acids, and the usual organelles
      b. typically, neurons are very active metabolically in order to support neural signaling and the synthetic requirements that are necessary to maintain the intricate protoplasmic processes that arise from neuronal somata

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[1] Visit **BrainFacts.org** for *Neuroscience Core Concepts* (©2012 Society for Neuroscience) that offer fundamental principles about the brain and nervous system, the most complex living structure known in the universe.

[2] Figure references to Purves et al., *Neuroscience, 5th Ed.*, Sinauer Assoc., Inc., 2012. [click here]

2. **dendrites**
    a. short (usually, about 100 microns in length) protoplasmic extensions that arise from somata
    b. primarily involved in receiving neural signals from other neurons
    c. dendritic spines
        i. neurons that excite their synaptic partners have very short "spines" (that typically resemble tiny mushrooms) or short filaments along the length of their dendrites
        ii. spines are primarily the sites where dendrites receive excitatory signals from the axon terminals of other neurons
        iii. the dendrites of some neurons lack spines and are called "smooth"; these neurons typically inhibit their synaptic partners
    d. exhibit an especially rich diversity of morphology among different classes of neurons
        i. pyramidal neurons in the cerebral cortex have a single long "apical" dendrite and numerous shorter "basal" dendrites
        ii. other neurons are "multipolar", meaning that their dendrites emanate from the soma in a somewhat regular array
3. **axons**
    a. long protoplasmic extension that arises from somata
    b. for some neurons, the axons are very short (<100 µm); for others, axons can be very long (> 1 meter!)
    c. involved in the transmission or sending of neural signals away from the cell body and toward other neurons or effector cells
4. synaptic terminals or "**synapses**"
    a. specialized contacts among neurons and between neurons and effector cells
    b. synapses may be "electrical" (the small minority in the mature CNS) or "chemical" (the vast majority in the mature CNS) (see **Figures 5.1 & 5.3**)
    c. usually found at the end of axons, with an axon terminal contacting a dendrite of another neuron
    d. however, axon terminals may contact cell bodies or even other axon terminals

II. Neural tissue

A. gray matter
  1. appears somewhat darker in coloration (brown or gray) when observed in a brain that is cut open obtained at autopsy
  2. contains:
    a. neurons (cell bodies, dendrites, axons, and axon terminals or synapses)
    b. glial cells
    c. vascular endothelium

B. white matter
  1. appears somewhat lighter in coloration (light tan or white) when observed in a brain that is cut open obtained at autopsy
  2. contains:
    a. the axons of neurons (but—with rare exceptions—no cell bodies, dendrites, or axon terminals)
    b. glial cells (those that make myelin—insulation around axons)
    c. vascular endothelium

III. classes of neurons (see **Figure 1.2**)
    a. projection neurons
      i. characterized by long axons that project far from somata (“project” signals to a distant target) (see blue cells in **Figure 26.2**)
      ii. some project away from the CNS in peripheral nerves (see **Figure 1.7**)
        - afferent neurons: projection neurons that *receive* information from the environment (e.g., via sensory receptors)
        - efferent neurons: projection neurons that *send* information out to effector cells (e.g., via nerves to muscle cells or glands)
      iii. however, projection neurons also make shorter connections to nearby neurons via axon collaterals
      iv. most projection neurons are excitatory (i.e., they “excite” their targets)
    b. interneurons
      i. characterized by shorter axons that project only a short distance (100s of microns) in the CNS to nearby neurons

ii. many are excitatory (see green cells in **Figure 26.2**), but most are inhibitory (they prevent their targets from becoming "excited") (see purple cell in **Figure 1.7**)

STUDY QUESTIONS

How does information flow through a neuron?

A. dendrite --> synapse --> cell body --> axon--> dendrite
B. synapse --> dendrite --> axon--> cell body --> synapse
C. synapse --> dendrite --> cell body --> axon--> synapse
D. axon--> dendrite --> synapse --> cell body --> axon

Which set of microanatomical structures are typically found in white matter?

A. synapses, vascular endothelium, neuronal cell bodies, axons
B. vascular endothelium, axons
C. synapses, vascular endothelium, neuronal cell bodies
D. vascular endothelium, neuronal cell bodies, axons

Medical Neuroscience | Tutorial Notes

Non-Neuronal Cells of the CNS

MAP TO NEUROSCIENCE CORE CONCEPTS[1]

NCC2. The brain is the body's most complex organ.

LEARNING OBJECTIVES

After study of the assigned learning materials, the student will:

1. Describe the basic classes of cells found in the central nervous system (CNS).
2. Describe the basic functions of the three types of glial cells found in the CNS.
3. Characterize the blood-brain barrier.

TUTORIAL OUTLINE

I. Neuroglia (or just "Glia" for short)
    A. general functions of neuroglia in the CNS
        1. support the metabolic and signaling functions of neurons
        2. participates in neuron circuit formation and synaptic plasticity
        3. make myelin (axonal insulation)
        4. contribute to formation of blood-brain barrier
        5. participate in inflammatory response in injured neural tissue, including phagocytosis of cellular debris
        6. contribute to the formation of scar tissue in damaged neural tissue
    B. major types of neuroglia (see **Figure 1.5**[2])
        1. **astrocytes**
            a. found primarily in gray matter, because they are closely associated with neuronal cell bodies, dendrites and synapses
            b. help maintain ionic balance of extracellular fluids
            c. remove and process neurotransmitters from synaptic clefts
            d. assist in the formation of new synapses ("synaptogenesis")

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        e. contribute to formation of blood-brain barrier and brain-ependymal (ventricular) barrier (see below)
        f. contribute to the formation of scars that fill-in small spaces that have been cleared of necrotic neural tissue following injury

2. **oligodendrocytes**
    a. form myelin in the CNS and are found, therefore, primarily in white matter (a different cell type, the Schwann cell, makes myelin in peripheral nerves)
    b. myelin aids in the propagation of neural signals along myelinated axons (see **Figure 3.11**)
        i. insulate by generating layers of membrane that wrap around a segment of an axon; this decreases the ionic (electrical) “leakiness” of the axonal membrane
        ii. gaps between myelin segments, called “nodes of Ranvier”, allow for the economical concentration of ion channels and ion pumps that are necessary for electrical signaling in axons (fewer channels are needed to propagate electrical signals than would be needed without myelin)
    c. oligodendrocytes present antigens that influence the outgrowth of axons in developing and recovering brain
    d. unfortunately, subject to immunological attack in certain diseases of the CNS (e.g., multiple sclerosis)
3. **microglia**
    a. special type of mononuclear phagocyte that resides in the CNS
    b. derived primarily from hematopoietic precursor cells that migrate into the brain during development
    c. exists in one of two forms: amoeboid and ramified
        i. the ramified form is the dormant state
        ii. the amoeboid form is the activated, mobile state when microglia cells are engaged in phagocytic activity
        iii. activated microglia secrete signaling molecules (cytokines) that modulate local inflammatory responses in injured tissue
4. **glial stem cells**
    a. subset of astrocytes located near the ventricles, often adjacent to blood vessels
        i. may give rise to more stem cells, mature astrocytes or oligodendrocytes, or mature neurons

        ii. exhibit key properties of somatic stem cells: proliferation, self-renewal, and the potency to make all the cells of a given tissue (CNS, in this case)

    b. oligodendroglial precursors scattered throughout the white matter

        i. mainly give rise to mature olgiodendrocytes, but may also generate astrocytes and neurons under certain conditions

    c. although the discovery of these intrinsic stem cells in the CNS has garnered an intense amount of current research activity, the functional and clinical significance of these populations of stem cells remains unclear

C. more on the blood-brain barrier (see **Figure A20**)

1. specialized permeability barrier between the capillary endothelium and the extracellular space in neural tissue

    a. formed by tight junctions between capillary endothelial cells, which are surrounded by "end-feet" processes of astrocytes (forming a "glia limitans", or limiting glial border)

    b. exclude large, water soluble molecules from freely diffusing into CNS, as well as pathogenic microbes and certain toxins

    c. some molecules, such as glucose and certain amino acids, are transported passive or actively across the capillary endothelium

    d unfortunately, this barrier also prevents the administration of many potentially useful pharmaceutical agents (e.g., dopamine)

    e. across the lifespan, the blood-brain barrier remains porous in certain regions of the CNS that are involved in hormone secretion (e.g., median eminence of the hypothalamus; pineal gland)

STUDY QUESTION

Consider a patient with a stroke that caused a small region of brain damage. Which happened first?

A. Microglia were stimulated to convert from ramified to amoeboid states.
B. Astrocytes formed scar tissue to fill-in space vacated by damaged tissue.
C. Microglia phagocytosed cellular debris.
D. Glial stem cells repopulated region of damage neural tissue.

Medical Neuroscience | Tutorial Notes

Basic Orientation in the Human CNS

MAP TO NEUROSCIENCE CORE CONCEPTS[1]

NCC1. The brain is the body's most complex organ.

LEARNING OBJECTIVES

After study of the assigned learning materials, the student will:

1. Discuss position in various divisions of the central nervous system (CNS) using the following pairs of direction terms: anterior/posterior; rostral/caudal; superior/inferior; dorsal/ventral; and medial/lateral
2. Demonstrate the three orthogonal planes that are used to section the CNS.

NARRATIVE

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Specification of location in the nervous system

The terms used to specify location in the central nervous system are the same as those used in gross vertebrate anatomy. One complication (that can become a source of confusion if you don't understand it) arises because some terms refer to the long axis of the body, which is straight, and others refer to the long axis of the central nervous system, which has a bend in it (see **Figure A1A**[2]). A flexure in the long axis of the nervous system arose as humans evolved upright posture. This flexure leads to a ~120 degree angle between the long axes of the hindbrain and forebrain. The two axes intersect at the junction of the midbrain and diencephalon.

This flexure has consequences for the application of standard anatomical terms used to specify location. The terms **anterior** and **posterior** and **superior** and **inferior** are used with reference to the long axis of the body, which is straight. Therefore, these terms refer to the same direction in space for both the forebrain and the hindbrain. In contrast, the terms **dorsal** and **ventral** and **rostral** and **caudal** are used with reference to the long axis of the nervous system, which bends. Thus, dorsal is toward the back for the hindbrain, but toward the top of the head for the forebrain. Ventral is toward the gut. Rostral is toward the top of the head for the hindbrain, but toward the front for the forebrain. Caudal is opposite.

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When you understand these terms and how they are used, you will see why the terminology of neuroanatomy can be confusing at first. For example, the ventral aspect of the spinal cord is also referred to as the anterior aspect in humans, since for the human spinal cord, the two words are synonymous. However, there is a nucleus (cluster of neurons) in the thalamus called the "ventral anterior nucleus". When reference is to the forebrain, the two terms specify different directions, so the compound name of this nucleus is not redundant.

Use of the terms discussed in this section allows us to specify the location of any part of the nervous system with reference to any other part.

The standard planes of section

The brain is commonly cut in one of the three standard planes of section that you may be familiar with from your studies of human (or mammalian) anatomy (see **Figure A1B**). Magnetic resonance images (MRIs) are also usually made in these planes (or close approximations of them). It will help you to understand three-dimensional relationships in the brain if you become familiar with these planes, the application of the positional terms discussed above, and the appearance of the internal structures of the brain in all three planes of section.

The **horizontal** or **axial plane** (hint: think, horizon) shows structures as they would appear from above or below. The **frontal** or **coronal plane** (hint: think, tiara-style crown) shows structures as they would appear from the front or back. The **sagittal plane** shows structures as they would appear from the side (hint: think, Sagittarius—the archer's plane).

Other pairs of terms that are important to know are:

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

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

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

STUDY QUESTIONS

In conventional human radiological imaging (e.g., MRI, PET, CT) of the head, the axial plane is synonymous with the horizontal plane. Which of the following statements about this plane is most accurate?

A. The axial plane is parallel to the coronal plane.
B. The axial plane is parallel to the sagittal plane.
C. The axial plane is parallel to the floor of the cranium.
D. The axial plane is in the plane of the face.
E. The long axis of the spinal cord is in the axial plane of the cranium.

Of the following pairs of **directional terms**, which pair contains terms that define PERPENDICULAR (orthogonal) directions when applied to the identified region of the central nervous system? [hint: you may wish to extend your arms and point in the indicated directions]

A. in the forebrain, rostral & anterior
B. in the forebrain, dorsal & superior
C. in the forebrain, ventral & inferior
D. in the brainstem, ventral & anterior
E. in the spinal cord, caudal & posterior

Medical Neuroscience | Tutorial Notes

Lateral Surface of the Brain

MAP TO NEUROSCIENCE CORE CONCEPTS[1]

NCC1. The brain is the body's most complex organ.

LEARNING OBJECTIVES

After study of the assigned learning materials, the student will:

1. Demonstrate the four paired lobes of the cerebral cortex and describe the boundaries of each.
2. Sketch the major features of each cerebral lobe, as seen from the lateral view, identifying major gyri and sulci that characterize each lobe.

NARRATIVE

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Overview

When you view the lateral aspect of a human brain specimen (see **Figures A3A** and **A10**[2]), three structures are usually visible: the **cerebral hemispheres**, the **cerebellum**, and part of the **brainstem** (although the brainstem is not visible in the specimen photographed in lateral view for **Fig. 1** below). The spinal cord has usually been severed (but we'll consider the spinal cord later), and the rest of the subdivisions are hidden from lateral view by the hemispheres. The diencephalon and the rest of the brainstem are visible on the medial surface of a brain that has been cut in the midsagittal plane. Parts of all of the subdivisions are also visible from the ventral surface of the whole brain. Over the next several tutorials, you will find video demonstrations (from the brain anatomy lab) and photographs (in the tutorial notes) of these brain surfaces, and sufficient detail in the narrative to appreciate the overall organization of the parts of the brain that are visible from each perspective. As you work through this text and if you have access to an interactive digital atlas of the human brain, such as ***Sylvius4 Online***, find the structures and regions that are described here[3].

The **cerebral hemispheres** are especially large in humans. They are entirely covered by a 2–3-mm thick layer of cells and cellular processes called the **cerebral cortex**. The surface of each hemisphere is highly

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[3] To do so, launch ***Sylvius4 Online*** and go to **Photographic Atlas**, then select one of the atlas filters, such as **Gyri**, **Lobes**, or **Sulci and Fissures**.

infolded; the ridges thus formed are known as **gyri** (singular: gyrus) and the valleys are called **sulci** (singular: sulcus) or **fissures** (if they are especially deep). The appearance of the sulci and gyri varies somewhat from brain to brain. (As you might guess, each one has its own name, but it is necessary to become familiar with only a few of them.) The hemispheres are conventionally divided into lobes named for the bones of the skull that overlie them, namely the **frontal**, **parietal**, **occipital** and **temporal lobes** (see **Figure A3**).

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

Lateral aspect of the brain

The frontal lobe is the most anterior of the four lobes and is separated from the parietal lobe by the **central sulcus**, which is one of the most important landmarks in the cerebral cortex (in **Figure A3**, boundary between blue and red colored regions; see tutorial on ***Finding the Central Sulcus***). An important gyrus in the frontal lobe is the **precentral gyrus**. (The prefix 'pre,' when used to refer to anatomical position, refers to something that is in front of something else or that is anterior.) The cortex of the precentral gyrus is the somatic 'motor cortex,' which contains neurons whose axons project to the motor nuclei in the brainstem and spinal cord that innervate the striated muscles of the body.

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

On the inferior-lateral aspect of the hemisphere, you should readily appreciate a deep, fairly straight fissure that separates the frontal and parietal lobes from the temporal lobe; this space is called the **lateral fissure** or Sylvian fissure, named after the important Renaissance neuroanatomist, *Franciscus Sylvius*[4]. If viewed from above, you would see that the hemispheres are separated by an even deeper fissure called the **longitudinal fissure** (or superior sagittal fissure) (see **Figure A11**). The gyral formations anterior to the precentral gyrus on the dorsal-lateral aspect of the frontal lobe between the lateral fissure and the longitudinal fissure can be recognized as three parallel, longitudinal gyri. Adjacent to the longitudinal fissure is the **superior frontal gyrus**, which is typically the most obvious of the three. This gyrus continues on the medial surface of the hemisphere in the depths of the longitudinal fissure; we will see it again when we examine the midsagittal section through the brain. Just inferior to the superior frontal gyrus is the **middle frontal gyrus**, with the **superior frontal sulcus** separating the two. Note that these two gyral formations are fairly straight and parallel to the longitudinal fissure in the parasagittal plane. At their posterior end, they sometimes merge with the precentral gyrus, which forms, of course, the anterior bank of the central sulcus. However, there is often an interrupted (i.e., a superficially discontinuous) sulcus that separates them from the precentral gyrus, named the **precentral sulcus**.

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[4] *Franciscus Sylvius* was the inspiration for the title of our digital brain atlas, ***Sylvius4 Online***; click here for more on this important figure in the history of human neuroanatomy.

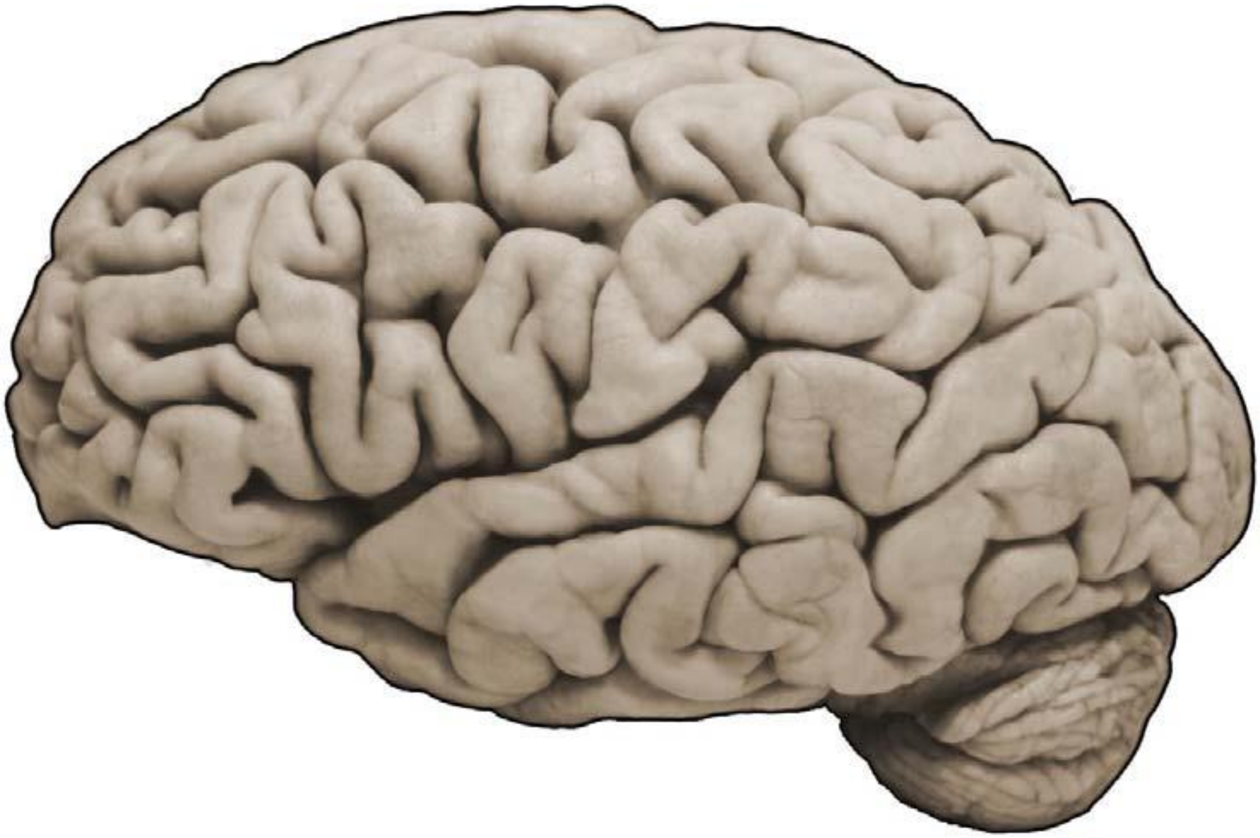

Fig. 1. Lateral surface of the human brain. This figure is not labeled so that you may refer to it for review; see **Figures A3** & **A10** for an illustrated and labeled view of the same hemisphere. (Image from ***Sylvius4 Online***)

Just inferior to the middle frontal gyrus, across the **inferior frontal sulcus**, is a much more complex gyral formation. For our purposes, we won't be concerned with the names of these subcomponents or their differential functional contributions to cognition and behavior. Suffice it to say that the **inferior frontal gyrus** contains a critical functional division of the motor cortex that participates in the production of speech. This division has a special name, **Broca's Area**, given in honor of the famous French neurologist, Pierre Paul Broca[5], who first recognized the significance of this gyral formation for human speech in the mid-19th century. Interestingly, the left hemisphere is dominant in most individuals (especially males and right-handers) for this function, such that damage to the left inferior frontal gyrus is more likely to produce an impairment of language expression, called *Broca's aphasia* (aphasia means "without speech"), than a comparable lesion involving the right inferior frontal gyrus. Interestingly, this is also the division of the premotor cortex where in non-human primates neurons with "mirror" properties have been characterized. That is, neurons in the posterior part of the inferior frontal gyrus fire when certain

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[5] click here for more on this important figure in the history of human neuroanatomy.

actions are executed *and* when those same actions are observed (mirrored) in the behavior of another individual. Whether these neurons participate in imitation learning—or perhaps even decoding the intentions of others—remains an area of intense investigation.

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

Notice how the lateral aspects of the frontal and temporal lobes bear some resemblance (at least conceptually): they both comprise three, parallel longitudinal gyri that extend from the anterior pole of each lobe back toward the parietal lobe.

Once you are familiar with these gyral features in one specimen, spend some time examining as many specimens as are available in digital format (a number of free digital resources are available that show lateral views of the human brain). As you do so, look for differences and common structural themes among brains and between hemispheres. If you can, carefully examine the pattern and length of the lateral fissure and consider the following questions.

- Are the two lateral fissures of the same brain roughly the same? If not, how are they different?
- Does the left lateral fissure tend to run mainly in the horizontal plane and extend further posteriorly, compared to the right lateral fissure?
- Is there an ascending branch of the posterior lateral fissure in the right hemisphere, but not the left?

These questions have been asked and addressed in studies of hemispheric asymmetries and gender differences related to language lateralization in the human brain. The superior aspect of the temporal lobe contains the cortical divisions whose functions pertain to audition and the reception of language. The posterior aspect of the superior temporal gyrus has a special functional name, **Wernicke's Area**, named in recognition of the seminal contributions of the 19th century German physician, Carl Wernicke[6], who described a disturbance of understanding speech, now called *Wernicke's aphasia*. You may find differences in the structure of the superior temporal gyrus in the two hemispheres reflected in the pattern and length of the lateral fissure; such differences may, in turn, be related to the language dominance of the left hemisphere. Hemispheric differences in this cortical region may even relate to musical abilities and other special talents that pertain to audition and semantic encoding.

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

Since you already worked through recognition of the central sulcus, you should now be able to view the lateral surface of any hemisphere and know to look for the central sulcus lazily coursing from the longitudinal fissure over the dorsal-lateral surface of the cerebrum in a lateral-ventral and slightly anterior direction (hopefully, the directional terms applied to the forebrain are also becoming second-nature to you). Much of the cortex that you observe posterior to the central sulcus is part of the parietal lobe. The prominent gyral structure that forms the posterior bank of the central sulcus is the **postcentral**

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[6] click here for more on this important figure in the history of human neuroanatomy.

gyrus, which is parallel to the precentral gyrus of course. This gyrus is concerned with somatic sensation and will be a major focus for clinicians concerned with the cerebral localization of touch and body position sensations. Immediately posterior to the postcentral gyrus is the **postcentral sulcus**, which separates the postcentral gyrus from two major gyral formations of the parietal lobe: the **superior** and **inferior parietal lobules**. The boundary between these two lobules is often difficult to appreciate; it is recognized as a meandering and often discontinuous sulcus called the **intraparietal sulcus** that tends to run in a parasagittal plane. We will return to the superior parietal lobule when we explore the medial surface of the hemisphere.

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

Likewise, it is often difficult to discern the boundaries where the posterior parietal and temporal lobes meet the anterior occipital lobe on the lateral surface of the cerebrum, and it may make no functional sense to attempt to do so. Nevertheless, we can define an imaginary lateral boundary between the parietal and occipital lobes in this complex and variable region. Emerging from the depths of the longitudinal fissure along the medial bank of the cerebral hemisphere (about one-fourth of the length of the fissure from its posterior limit) is the **parieto-occipital sulcus** (see **Figure A10**). We will see this sulcus more plainly when we explore the medial face of the hemisphere in another tutorial. For now, appreciate that the parieto-occipital sulcus is the medial boundary between the parietal and occipital lobes. View the lateral surface of the hemisphere again and carefully inspect its inferior margin. Just above the cerebellum, there is often a small groove or notch in the gyral structure that can be appreciated 3-4 cm anterior from the caudal pole of the hemisphere. This groove is called the "pre-occipital notch" (see **Figure A10**). Now, draw an imaginary line between the parieto-occipital sulcus dorsally and the pre-occipital notch ventrally; this line will serve as the lateral boundary between the parietal and occipital lobes. Simply put, all gyral structures posterior to this line are occipital and have some role to play in elaborating visual perception. Fortunately for you, the complexity and inter-individual variation of these gyri defies easy application of standard nomenclature; for this reason, we will refer to these gyral structures as **lateral occipital gyri** and leave the business of naming these gyri for the cortical cartographers.

Lastly, there is a region of cortex called the **insula**, which is not visible from the lateral surface of the hemisphere because it is hidden beneath the frontal, temporal, and parietal lobes. The components of these lobes that cover the insular cortex are often called 'opercular' components ('opercular' means a lid or cover). It can be seen if portions of these two lobes are retracted (as is illustrated in **Figure A10**). In spite of its name, the insular cortex does not form an island; it is a part of the continuous sheet of cortex and is deeply buried only because of the relatively greater growth of the cortex around it. Neurons in the insular cortex are concerned with visceral, autonomic, and taste functions and are thought to contribute in complex ways to integrative brain functions that impact emotion and social cognition.

STUDY QUESTIONS

Q1. Which of the following statements concerning the **central sulcus** is most correct?

- A. The central sulcus terminates laterally in or very near the longitudinal fissure.
- B. The central sulcus is the principal landmark that divides the two cerebral hemispheres from one another.
- C. The central sulcus terminates medially in or very near the lateral (Sylvian) fissure.
- D. The central sulcus is formed by gyral formations that harbor the somatic sensory and motor divisions of the cerebral cortex in the human brain.
- E. The central sulcus is mainly in the axial plane of the cranium.

Q2. Which two lobes of the cerebral hemisphere feature three **parallel, longitudinal gyri** on their lateral aspect?

- A. frontal and temporal lobes
- B. frontal and parietal lobes
- C. parietal and occipital lobes
- D. temporal and occipital lobes
- E. temporal and parietal lobes

Medical Neuroscience | Tutorial Notes

Medial Surface of the Brain

MAP TO NEUROSCIENCE CORE CONCEPTS[1]

NCC1. The brain is the body's most complex organ.

LEARNING OBJECTIVES

After study of the assigned learning materials, the student will:

1. Demonstrate the four paired lobes of the cerebral cortex and describe the boundaries of each.
2. Sketch the major features of each cerebral lobe, as seen from the medial view, identifying major gyri and sulci that characterize each lobe.

NARRATIVE

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Overview

When you view the lateral aspect of a human brain specimen (see **Figures A3A** and **A10**[2]), three structures are usually visible: the **cerebral hemispheres**, the **cerebellum**, and part of the **brainstem** (although the brainstem is not visible in the specimen photographed in lateral view for **Fig. 1** below). The spinal cord has usually been severed (but we'll consider the spinal cord later), and the rest of the subdivisions are hidden from lateral view by the hemispheres. The diencephalon and the rest of the brainstem are visible on the medial surface of a brain that has been cut in the midsagittal plane. Parts of all of the subdivisions are also visible from the ventral surface of the whole brain. In this set of tutorials, you will find video demonstrations (from the brain anatomy lab) and photographs (in the tutorial notes) of these brain surfaces, and sufficient detail in the narrative to appreciate the overall organization of the parts of the brain that are visible from each perspective. As you work through this text and if you have access to an interactive digital atlas of the human brain, such as ***Sylvius4 Online***, find the structures and regions that are described here[3].

The **cerebral hemispheres** are especially large in humans. They are entirely covered by a 2–3-mm thick layer of cells and cellular processes called the **cerebral cortex**. The surface of each hemisphere is highly

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infolded; the ridges thus formed are known as **gyri** (singular: gyrus) and the valleys are called **sulci** (singular: sulcus) or **fissures** (if they are especially deep). The appearance of the sulci and gyri varies somewhat from brain to brain. (As you might guess, each one has its own name, but it is necessary to become familiar with only a few of them.) The hemispheres are conventionally divided into lobes named for the bones of the skull that overlie them, namely the **frontal**, **parietal**, **occipital** and **temporal lobes** (see **Figure A3**).

Medial aspect of the brain

When the brain is cut in the midsagittal plane, all of its subdivisions are visible on the cut surface (see **Fig. 1** below). Just as in the embryo, the subdivisions are arranged as though they were stacked on top of one another, with the hemispheres bulging out laterally at the top and the cerebellum bulging out dorsally and laterally about half-way up the stack. The cerebral hemisphere is still the most prominent part of the brain in this view.

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

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

The caudal portion of the superior frontal gyrus forms the **paracentral lobule**, as it joins the medial continuation of the pre- and post-central gyri. Just as on the lateral surface of the hemisphere, on the medial face of the hemisphere the frontal lobe extends from the central sulcus forward. At the inferior margin of the frontal lobe is the medial aspect of an inferior gyrus called the **gyrus rectus** (see 'ventral view' below), and a small cortical division, called the **subcallosal area**, just below the genu ("knee") of the corpus callosum. This subcallosal area has become an important target for deep brain stimulation in the treatment of various psychiatric diagnoses, including major depressive disorder.

Locate again the medial terminus of the central sulcus in the paracentral lobule. That sulcus marks the anterior boundary of the parietal lobe, at least its dorsal portion; the rest of the anterior boundary follows the posterior limit of the cingulate gyrus. Now, about half-way between the central sulcus and the posterior pole of the hemisphere, note the presence of a prominent sulcus running in nearly the coronal plane (actually, it is usually angled posteriorly from its inferior to superior ends) (see **Figure A3B** and **A12**). This sulcus is the **parieto-occipital sulcus** and it divides the parietal and occipital lobes. The entire gyral formation visible in this view of the parietal lobe is called the **precuneus gyrus** (its name will make sense as you read on).

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

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

To appreciate the medial parietal and occipital lobes, reorient yourself to the parieto-occipital sulcus (see **Figure A12**). Next, recognize the **calcarine sulcus**, which intersects the parieto-occipital sulcus at nearly a right angle and extends typically to the occipital pole of the hemisphere. We'll come back to this part of the brain when we study the visual system. For now, notice the "tongue"-like gyral structure that forms the inferior bank of the calcarine sulcus, and the "wedge"-shaped gyrus that forms its superior bank. Thankfully, the formal terms for these gyri mean just that:

- **Lingual gyrus**; "lingual" (Latin, *lingua*) means "tongue"
- **Cuneus gyrus**; "cuneus" (Latin, *cuneus*) means "wedge"

The precuneus gyrus, of course, lies just in front of (anterior to) the cuneus gyrus. Note that the precuneus gyrus is really a medial extension of the superior parietal lobule. But on the medial face of the hemisphere, we call this the precuneus gyrus (which you can now remember as the gyrus in front of the "wedge").

The occipital lobe serves vision. The cortex in the banks of the calcarine sulcus is the first division of the occipital lobe to receive information derived from the retinas (relayed via the thalamus); hence it is called the **primary visual cortex** (also called the "striate cortex" because of a conspicuous stripe or striation that runs through the middle of the cortex in the banks of the calcarine sulcus). Damage to this part of the occipital lobe can result in blindness for some portion of the visual field. Surrounding occipital regions—and posterior parts of the parietal and temporal lobe—process increasingly more complex aspects of vision (e.g., the location, color, form and motion of objects, and recognition of their identity). Localized injury or disease affecting one of these "higher-order" or associational visual areas can result in remarkably specific impairments of visual function, such as the inability to appreciate motion or recognize a familiar face (more on such visual functions in later class sessions).

Three prominent fiber bundles (i.e., bundles of axons extending from one part of the brain to another) associated with the cerebral hemispheres can be seen from the medial view (see **Figure A12** and **Fig. 1** below). These are:

1. the **corpus callosum**, a huge structure that contains 100s of millions of axons and connects the cortices of the two hemispheres, except for cortex in the anterior temporal and ventral (orbital) frontal lobes;
2. the **anterior commissure**, a much smaller bundle of axons that connects cortex in the anterior temporal and ventral frontal lobes, in addition to other ventral telencephalic structures; and
3. the **fornix**, a large fiber bundle that connects the hippocampus (a part of the temporal lobe that you haven't seen yet) with the hypothalamus and related ventral, midline structures.

In the view shown in **Fig. 1**, the axons in the corpus callosum and anterior commissure are running perpendicular to the plane of the page, and the visible fibers of the fornix are running within the plane of the page.

The other subdivisions of the brain, all of which can be seen in **Fig. 1** (labeled in **Figure A12**), are as follows:

1. The **diencephalon** consists of four parts arrayed from dorsal to ventral. A. The epithalamus is a small strip of tissue to which is attached the **pineal gland**. B. The **thalamus**, the largest part, relays most of the information going into the cortex from other parts of the brain and spinal cord. The thalamus consists of many further subdivisions, some of which you will learn about in later tutorials. C. The **subthalamus**, a small area concerned with control of motor and cognitive functions, cannot be seen from this view since it does not extend all the way to the midline (this small diencephalic region is a frequent target of deep brain stimulation for control of movement disorders). D. The **hypothalamus**, a small but crucial part of the brain, is devoted to the control of homeostasis and a rich variety of physiological activities that are essential for survival and reproduction. It is bounded rostrally by the optic chiasm, and its caudal extremity is made up of swellings known as the mammillary bodies. On some brain specimens, the pituitary gland or part of its stalk (the infundibulum) may still be attached to the ventral surface of the hypothalamus.
2. The **mesencephalon** or **midbrain** lies just caudal to the thalamus. Prominent landmarks that can be seen on the dorsal surface of the midbrain are the **superior** and **inferior colliculi**. They are concerned with oculomotor function and postural adjustments (superior colliculi) and audition (inferior colliculi). The other prominent external feature of the midbrain, the cerebral peduncles, cannot be seen very well from this view as they do not quite reach the midline (we will return to them in another tutorial).
3. The **pons** is next as we proceed caudally. It would be difficult to miss the pons because of the massive enlargement on its ventral surface. (Pons means ‘bridge’; the enlargement is made up of cells with transversely oriented axons that cross the midline and could be said to form a bridge across the base of the brainstem.) A further feature that identifies the pons is its attachment to the cerebellum which lies dorsal to it. The cerebellum plays a crucial role in the coordination of movement.
4. Finally, the most caudal subdivision of the brainstem is the **medulla oblongata** (or “medulla” for short). From the medial view shown in **Fig. 1**, it looks relatively featureless. We will explore its external landmarks further on the ventral view of the brain in another tutorial.

Fig 1. Medial surface of the hemisected human brain. This figure is not labeled so that you may refer to it for review; see Figure A12 for illustrated and labeled views of the same hemisphere. (Image from ***Sylvius4 Online***)

All components of the ventricular system, except perhaps for the lateral ventricles, can be seen on a typical medial surface of the brain cut in the midsagittal plane. In **Fig. 1**, the **lateral ventricle** is visible in this hemisphere because the septum pellucidum has been dissected away; this is a very thin layer of tissue that forms the medial wall separating the two lateral ventricles. The **third ventricle** forms a narrow space in the midline region of the diencephalon, between the one that you see and the one that has been cut away. The communication of the third ventricle with the lateral ventricle is through a small hole, the **interventricular foramen** (or foramen of Monroe), at the anterior-dorsal end of the third ventricle. The third ventricle is continuous caudally with the **cerebral aqueduct** which runs through the midbrain. At its caudal end, it joins the **fourth ventricle**, a large space in the dorsal pons and medulla. The fourth ventricle narrows caudally to join the **central canal**. We will take a closer look at the ventricles when we inspect cross-sections through the forebrain in a later tutorial.

STUDY QUESTIONS

Q1. Which of the following **external spaces** provides a major landmark dividing one cerebral lobe from another?

A. superior frontal sulcus
B. parieto-occipital sulcus
C. calcarine sulcus
D. cingulate sulcus
E. lateral (Sylvian) fissure

Q2. Which of the following pairs of terms identify **spaces** that are roughly PERPENDICULAR (orthogonal) in the human brain (give or take 30 degrees or so)?

A. calcarine sulcus and central sulcus
B. precentral sulcus and postcentral sulcus
C. superior temporal sulcus and inferior temporal sulcus
D. superior frontal sulcus and intraparietal sulcus
E. central sulcus and the parieto-occipital sulcus

Medical Neuroscience | Tutorial Notes

Finding the Central Sulcus

MAP TO NEUROSCIENCE CORE CONCEPTS[1]

NCC1. The brain is the body's most complex organ.

LEARNING OBJECTIVES

After study of the assigned learning materials, the student will:

1. Recognize the central sulcus from its medial terminus in the paracentral lobule to its lateral terminus in the lateral fissure.
2. Sketch the central sulcus in the cerebral hemisphere and label the segments of the pre- and post-central gyri that represent somatic motor control and somatic sensation for the contralateral leg, arm and face.

NARRATIVE

by Leonard E. WHITE and Nell B. CANT
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Department of Neurobiology
Duke University School of Medicine

Overview

When you view the lateral aspect of a human brain specimen (see **Figures A3A** and **A10**[2]), three structures are usually visible: the **cerebral hemispheres**, the **cerebellum**, and part of the **brainstem** (although the brainstem is not visible in the specimen photographed in lateral view for **Fig. 1** below). The spinal cord has usually been severed (but we'll consider the spinal cord later), and the rest of the subdivisions are hidden from lateral view by the hemispheres. The diencephalon and the rest of the brainstem are visible on the medial surface of a brain that has been cut in the midsagittal plane. Parts of all of the subdivisions are also visible from the ventral surface of the whole brain. Over the next several tutorials, you will find video demonstrations (from the brain anatomy lab) and photographs (in the tutorial notes) of these brain surfaces, and sufficient detail in the narrative to appreciate the overall organization of the parts of the brain that are visible from each perspective. As you work through this text and if you have access to an interactive digital atlas of the human brain, such as ***Sylvius4 Online***, find the structures and regions that are described here[3].

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The **cerebral hemispheres** are especially large in humans. They are entirely covered by a 2–3-mm thick layer of cells and cellular processes called the **cerebral cortex**. The surface of each hemisphere is highly infolded; the ridges thus formed are known as **gyri** (singular: gyrus) and the valleys are called **sulci** (singular: sulcus) or **fissures** (if they are especially deep). The appearance of the sulci and gyri varies somewhat from brain to brain. (As you might guess, each one has its own name, but it is necessary to become familiar with only a few of them.) The hemispheres are conventionally divided into lobes named for the bones of the skull that overlie them, namely the **frontal**, **parietal**, **occipital** and **temporal lobes** (see **Figure A3**).

Lateral aspect of the brain

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

Surprisingly, the most reliable way to find the central sulcus is not by inspecting the lateral surface of the brain, where this is one of the longest and deepest sulci of the human cerebral cortex. Rather, the best way to find the central sulcus is to start on the medial surface of the hemisphere. So refer to **Fig. 1** below (see also **Figure A12**) or view the medial surface of the brain using ***Sylvius4 Onine*** and locate the **cingulate sulcus** on the medial surface of the hemisphere. Follow this posteriorly to its marginal ramus, a sharp turn in the sulcus where it ascends to the top of the hemisphere. The sulcus just anterior to the marginal ramus (on the dorsal-lateral surface of the hemisphere) is the central sulcus.

To be certain that the first sulcus anterior to the marginal branch of the cingulate sulcus is the central sulcus, follow the course of the sulcus that you just identified as the central sulcus and you should see that it courses along the lateral surface in a gentle anterior progression as you trace it from the dorsal midline toward its inferior margin (see **Fig. 2** below; see also **Figure A10**). Along the way, note the lazy "S"-shaped bend it takes near the middle of the cerebral hemisphere. With remarkable consistency, that is where the somatic sensory and motor representations of the contralateral arm and hand are localized.

The gyral structure bounded by the marginal branch of the cingulate sulcus on the dorsal midline of the hemisphere is also important; this structure, named the **paracentral lobule**, contains the somatic sensory and motor representations of the contralateral foot. So where's the face represented? Here's another surprise—the contralateral face is localized to the inferior segment of the central sulcus below that lazy "S" shape (not where you might expect it, if the body where mapped contiguously). As you take all of this in, remember: in each of these segments, somatic sensation is represented on the posterior or parietal side of the central sulcus (in the **postcentral gyrus**) and motor control is localized to the anterior or frontal side of the sulcus (in the **precentral gyrus**).

If you have access to ***Sylvius4 Online***, open the Unlabeled image set in the Sectional Anatomy group and view the most dorsal horizontal (axial) section in the set. At this level and plane, the central sulcus is usually the deepest sulcus near the middle of the hemisphere. If you don't have Sylvius4, then refer to **Fig. 3** below, which shows a similar plane of section in a T1-weighted MR image. In either section, notice that in the depths of the central sulcus, there should also be a conspicuous Ω shape (i.e., "omega-shape") formed by an interdigitation of the sulcal walls. This gyral feature is what accounts for the "S" shape that can be appreciated when the central sulcus is viewed from the dorsal-lateral surface of the hemisphere. More importantly, the somatic motor and sensory representation of the contralateral hand invariably includes this distinctive Ω-shape deep in the central sulcus. Evidently, this morphological feature reflects the "over-representation" of the hand in the human brain and the instantiation of this important functional representation with as much cortical structure as can be packaged into a cramped space. The Ω-shape (which is sometimes called the "hand knob" by neurologists and neuroradiologists) is mainly attributed to a posterior outgrowth of the precentral gyrus, which harbors the primary motor cortex.

Fig. 1. Medial surface of the hemisected human brain. This figure is not labeled so that you may refer to it for review; see Figure A12 for illustrated and labeled views of the same hemisphere. (Image from ***Sylvius4 Onilne***)

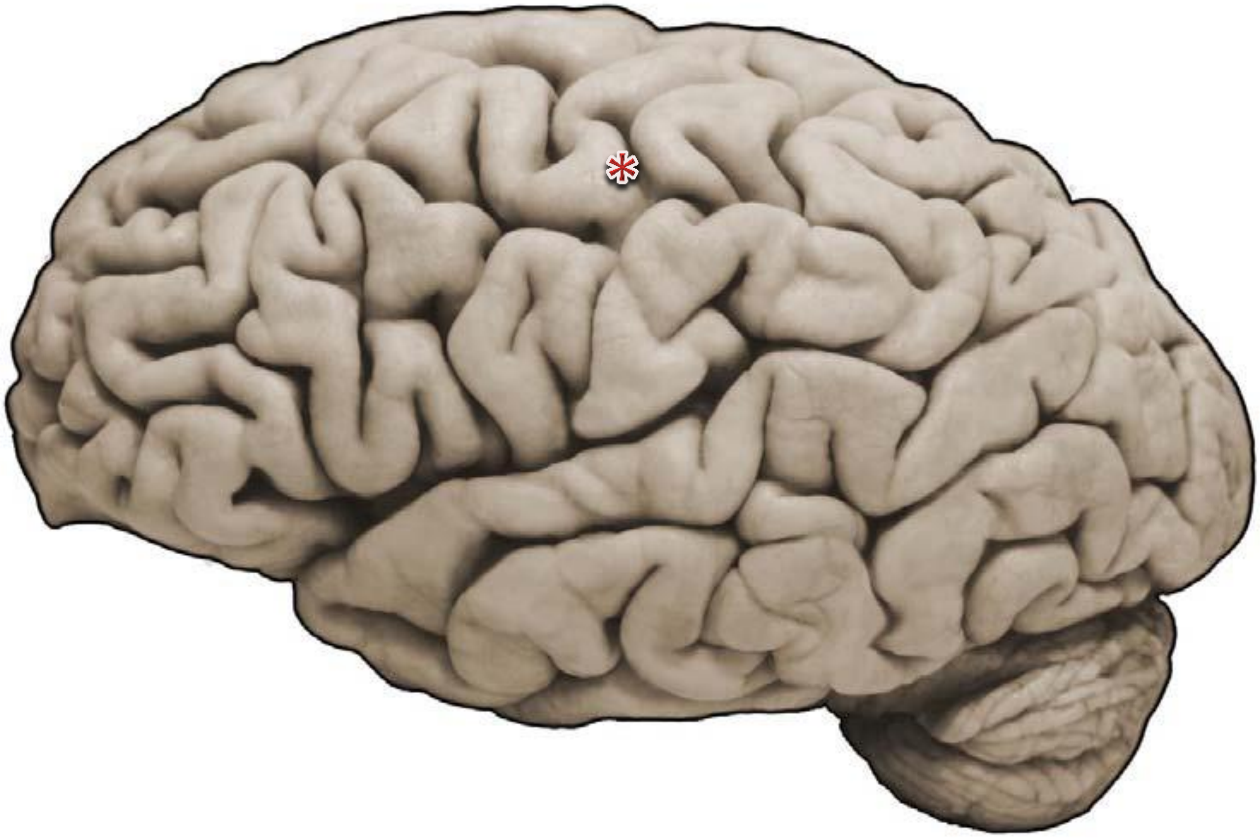

Fig. 2. Lateral surface of the human brain. This figure is not labeled so that you may refer to it for review; see **Figures A3** & **A10** for an illustrated and labeled view of the same hemisphere. The asterisk marks the lazy "S"-shaped bend in the central sulcus near the middle of the cerebral hemisphere. (Image from ***Sylvius4 Online***)

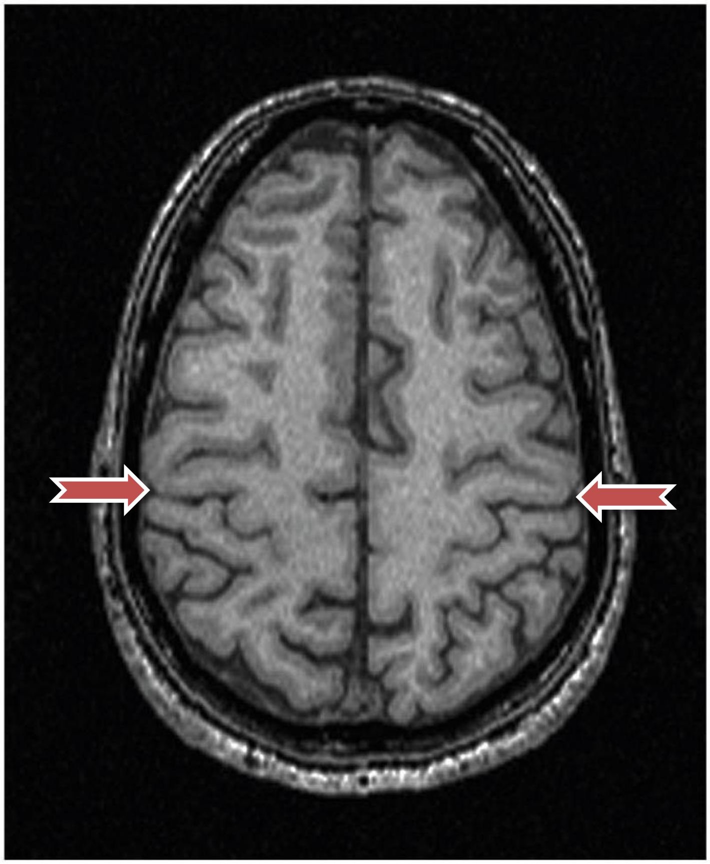

Fig. 3. Axial image through the forebrain acquired with T1-weighted MR imaging (anterior is toward the top). The red arrows identify the central sulcus. (Image from ***Sylvius4 Online***)

STUDY QUESTIONS

Which of the following statements concerning the **central sulcus** is most correct?

A. The central sulcus terminates laterally in or very near the longitudinal fissure.
B. The central sulcus terminates medially in or very near the lateral (Sylvian) fissure.
C. The central sulcus by gyral formations that harbor the primary visual cortex in the human brain.
D. The central sulcus is formed by the growth and morphogenesis of the cuneus gyrus and the lingual gyrus of the cerebral cortex in the human brain.
E. The central sulcus is formed by the growth and morphogenesis of the precentral gyrus and the postcentral gyrus of the cerebral cortex in the human brain.

Medical Neuroscience | Tutorial Notes

Ventral Surface of the Brain

MAP TO NEUROSCIENCE CORE CONCEPTS[1]

NCC1. The brain is the body's most complex organ.

LEARNING OBJECTIVES

After study of the assigned learning materials, the student will:

1. Describe the major features of the cerebral lobes, as seen from the ventral view, discussing major gyri and sulci that characterize each lobe.
2. Recognize the major embryological subdivisions of the brain that are visible from the ventral view.

NARRATIVE

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Overview

When you view the lateral aspect of a human brain specimen (see **Figures A3A** and **A11**[2]), three structures are usually visible: the **cerebral hemispheres**, the **cerebellum**, and part of the **brainstem** (although the brainstem is not visible in the specimen photographed in lateral view for **Fig. 1** below). The spinal cord has usually been severed (but we'll consider the spinal cord later), and the rest of the subdivisions are hidden from lateral view by the hemispheres. The diencephalon and the rest of the brainstem are visible on the medial surface of a brain that has been cut in the midsagittal plane. Parts of all of the subdivisions are also visible from the ventral surface of the whole brain. In this set of tutorials, you will find video demonstrations (from the brain anatomy lab) and photographs (in the tutorial notes) of these brain surfaces, and sufficient detail in the narrative to appreciate the overall organization of the parts of the brain that are visible from each perspective. As you work through this text and if you have access to an interactive digital atlas of the human brain, such as ***Sylvius4 Online***, find the structures and regions that are described here[3].

The **cerebral hemispheres** are especially large in humans. They are entirely covered by a 2–3-mm thick

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layer of cells and cellular processes called the **cerebral cortex**. The surface of each hemisphere is highly infolded; the ridges thus formed are known as **gyri** (singular: gyrus) and the valleys are called **sulci** (singular: sulcus) or **fissures** (if they are especially deep). The appearance of the sulci and gyri varies somewhat from brain to brain. (As you might guess, each one has its own name, but it is necessary to become familiar with only a few of them.) The hemispheres are conventionally divided into lobes named for the bones of the skull that overlie them, namely the **frontal**, **parietal**, **occipital** and **temporal lobes** (see **Figure A3**).

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

Ventral aspect of the brain

Fig. 1 below provides another look at the surface of the whole brain (see also **Figure A11**). Most of the subdivisions of the brain can be seen when it is viewed from its ventral aspect. The inferior surfaces of the frontal and temporal lobes of the cerebral hemispheres are prominent in this view. Running along the inferior surface of the frontal lobe near the midline are the olfactory tracts, which arise in little swellings at their anterior ends, the **olfactory bulbs**. The olfactory bulbs receive the axons of sensory cells in the olfactory mucosa (these axons are the first cranial nerve), and neurons in the bulbs give rise to fibers in the olfactory tracts (therefore, the tracts are part of the forebrain). Just superior to the bulbs, of course, is the ventral aspect of the frontal lobe, often referred to as the “orbital cortex” since this is the portion of the frontal lobe the overlies the orbits. The olfactory bulbs and tracts lie in the olfactory sulci (one in each hemisphere). This sulcus divides the **gyrus rectus** at the medial margin of the ventral frontal lobe from the more complex gyral structures that occupy much of the remaining ventral aspect; we will refer to these gyri simply as **orbital gyri**. Most of the ventral aspect of the frontal lobe is visible in **Fig. 1**, except for that posterior portion hidden by the underlying anterior temporal lobes.

On the ventral surface of the temporal lobe, the inferior temporal gyrus occupies most of the visible surface of the lobe (with brainstem and cerebellum intact). However, it is possible to appreciate additional gyral structures on the medial side of the ventral temporal lobe. The medial boundary of the inferior temporal gyrus is formed by two sulci, the rhinal sulcus more anteriorly and the collateral sulcus more posteriorly. Just on the medial side of these sulci are gyral structures that are associated with the *hippocampal formation* (a primitive cortical structure that we will see when we dissect the brain); first, is the **parahippocampal gyrus** and then a medial protuberance of this gyrus called the **uncus**. Just posterior to the parahippocampal gyrus is another prominent structure called the **occipito-temporal gyrus** (also called—especially by functional brain imagers—the **fusiform gyrus**), but this gyrus is mostly hidden from view in **Fig. 1** by the cerebellum.

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

The pons is obvious in this view, as are the **middle cerebellar peduncles**, which attach the pons to the cerebellum. Cranial nerve V (the trigeminal nerve), the largest of the cranial nerves, arises at the level of the pons. Caudal to the pons is the medulla. The columnar swellings on its ventral surface on either side of the midline are known as the **medullary pyramids**. They contain axons that arise in the precentral (the motor cortex) and the postcentral gyri (the somatic sensory cortex) and terminate in the spinal cord (i.e., the corticospinal tract) and medulla (a portion of the corticobulbar tract). Lateral to the pyramids are the **inferior olives**. Caudal to the medulla, a portion of the cervical spinal cord is seen. Cranial nerves VI-XII arise from the medulla or at the junction of the pons and medulla. We will consider them in detail later, when we discuss more comprehensively the brainstem and its relation to the cranial nerves (see the tutorial, ***Surface Anatomy of the Brainstem***).

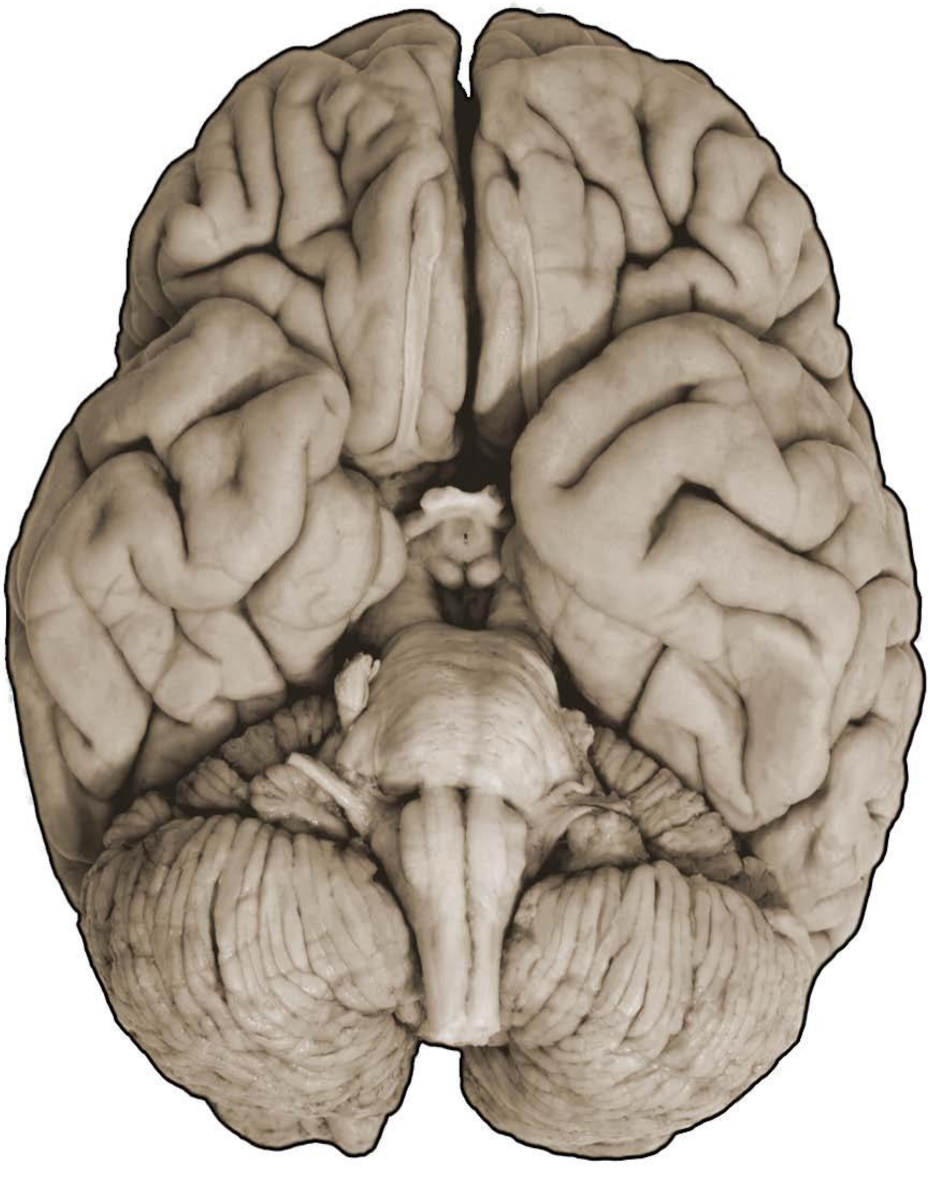

Fig. 1. The ventral surface of the brain. (Image from ***Sylvius4 Online***)

STUDY QUESTION

Which of the following structures is hidden from view when the brain is seen from its **ventral surface**?

A. midbrain
B. hypothalamus
C. corpus callosum
D. medullary pyramids
E. cerebral peduncles

Medical Neuroscience | Tutorial Notes

Blood Supply to the Brain

MAP TO NEUROSCIENCE CORE CONCEPTS[1]

NCC1. The brain is the body's most complex organ.

LEARNING OBJECTIVES

After study of the assigned learning materials, the student will:

1. Identify the major blood vessels that comprise the anterior and posterior circulation of the brain.
2. Discuss the source of blood to the anterior and posterior circulation.
3. Sketch the anastomotic ring of blood vessels (the circle of Willis) at the base of the brain.
4. Identify the major blood vessels that supply the spinal cord.
5. Describe the system of vessels for venous drainage of blood from the brain into the jugular veins.

NARRATIVE

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Overview of the anterior and posterior circulation

This tutorial contains a brief overview of the distribution of blood supply to each subdivision of the brain and to the spinal cord. Lesions involving the different vessels and their branches lead to specific syndromes that are easy to understand if you learn the distribution patterns of the vessels and the organization of the brain and spinal cord subdivisions that they supply.

The brain receives its arterial supply from two sources: the **internal carotid arteries** and the **vertebral/basilar arteries** (the two vertebral arteries join to form the basilar artery at the base of the pons). Both the internal carotid arteries and the vertebral/basilar arteries give rise to four main branches, commonly referred to as the *anterior circulation* and the *posterior circulation*, as depicted in the chart (next page; see also **Figures A15 & A16**[2]. This chart accounts for the major branches of the carotid and vertebral/basilar arteries. The two systems of arteries are joined at the junction between

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[1] Visit **BrainFacts.org** for *Neuroscience Core Concepts* (©2012 Society for Neuroscience) that offer fundamental principles about the brain and nervous system, the most complex living structure known in the universe.

[2] Figure references to Purves et al., *Neuroscience, 5th Ed.*, Sinauer Assoc., Inc., 2012. [click here]

the posterior communicating artery and the posterior cerebral artery. In most humans, the posterior cerebral artery receives its blood supply from the vertebral/basilar system. In some people, the posterior communicating artery is quite large, and the posterior cerebral artery may be perfused significantly by the carotid artery.

Generally speaking, the anterior circulation supplies the forebrain (the cerebral hemispheres and the diencephalon), and the posterior circulation supplies the brainstem and the upper spinal cord. However, for most people, the arterial supply to the CNS is not quite that simple. As just mentioned, the posterior cerebral artery supplies the posterior forebrain, including some deep structures, and it also supplies parts of the midbrain in the brainstem. Thus, as indicated in the chart (by listing the posterior cerebral artery twice, once in each group), the posterior cerebral artery contributes to both the anterior and posterior circulations. As you study this tutorial, you should learn the distributions of these 8 arteries listed in this chart.

Supply	Cerebral artery	Group
Internal carotid	1. Anterior cerebral artery 2. Middle cerebral artery 3. Anterior choroidal artery 4. Posterior communicating artery 5. Posterior cerebral artery	Anterior circulation
Vertebral / Basilar	5. Posterior cerebral artery 6. Superior cerebellar artery 7. Anterior inferior cerebellar artery 8. Posterior inferior cerebellar artery	Posterior circulation

The anterior circulation

The four major arteries that arise from the **internal carotid artery** plus the posterior cerebral artery form the *anterior circulation*. The pattern of branching of each artery is similar: each gives rise to branches that supply cortical structures and each gives rise to branches that penetrate the ventral surface of the brain and supply deep structures (the basal ganglia, thalamus and internal capsule), as illustrated in the **Figures A17 & A18**. (The branches that supply deep structures are known collectively as perforating arteries, central arteries, striate arteries, or ganglionic arteries.)

An extensive region of the central and lateral cerebral hemispheres is supplied by the **middle cerebral artery** (green shade in **Figure A18**). Included in this region are the sensorimotor areas that govern the upper extremities and face, and the language areas of the left hemisphere (Broca's area and Wernicke's area). The **anterior cerebral artery** supplies regions in the medial aspect and dorsal and orbital margins of the frontal lobe, and the medial aspect and dorsal margin of the anterior parietal lobe (yellow shade in **Figure A18**). Included in this extended territory are sensorimotor areas in the paracentral lobule that govern the lower extremity, accessory motor areas in the cingulate gyrus that govern the upper face (see **Box 17A** in *Neuroscience, 5th Ed.*), and limbic areas in the medial frontal lobe. The **posterior cerebral artery** supplies regions in the posterior parietal lobe, inferior temporal lobe and occipital lobe (blue shade in **Figure A18**). Included in this region are primary and associational (higher-order) visual areas in each lobe and 'limbic' regions in the posterior cingulate and parahippocampal gyri.

At this point, you should recognize that this tutorial on blood supply affords the opportunity to review what you have already learned regarding the localization of function in the cerebral cortex. One of the main goals of this course is to understand the functional consequences of injury to various structures in the human central nervous system. One of the most prevalent forms of brain injury is attributable to cerebral vascular disease (i.e., cerebral vascular accident or stroke). To prepare you for considering clinical cases involving stroke (which we will do later in the course), work to become thoroughly familiar with the distributions of the major cerebral arteries relative to the cerebral cortex. Refer back to previous tutorials and review as many of the specific functional areas of the cerebral cortex as were identified (note the bold terms, including Broca's and Wernicke's areas). More generally, as you study the distribution of the cerebral vessels and what you now know about the four lobes of the cerebral cortex, see if you can predict what kinds of neurological signs and symptoms might result from stroke involving the right or left anterior, middle or posterior cerebral arteries.

Each of the four major branches of the internal carotid artery give rise to penetrating branches, in addition to the superficial branches just described, that supply gray and white matter structures deeper in each hemisphere. These deep branches follow a reasonably straight-forward, anterior-to-posterior pattern of branching (see **Figure A18**). We will introduce the deep structures of the cerebral hemispheres in a later tutorial; here, you should simply learn the basic pattern of deep supply outlined below. The anterior cerebral artery supplies the anterior caudate and putamen, the nucleus accumbens, and the anterior limb of the internal capsule—all structures in the anterior deep forebrain. The middle cerebral artery supplies the body of the caudate and most of the putamen, most of the globus pallidus, the middle part (or genu) of the internal capsule, and the anterior hypothalamus—all structures near the middle of the deep forebrain. These deep penetrating branches of the middle cerebral artery are usually called the **lenticulostriate arteries** (see **Figure A18**). The **anterior choroidal artery** supplies the amygdala, hippocampus, the anterior part of the thalamus, part of the globus pallidus, the posterior limb of the internal capsule, and the choroid plexus of the lateral ventricle—all structures that are also in middle of the deep forebrain, but mainly just posterior to the distribution of the lenticulostriate arteries. Lastly, the posterior communicating and posterior cerebral arteries supply the posterior hypothalamus, most of the thalamus, and the choroid plexus of the third ventricle—all structures in the posterior deep forebrain. (Branches of the posterior cerebral artery also supply the midbrain as described later.)

The good news is that it is not necessary to remember all of these details! You should, however, know the arteries in bold font above, and you should remember that the deep structures of the forebrain are divided approximately into four sectors progressing from anterior to posterior, and each sector is perfused by a different artery.

The posterior circulation

The pattern of arterial distribution is similar in all three subdivisions of the brainstem, as illustrated schematically in **Fig. 1** below. The specific pattern in each subdivision is shown in *Neuroscience, 5th Ed.*, **Figure A19**.

The brainstem blood supply can be loosely divided into median and paramedian perforating arteries, lateral perforating arteries and dorsal perforating arteries. The vertebral and basilar arteries and their four major branches give rise to these perforating arteries. As their names imply, the three cerebellar arteries also supply the cerebellum.

Each of the three subdivisions of the brainstem can be divided into medial and lateral 'wedges' of tissue that are supplied by different perforating branches. Vascular lesions that affect individual wedges of brainstem tissue lead to distinct neurological syndromes, as you will study later in this course in the context of understanding the organization of long pathways in the brainstem and the distribution of cranial nerve nuclei. For now, note that most vascular lesions of the brainstem are usually *unilateral*, since each side of the brainstem is supplied by different sets of circumferential vessels. However, this may not be true if the basilar artery itself is blocked, since it gives rise to vessels that supply both sides.

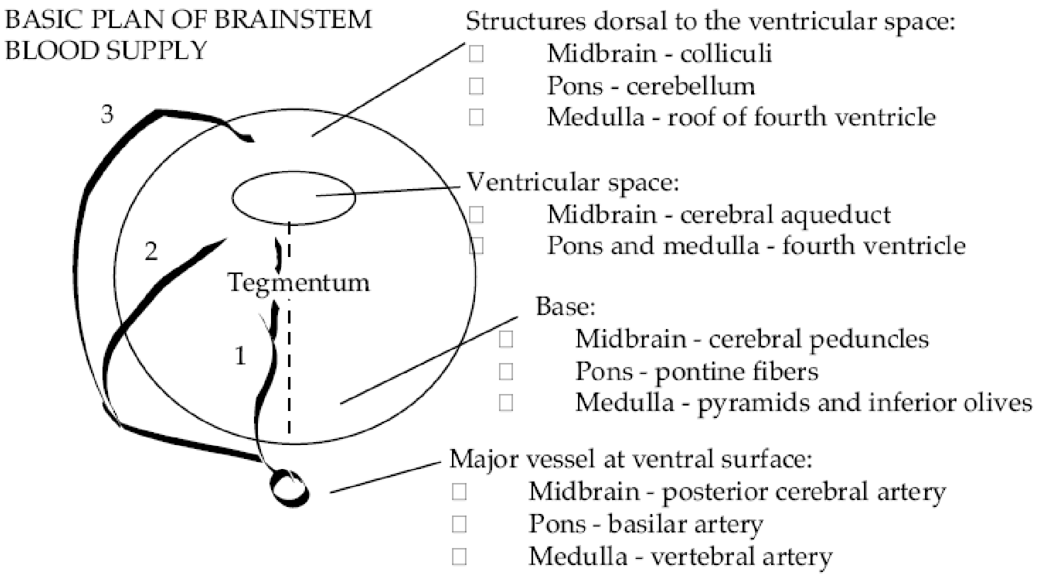

Fig. 1. The basic plan of blood supply to the brainstem. The major vessel on the ventral surface of the brainstem gives rise to:

1. median and paramedian perforating arteries
2. lateral perforating arteries (short circumferential arteries)
3. dorsal perforating arteries (long circumferential arteries)

Drainage of venous blood

Figure A15A (*Neuroscience, 5th Ed.*) illustrates the system of veins that provides for the drainage of venous blood from the brain and cranium. This figure provides an overview of the means by which blood completes its passage through the brain from the arterial vasculature back to the heart via the internal jugular veins. In brief, the more superificial veins of the cerebrum drain into the **superior sagittal sinus** along the dorsal midline of the hemisphere, or the **cavernous sinus** in the base of the cranium. The deeper veins of the brain drain into the **inferior sagittal sinus** at the inferior margin of the falx cerebri, and the great vein of Galen, which in turn join to form the straight sinus. The major venous sinuses inside the cranium are formed by a separation of the two layers of dura mater. The superior sagittal sinus and the straight sinus drain into a pair of **transverse sinuses**, which are oriented roughly in the horizontal plane along the posterior margin of the tentorium. The transverse sinuses then turn in the inferior direction, becoming the **sigmoid sinuses**, which finally exit the cranial vault as the **internal jugular veins**.

The arterial supply of the spinal cord

The arterial blood that supplies the spinal cord comes from two sources: the vertebral arteries (and/or posterior inferior cerebellar arteries) and segmental arteries that arise from branches of the aorta. These arteries join the **anterior** and **posterior spinal arteries** (as illustrated in **Figure A16**). At the level of the medulla, the vertebral arteries give off branches that merge to form the single anterior spinal artery. Approximately 10 segmental arteries (that arise from various branches of the aorta) join the anterior spinal artery along its course. These segmental arteries are known as medullary arteries. [Other segmental arteries supply the dorsal root ganglia but do not join the spinal artery; these are known as radicular arteries]. It is important to realize that if any of the medullary arteries are obstructed or damaged, blood supply to part of the spinal cord may be compromised and neurological damage will result. The pattern of damage depends on whether the supply to the posterior arteries or anterior artery is interrupted. An anastomotic network of vessels known as the **vasocorona** connects these two sources of supply and sends branches into a narrow zone of white matter around the margin of the spinal cord. The vasocorona may be sufficient to supply the most lateral white matter in cases in which the anterior spinal artery is occluded. The anterior spinal artery gives rise to about 200 sulcal arteries that branch to supply the anterior two-thirds of the spinal cord. Thus, the anterior spinal artery supplies the ventral horn and the surrounding ventral and lateral columns of white matter.

The vertebral arteries (or the posterior inferior cerebellar artery) also give rise to paired posterior spinal arteries that run along the dorsal (posterior) surface of the spinal cord. As for the anterior spinal artery, medullary arteries supply the posterior spinal artery (actually an anastomotic network of arteries) along its length. The posterior spinal artery gives rise to branches that penetrate the posterior one-third of the spinal cord and so supply much of the dorsal horn and the dorsal columns.

STUDY QUESTIONS

Q1. A patient presents with “foot drop”, meaning that when the person walks, one foot is “floppy” requiring exaggerated movements to compensate for weak ankle dorsiflexion during ambulation. (There were no other major complaints or impairments.) There are different possible etiologies for this particular neurological dysfunction, including peripheral neuropathy. However, you should also consider a stroke involving **blood supply to the cerebral cortex**.

Of the possible stroke syndromes attributable to major cerebral arteries, which one is most likely to give this patient **foot drop**?

A. anterior choroidal artery
B. middle cerebral artery
C. posterior cerebral artery
D. anterior cerebral artery
E. vertebral artery

Q2. The supply of blood to the **spinal cord** is derived from which vessels?

A. the vertebral arteries only
B. medullary (segmental) arteries only
C. posterior inferior cerebellar arteries only
D. radicular arteries only
E. medullary (segmental) arteries and vertebral arteries

Medical Neuroscience | Tutorial Notes

Cranial and Spinal Nerves

MAP TO NEUROSCIENCE CORE CONCEPTS[1]

NCC1. The brain is the body's most complex organ.

LEARNING OBJECTIVES

After study of the assigned learning materials, the student will:

1. Discuss the functions of the cranial nerves in terms of the sensory and motor signals conveyed by each nerve.
2. Discuss the organization and composition of a typical spinal nerve.

NARRATIVE

by **Leonard E. White** and **Nell B. Cant**
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Introduction

After working through this tutorial, you should be able to discuss the composition and function of the cranial nerves, and you should be able to discuss the general organization of spinal nerves. In the next tutorial, you will learn how the cranial nerves relate to gray matter structures in the brainstem that grew out the axons in the cranial nerves (motor axons) or receive synaptic input from ganglionic neurons associated with the nerves (sensory axons). But before proceeding, you should make sure that you understand the basic layout of sensory and motor neurons in the brainstem and spinal cord.

The central nervous system interacts with the outside world through primary sensory neurons, which convey information from the body or its environment into the brain and spinal cord, and motor neurons, which activate striated muscles and modulate the activity of cardiac and smooth muscles and glands (see **Fig. 1** below and/or **Figure A1A**[2]). The cell bodies of primary sensory neurons lie in the **dorsal root ganglia** or the **cranial nerve ganglia**. Each neuron gives rise to a peripheral process, which receives information either directly or through association with receptors, and a central process, which enters the central nervous system and forms synapses with second order neurons. The cell bodies of somatic motor neurons lie in clusters or **nuclei** within the central nervous system and give rise to axons that innervate striated muscles in the body or head. You will also be introduced to other motor neurons that are part of the visceral motor system (a.k.a., autonomic nervous system) and are indirectly responsible

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[2] Figure references to Purves et al., *Neuroscience, 5th Ed.*, Sinauer Assoc., Inc., 2012. [click here]

for governing cardiac muscle, smooth muscle or glands. By the conclusion of this and the next tutorial, you will learn how to locate:

1. nuclei that are the destination of all primary somatic sensory, visceral sensory, and special sensory *input* into the CNS (i.e., the location of all of the second-order neuronal cell bodies that receive the primary sensory input), except for olfaction and vision. The olfactory nerve and the optic nerve are not included in this discussion; for several reasons they are atypical.
2. nuclei that are the origin of all of the somatic and visceral motor *output* of the CNS (i.e., the location of all of the alpha motor neurons and preganglionic visceral motor neurons).

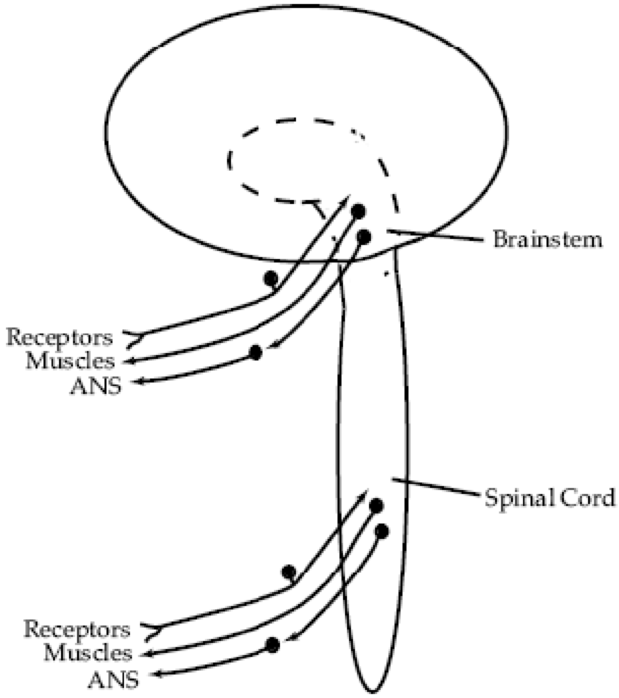

Fig. 1. Both the spinal cord and brainstem receive input from primary sensory neurons; the cell bodies of these neurons lie in sensory ganglia. In addition, both the spinal cord and brainstem give rise to motor output to striated muscles and to the autonomic ganglia (*ANS*, autonomic nervous system; synonymous with visceral motor system). (Illustration by N.B. Cant)

From the viewpoint of clinical practice, the most important general principle of organization in the central nervous system is that each ***CNS function*** (e.g., perception of sensory stimuli, control of motor behavior) ***involves groups of neurons—interconnected through synapses—that are spatially distributed throughout several CNS subdivisions***. Groups of neurons that together subserve a particular function are called a ‘system’; for example, there are the visual, motor, and somatic sensory systems. The structures containing the neurons and axons of a particular system are collectively referred to as a ‘pathway’. (The term ‘system’ has a functional connotation, whereas the term ‘pathway’ refers to the structures involved.) We will study several important sensory and motor pathways in detail in future tutorials.

Simple tests of cranial nerve function provide clues for localization of neurological injury and disease

One means for reinforcing your understanding of the functional significance of the cranial nerves is to actually test their functions in yourself and a willing friend or family member. Review **Table A2** below (from Purves et al., *Neuroscience, 5th Ed.*, Sinauer Assoc., Inc.), which lists the cranial nerve nuclei from which the sensory and motor components of each nerve arise. Then, consider the means by which you would assess the functional integrity of the cranial nerves. Actually, there are a number of tests of cranial nerve function that can be done with very simple materials. These tests provide considerable information about the presence or absence of normal function in the brainstem and the nerves themselves. Some of these are described on these next few pages to give you an idea of the types of tests that can be used and why a foundational understanding of functional neuroanatomy is critical for clinical practice[3].

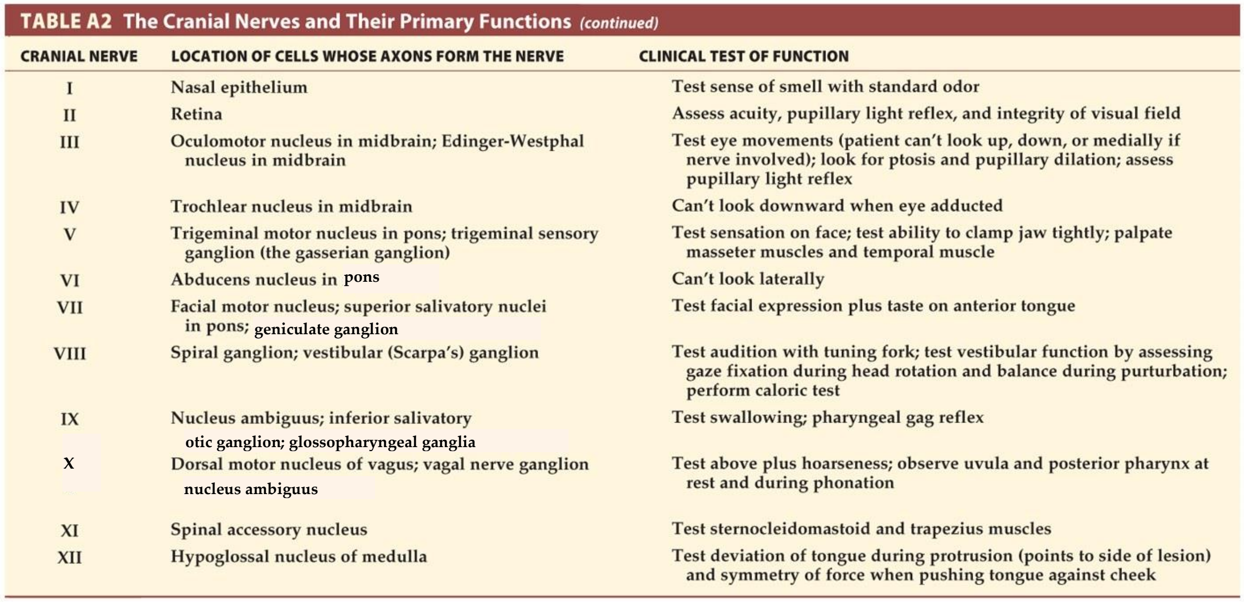

TABLE A2 The Cranial Nerves and Their Primary Functions *(continued)*

CRANIAL NERVE	LOCATION OF CELLS WHOSE AXONS FORM THE NERVE	CLINICAL TEST OF FUNCTION
I	Nasal epithelium	Test sense of smell with standard odor
II	Retina	Assess acuity, pupillary light reflex, and integrity of visual field
III	Oculomotor nucleus in midbrain; Edinger-Westphal nucleus in midbrain	Test eye movements (patient can't look up, down, or medially if nerve involved); look for ptosis and pupillary dilation; assess pupillary light reflex
IV	Trochlear nucleus in midbrain	Can't look downward when eye adducted
V	Trigeminal motor nucleus in pons; trigeminal sensory ganglion (the gasserian ganglion)	Test sensation on face; test ability to clamp jaw tightly; palpate masseter muscles and temporal muscle
VI	Abducens nucleus in pons	Can't look laterally
VII	Facial motor nucleus; superior salivatory nuclei in pons; geniculate ganglion	Test facial expression plus taste on anterior tongue
VIII	Spiral ganglion; vestibular (Scarpa's) ganglion	Test audition with tuning fork; test vestibular function by assessing gaze fixation during head rotation and balance during purturbation; perform caloric test
IX	Nucleus ambiguus; inferior salivatory otic ganglion; glossopharyngeal ganglia	Test swallowing; pharyngeal gag reflex
X	Dorsal motor nucleus of vagus; vagal nerve ganglion nucleus ambiguus	Test above plus hoarseness; observe uvula and posterior pharynx at rest and during phonation
XI	Spinal accessory nucleus	Test sternocleidomastoid and trapezius muscles
XII	Hypoglossal nucleus of medulla	Test deviation of tongue during protrusion (points to side of lesion) and symmetry of force when pushing tongue against cheek

***NEUROSCIENCE 5e,* Table A2 (Part 2)**
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Cranial nerves III, IV, and VI

These nerves are tested as a unit, since all supply muscles for eye movement. The oculomotor nerve also supplies the levator muscle that elevates the lids and the smooth muscles that constrict the pupils. Range of ocular movement is checked by asking the patient to follow the movements of the examiner's fingers as they are moved in all directions of gaze. With involvement of the oculomotor nerve, the patient will not be able to look up, down or medially with the affected eye. There will also be dilatation of the pupil and droopiness (ptosis) or closure of the lid on the affected side. If the trochlear nerve is affected, the patient will be unable to look downward when the eye is adducted. If the abducens nerve is affected, the patient will not be able to look laterally with the involved eye. In any of these cases, the patient may complain of double vision. (It is important to remember that either the nerves themselves or their nuclei in the midbrain and pons may be involved.) Examination of the pupillary reflexes involving nerves II and III will be explored in a later course session.

Cranial nerve V

The examiner first checks for the presence of the several types of sensation and then determines whether both sides of the face are equally sensitive. Failure to feel wisps of cotton touching the forehead, cheeks and jaw indicates anesthesia to light touch. Differences in response on the two sides of the face indicate increased or decreased sensitivity to light touch. The same procedure is followed in

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[3] For more on cranial nerve exams, visit **neuroexam.com** [click here] and explore videos that show tests of cranial nerve function, with accompanying explanation by Dr. Hal Blumfeld, MD, PhD (author of *Neuroanatomy through Clinical Cases*; Sinauer Assoc., Inc.).

testing for degree of sensitivity to pinpricks and to warm and cold objects.

The masseter and temporalis muscles (muscles of mastication innervated by the motor component of the fifth nerve) are examined by palpating them when the jaws are clamped tightly together. The examiner should note whether there is deviation of the jaw when the mouth is opened.

Cranial nerve VII

The patient is asked to imitate the examiner as he or she looks at the ceiling, wrinkles the forehead, frowns, smiles, shows teeth, and raises the eyebrows. Any asymmetry of the face is noted. To test the strength of the eyelid muscles, the patient is asked to keep his or her eyes closed while the examiner attempts to open them. The sensory portion of the facial nerve can be tested by having the patient identify the taste of sugar or salt placed on the anterior part of the tongue on each side.

Cranial nerve VIII

The eighth nerve is divided into two parts, the cochlear or auditory nerve and the vestibular nerve. Special equipment is required to examine the vestibular nerve and it is not tested routinely. (If the patient gives a history of vertigo or disturbed balance, the possibility of vestibular dysfunction should be considered and the patient can be given a caloric test, which is described in Purves et al., *Neuroscience 5th Ed.*, Chapter 14, Box 14C.) Preliminary tests of hearing can be done with a tuning fork, but detailed auditory testing is done by an audiologist.

Cranial nerves IX and X

The pharyngeal gag reflex is tested by touching each side of the pharynx with a tongue depressor or applicator stick. The palatal reflex is tested by stroking each side of the mucous membrane of the uvula. The side touched should rise. Normal function of the vagus nerve is revealed by the patient's ability to swallow and to speak clearly without hoarseness, by symmetrical movements of the vocal cords, and by symmetrical movements of the soft palate when he or she says "Ahhh."

Cranial nerve XI

The examiner 1) palpates and notes the strength of the trapezius muscle while the shoulders are shrugged against resistance, and 2) palpates and tests the sternocleidomastoid muscle for strength.

Cranial nerve XII

Any lateral deviation of the tongue when it is protruded is noted. The examiner also looks for atrophy or tremor of the tongue. The strength of the tongue is tested by asking the patient to protrude it and to move it from side to side against a tongue depressor.

The spinal cord

The spinal cord extends caudally from the brainstem, running from the medullary-spinal junction at about the level of the first cervical vertebra to about the level of the twelfth thoracic vertebra. The vertebral column (and the spinal cord within it) is divided into **cervical**, **thoracic**, **lumbar**, **sacral**, and **coccygeal** regions. The peripheral nerves (called the spinal or segmental nerves) that innervate much of the body arise from the spinal cord's 31 pairs of spinal nerves. On each side of the midline, the cervical region of the cord gives rise to eight cervical nerves (C1–C8), the thoracic region to twelve thoracic nerves (T1–T12), the lumbar region to five lumbar nerves (L1–L5), the sacral region to five sacral nerves

(S1–S5), and the coccygeal region to one coccygeal nerve. The segmental spinal nerves leave the vertebral column through the intervertebral foramina that lie adjacent to the respectively numbered vertebral body. Sensory information carried by the afferent axons of the spinal nerves enters the cord via the dorsal roots, and motor commands carried by the efferent axons leave the cord via the ventral roots. Once the dorsal and ventral roots join, sensory and motor axons (with some exceptions) travel together in the segmental spinal nerves.

Two regions of the spinal cord are enlarged to accommodate the greater number of nerve cells and connections needed to process information related to the upper and lower limbs. The spinal cord expansion that corresponds to the arms is called the cervical enlargement and includes spinal segments C3–T1; the expansion that corresponds to the legs is called the lumbar enlargement and includes spinal segments L1–S2. Because the spinal cord is considerably shorter than the vertebral column, lumbar and sacral nerves run for some distance in the vertebral canal before emerging, thus forming a collection of nerve roots known as the *cauda equina*. This region is the target for an important clinical procedure called a "lumbar puncture" that allows for the collection of cerebrospinal fluid by placing a needle into the space surrounding these nerves to withdraw fluid for analysis. In addition, local anesthetics can be safely introduced to produce spinal anesthesia; at this level, the risk of damage to the spinal cord from a poorly placed needle is minimized.

STUDY QUESTION

Q1. Identify the CORRECT pairing of **cranial nerve** to function.

A. hypoglossal nerve / movement of facial muscles for expression
B. trigeminal nerve / somatic sensation from face
C. optic nerve / eye movements
D. abducens nerve / medial eye movement (eye adduction)
E. spinal accessory nerve / vocal articulation

Q2. Which of the following structures associated with the spinal cord contains the cell bodies of **primary somatic sensory neurons**?

A. dorsal column
B. ventral horn
C. dorsal horn
D. dorsal root ganglia
E. sympathetic chain ganglia

Medical Neuroscience | Tutorial Notes

Internal Anatomy of the Brainstem

MAP TO NEUROSCIENCE CORE CONCEPTS[1]

NCC1. The brain is the body's most complex organ.

LEARNING OBJECTIVES

After study of the assigned learning materials, the student will:

1. Identify the major subdivisions of the brainstem and spinal cord, as seen in representative transverse cross-sections.

NARRATIVE

by **Leonard E. White** and **Nell B. Cant**
Duke Institute for Brain Sciences
Department of Neurobiology
Duke University School of Medicine

Introduction

Of chief importance in understanding the organization of the brainstem is knowledge of what is localized in each embryological subdivision and in any transverse section. This is a significant challenge for every student of neuroanatomy and we will now turn our attention progressively to this challenge. You have already faced the first step toward competency with the essential knowledge: recognition of the external features of each brainstem subdivision, including the associated cranial nerves. After working through this tutorial, you should be able to recognize any transverse section through the brainstem in terms of what level is represented and what distinctive features may be present. But before proceeding, it will be worth again reminding yourself of the basic layout of sensory and motor neurons in the brainstem and spinal cord.

The central nervous system interacts with the outside world through primary sensory neurons, which convey information from the body or its environment into the brain and spinal cord, and motor neurons, which activate striated muscles and modulate the activity of cardiac and smooth muscles and glands (see **Fig. 1** below and/or **Figure A1A**[2]). The cell bodies of primary sensory neurons lie in the **dorsal root ganglia** or the **cranial nerve ganglia**. Each neuron gives rise to a peripheral process, which receives information either directly or through association with receptors, and a central process, which enters the central nervous system and forms synapses with second order neurons. The cell bodies of somatic motor neurons lie in clusters or **nuclei** within the central nervous system and give rise to axons that

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[2] Figure references to Purves et al., *Neuroscience, 5th Ed.*, Sinauer Assoc., Inc., 2012. [click here]

innervate striated muscles in the body or head. In this tutorial, you will be especially concerned with the organization of these second-order sensory neurons and somatic motor neurons. You will also be introduced to other motor neurons that are part of the visceral motor system (a.k.a., autonomic nervous system) and are indirectly responsible for governing cardiac muscle, smooth muscle or glands. By the conclusion of this learning experience, you will learn how to locate:

1. nuclei that are the destination of all primary somatic sensory, visceral sensory, and special sensory *input* into the CNS (i.e., the location of all of the second-order neuronal cell bodies that receive the primary sensory input), except for olfaction and vision. The olfactory nerve and the optic nerve are not included in this discussion; for several reasons they are atypical.
2. nuclei that are the origin of all of the somatic and visceral motor *output* of the CNS (i.e., the location of all of the alpha motor neurons and preganglionic visceral motor neurons).

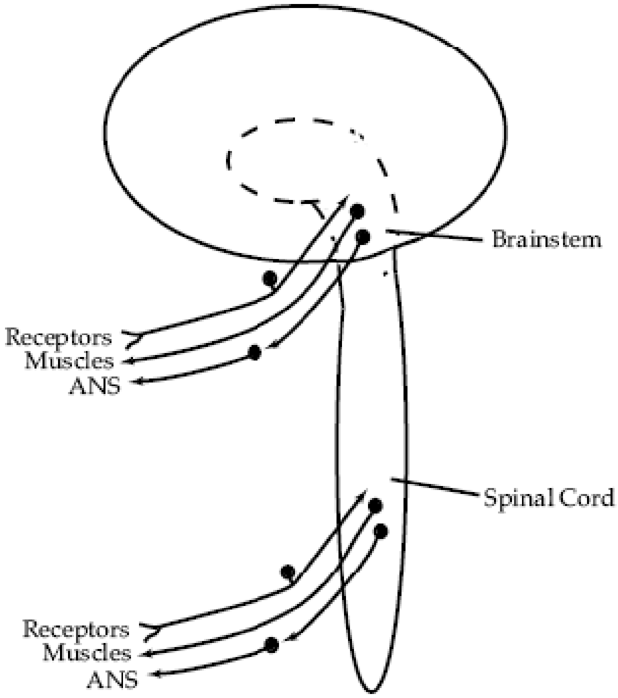


Fig. 1. Both the spinal cord and brainstem receive input from primary sensory neurons; the cell bodies of these neurons lie in sensory ganglia. In addition, both the spinal cord and brainstem give rise to motor output to striated muscles and to the autonomic ganglia (*ANS*, autonomic nervous system; synonymous with visceral motor system). (Illustration by N.B. Cant)

From the viewpoint of clinical practice, the most important general principle of organization in the central nervous system is that each ***CNS function*** (e.g., perception of sensory stimuli, control of motor behavior) ***involves groups of neurons—interconnected through synapses—that are spatially distributed throughout several CNS subdivisions***. Groups of neurons that together subserve a particular function are called a 'system'; for example, there are the visual, motor, and somatic sensory systems. The structures containing the neurons and axons of a particular system are collectively referred to as a 'pathway'. (The term 'system' has a functional connotation, whereas the term 'pathway' refers to the structures involved.) We will study several important sensory and motor pathways in detail in future tutorials.

If damage to the CNS at every level gave rise to exactly the same signs and symptoms, it would not be worthwhile for you to learn the details of neuroanatomy. However, as neurologists and neuroscientists recognized long ago, the neurons involved in specific functions occupy specific locations in the central nervous system. Even those systems that are represented in multiple subdivisions bear different physical relationships to one another from one subdivision to the next. Because neurons that subserve specific functions occupy specific locations, the combinations of neurological signs and symptoms exhibited by particular patients often provide detailed information about the location of damage in the CNS. These principals will guide our survey of the cranial nerve nuclei that are distributed across the three major subdivisions of the brainstem. Knowledge of their location and function will provide key information that will help you localize neurological injury and dysfunction in clinical patients.

The internal anatomy of the brainstem

The internal organization of the brainstem is considerably more complicated than that of the spinal cord. However, two factors work in your favor as you study its features. First, important general principles of organization of the spinal cord also hold true for the brainstem. Second, much of the complexity of the brainstem is contributed by cell groups and axon tracts that will not be considered in this course. In the following discussion, the general plan of organization of the brainstem is presented first. Then, the prominent internal features that characterize each subdivision are identified.

It would be convenient if each subdivision of the brainstem were sufficiently homogeneous along its length that one cross-section could serve as a 'typical' representative for the entire subdivision. However, the brainstem changes continuously along its length—the subdivision into three parts is somewhat arbitrary. As a compromise between examining three sections (one for each subdivision) and hundreds, seven sections of the brainstem are shown to serve as representatives (**Figure 2**).

Once you understand the organization of these seven levels and the way various pathways traverse them, you should be able to identify the location of any section through the brainstem and the important pathways represented in it.

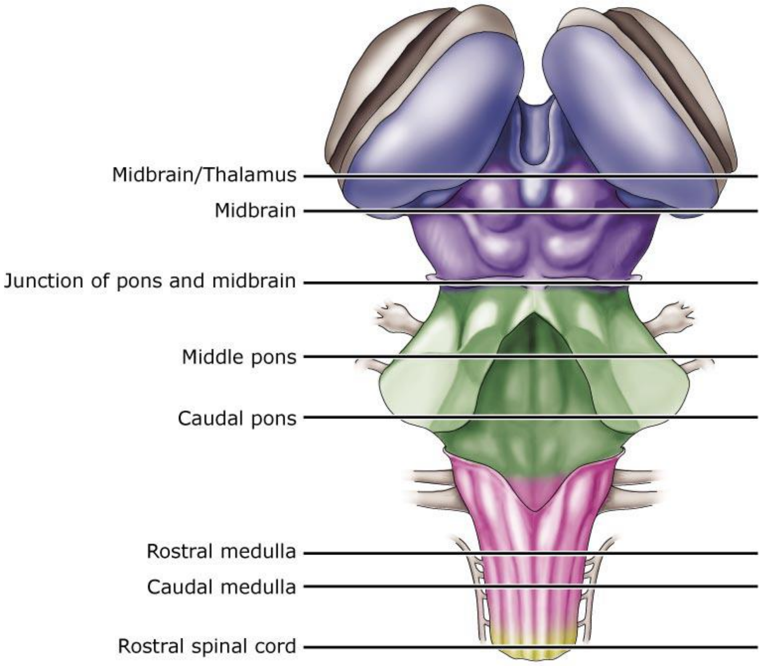
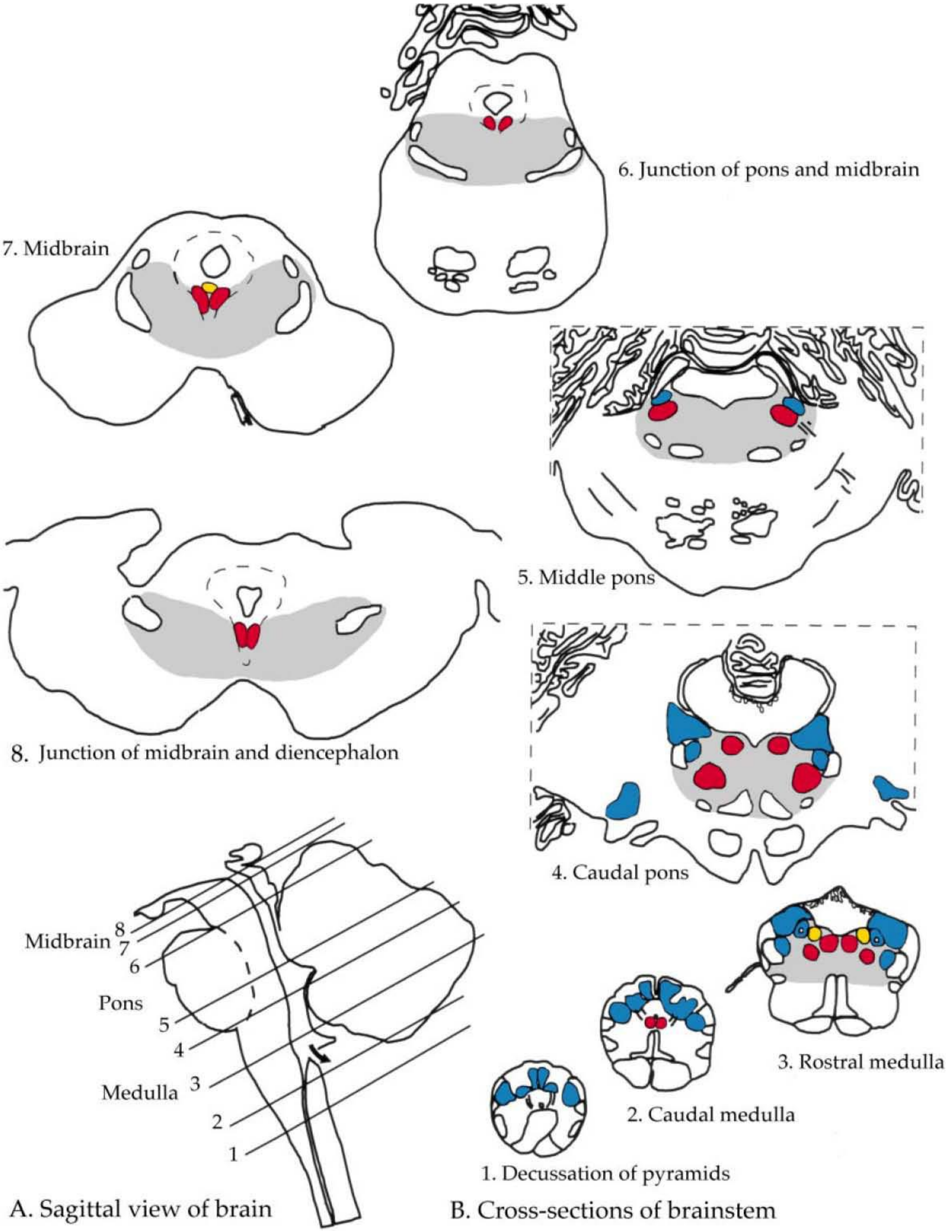


Figure 2. Drawing of the dorsal surface of the brainstem with lines to indicate the seven levels that will be illustrated in the following pages. These same sections are also annotated in the **Brainstem Cross Sectional Atlas** in ***Sylvius4 Online***. (Illustration courtesy of Pyramis Studios, Durham NC)

A schematic overview of the levels of the brainstem to be discussed is presented in **Figure 3**. At this stage, it is not important to study the details; we will come back to them. For now, three points should be taken from the figure. (1) All of the sections are shown at the same magnification. In most atlases (including ***Sylvius4 Online***), the smaller sections are magnified more than the larger ones, and it is easy to lose sight of the relative proportions of the different subdivisions. (2) The cranial nerve nuclei lie in the tegmentum of the brainstem, as do many of the major ascending and descending tracts. (3) Just as in the spinal cord, the nuclei that receive sensory inputs via the cranial nerves are spatially separate from those that give rise to motor output. The sensory nuclei are located laterally in the brainstem, whereas the motor nuclei are located medially. The spatial segregation of sensory and motor functions provides an important clue for localization of focal damage in the brainstem.



A. Sagittal view of brain

B. Cross-sections of brainstem

Figure 3. (previous page) A. Sagittal view of the brainstem to show the level of the sections in part B. (The small curved arrow indicates the location of the median aperture through which cerebrospinal fluid escapes from the ventricular system.) B. Sections through the brainstem. (These are not drawings of the sections illustrated in the following figures, but they are taken from approximately the same levels, with an additional section to illustrate midbrain structures.) The sections are all drawn at the same magnification (a little less than two times actual size). The tegmentum of the brainstem is indicated in gray. Note that although the sections themselves vary greatly in size, the tegmentum is approximately the same size in all of them. Much of the effort in this course will be spent on learning the organization of the structures in the tegmentum. The positions of the cranial nerve nuclei (and also the sensory nuclei known as the dorsal column nuclei, which will be covered in a later session of this course) are indicated. Motor nuclei are represented in red and yellow, indicating **somatic motor** and **visceral motor nuclei**, respectively; **sensory nuclei** are represented in blue; important tracts are represented in unfilled outline. Note that the tracts are external to the sensory and motor nuclei, as is the case in the spinal cord. (Only a portion of the cerebellum is included in the drawings of sections 4, 5 and 6). (Illustration by N.B. Cant)

In **Figures 4–9** on the following pages, major landmarks in each of the subdivisions are identified in sections prepared to enhance the appearance of myelin (again, it is conventional to prepare sections of the brainstem and spinal cord with stains that make the white matter appear dark). As usual, be sure to focus on the structures identified in the figure legends in **bold font**.

Medulla oblongata

[next page]

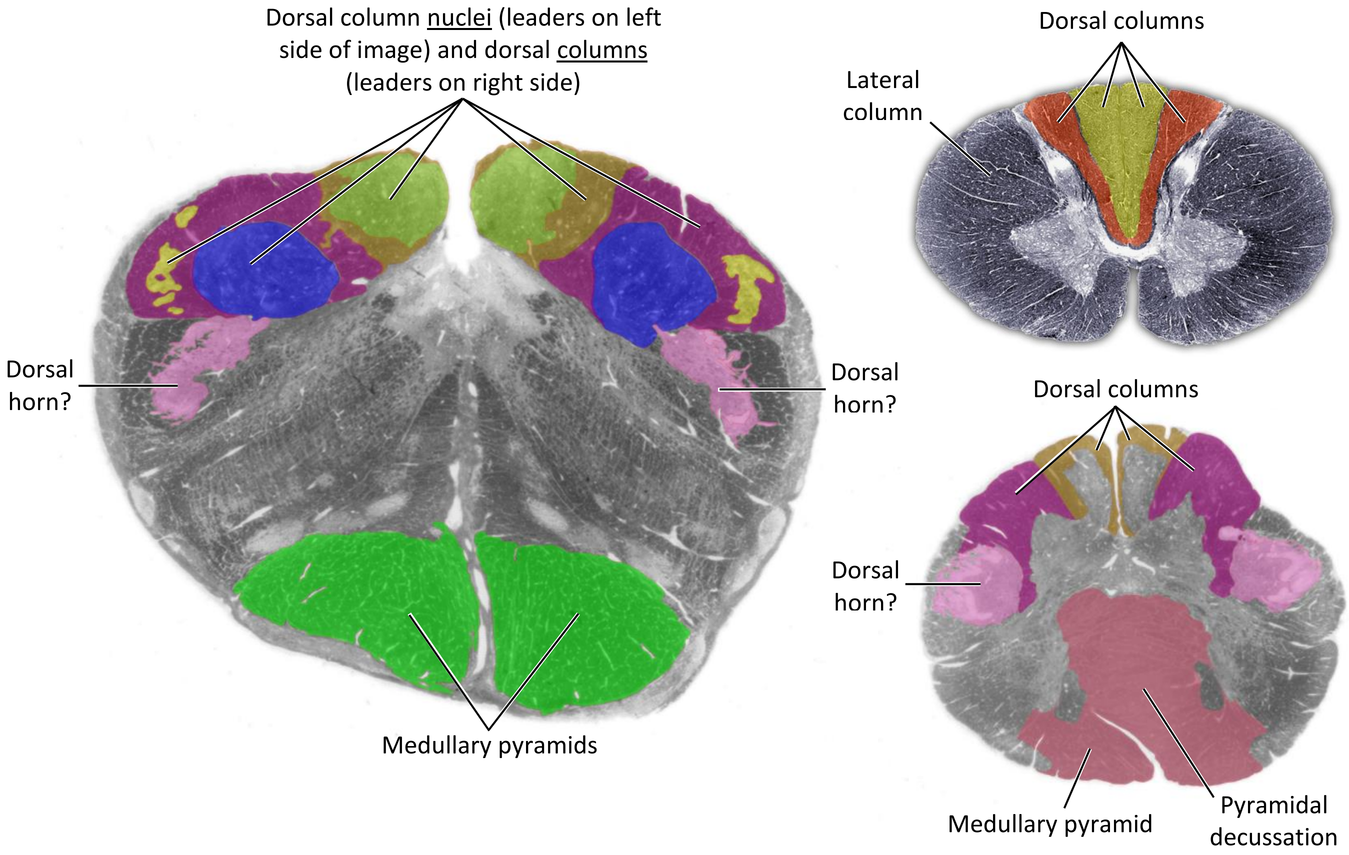


Figure 4. Section through the caudal medulla (left picture; "11-medulla" in ***Sylvius4 Online***). The shape is similar to that of the spinal cord (a section through the cervical cord is shown in top right picture; "14-Spinal Cord-cervical" in ***Sylvius4***). But, although the internal organization bears a resemblance to that of the spinal cord, there are some obvious differences. First, the **medullary pyramids** occupy the base of the caudal medulla; the anterior columns of the spinal cord do not contain so many fibers (and do not have the same pyramidal shape). On the other hand, the lateral columns are quite large in the cervical spinal cord, but there are relatively few myelinated axons in the lateral part of the caudal medulla. The bottom right picture is a photograph of the point of transition between the spinal cord and medulla ("13-medulla" in ***Sylvius4 Online***). Here, at the level of the **pyramidal decussation**, the axons in the pyramids not only cross the midline, they also move laterally to enter the lateral columns of the spinal cord. This change in relative location of the axons explains why the anterior columns of the spinal cord are smaller in size and why the lateral columns are larger when the spinal cord is compared to the caudal medulla. A second difference between the spinal cord and lower medulla is that in the spinal cord, the dorsal columns are made up exclusively of white matter. In the caudal medulla, you can still see bundles of axons dorsally but now cell groups (the **dorsal column nuclei**) have appeared in the same location. These nuclei are second order sensory nuclei that will be discussed in a later session of this course. Finally, note that a cell group that resembles the dorsal horn is also present in the caudal medulla (it is labeled "dorsal horn?"). This is a nucleus known as the **spinal trigeminal nucleus**, and it is continuous with the dorsal horn of the spinal cord and serves comparable functions, except for representation of a different region of the body.

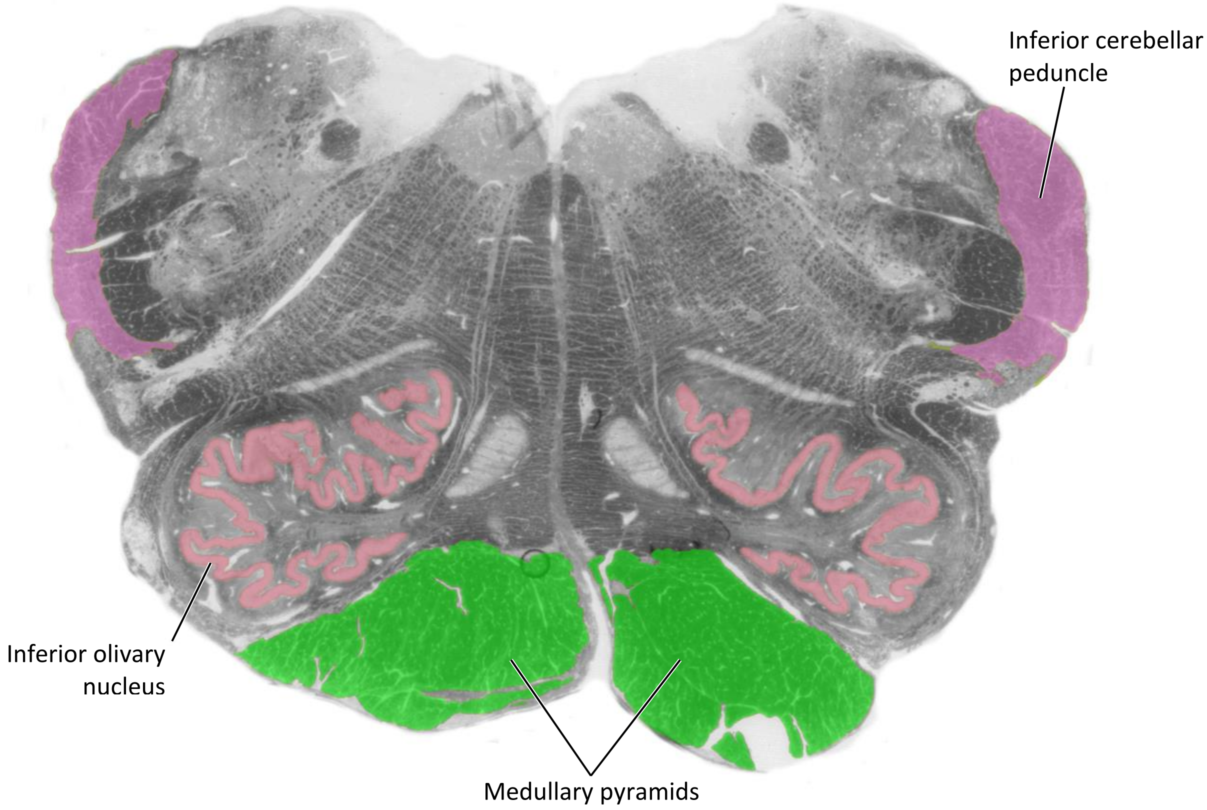


Figure 5. The rostral medulla is easy to identify and is not likely to be confused with any other part of the brain (section shown is "9-medulla" in ***Sylvius4 Online***). It features the large nuclei known as the paired **inferior olivary nucleus** (this is what accounts for the outward bulging seen superficially as the inferior olive). This nucleus is part of an extensive group of brainstem nuclei that project to the cerebellum. Together with the medullary pyramids, they form the base of the rostral medulla. A prominent fiber bundle on the lateral surface of the medulla is the incipient **inferior cerebellar peduncle** (not yet attached to the cerebellum at this point). The thin roof of the fourth ventricle (IV) has been torn off of this specimen. It is made up of pia, ependyma, and blood vessels. You can see that the tegmentum of the medulla contains many different cell groups. They will be discussed later.

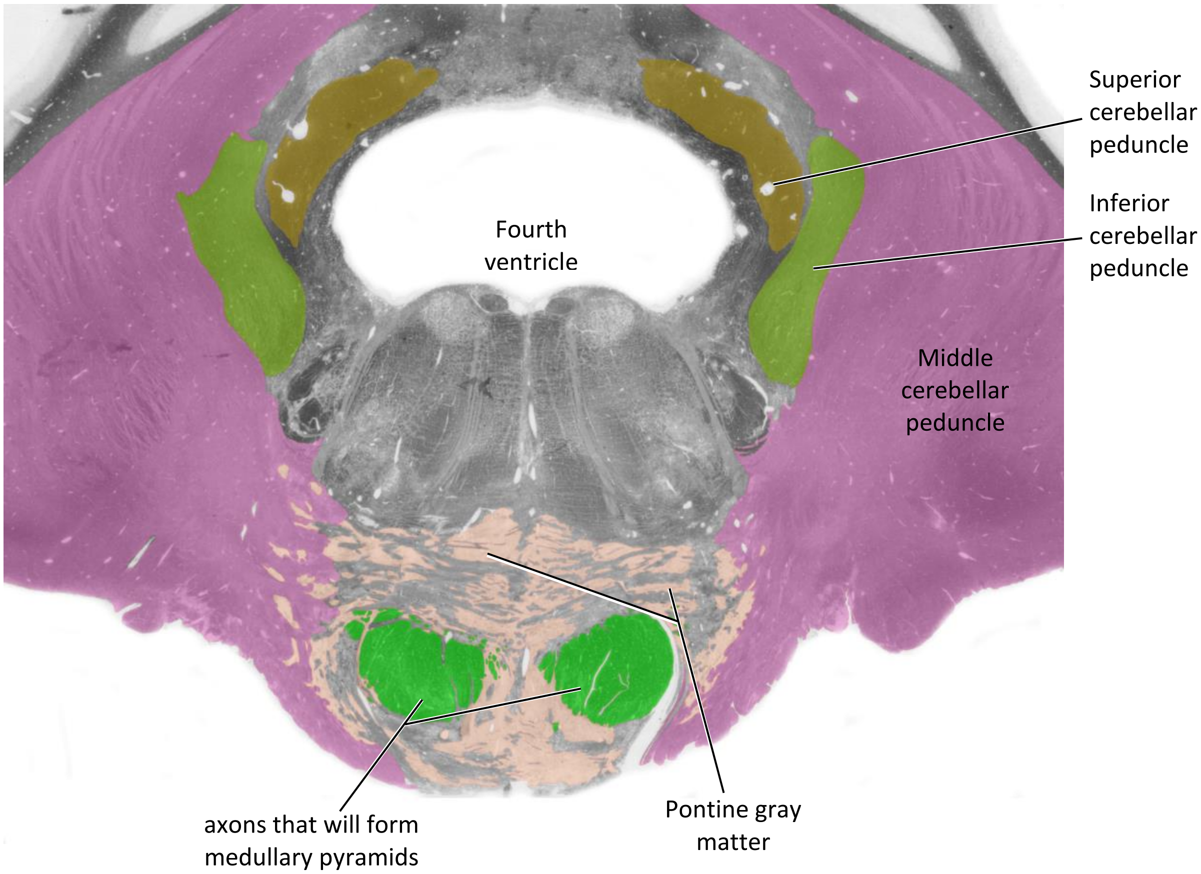
With reference to **Figures 4 & 5** and the chart below, carefully inspect the internal features of the medulla from its caudal union with the spinal cord to the pons. Spend some time browsing these medullary sections (and the sections in ***Sylvius4 Online***), and find each of the internal features described in the chart below.

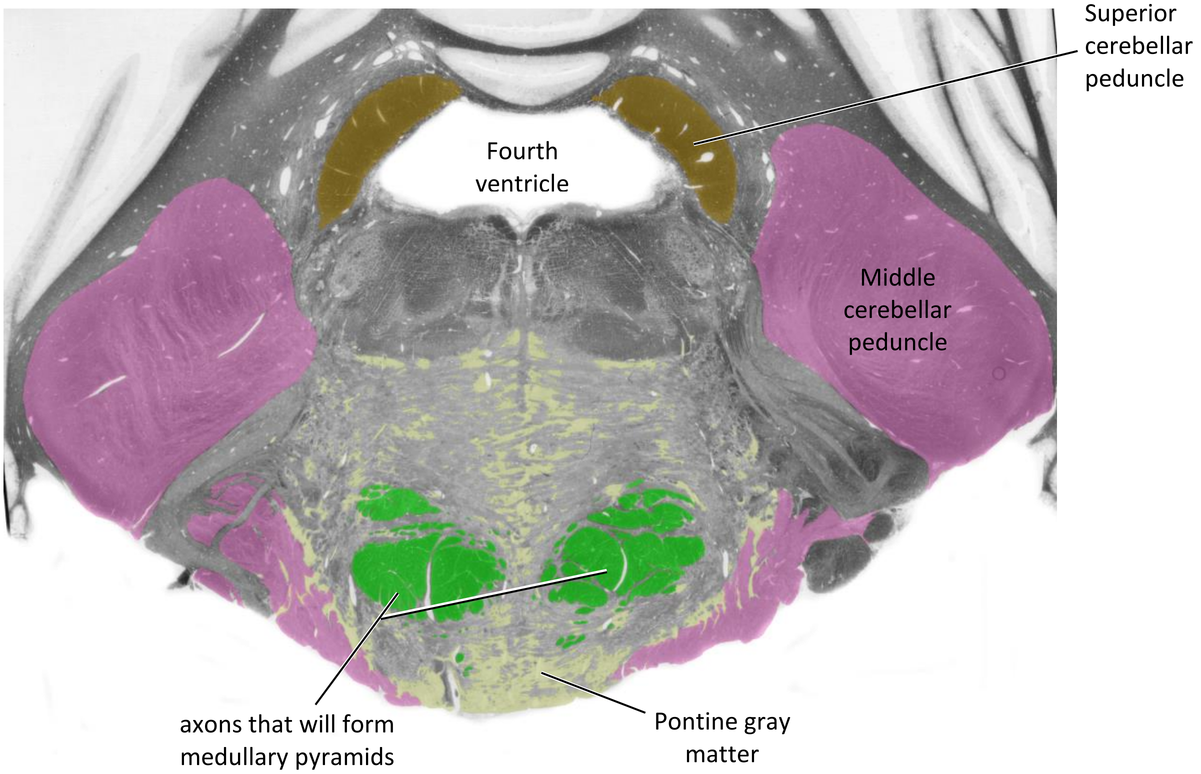
Subdivision	Surface feature	Internal structure
Caudal medulla (**Figure 4**)	**Gracile tract** (dorsal surface) • pair of extended longitudinal bulges or columns on either side of a deep midline furrow; technically, this bulge is called the *tuberculum gracilis*, which is formed by the underlying gracile tract • continuation of the tract of the dorsal spinal cord	**Gracile tract & nucleus** • medial, superficial bundle of myelinated axons arising from the dorsal column of the spinal cord • just deep to the gracile tract is the **gracile nucleus**, a compact gray matter structure that receives the synapses made by gracile tract axons
	Cuneate tract (dorsal surface) • pair of extended longitudinal bulges or columns just lateral to the gracile tracts; technically, this bulge is called the *tuberculum cuneatus*, which is formed by the underlying cuneate tract • continuation of the tract of the dorsal spinal cord	**Cuneate tract & nucleus** • just lateral to the gracile tract, superficial bundle of myelinated axons arising from the dorsal column of the spinal cord • at the superior "head" of the cuneate tract is the **cuneate nucleus**, a compact gray matter structure that receives the synapses made by cuneate tract axons
	Pyramidal decussation (ventral surface) • see **Medullary pyramids** below • apparent "stitching" of fibers that cross the midline	**Pyramidal decussation** • see **Medullary pyramids** below • midline crossing of dense bundles of myelinated axons that run the longitudinal extent of the ventral brainstem • accounts for the formation of the **lateral** and **ventral** (**anterior**) **corticospinal tracts** of the spinal cord
Middle to rostral medulla (**Figure 5**)	**Medullary pyramids** (ventral surface) • pair of extended longitudinal bulges or columns on either side of a deep midline furrow	**Medullary pyramids** • dense bundle of myelinated axons that run the longitudinal extent of the ventral brainstem; these axons are also known as the **corticospinal tract** • these same axons are present in the **internal capsule**, **cerebral peduncles**, basilar pons, and about 90% are present in the **lateral columns** of the spinal cord
	Inferior olive (ventral-lateral surface) • pair of elongated bulges just lateral to the pyramids; a shallow furrow separates the pyramid and olive on each side	**Inferior olivary nucleus** • prominent nucleus of the ventral-lateral medulla just dorsal to the medullary pyramids • note the highly convoluted bands of gray matter that account for the superficial, ventral-lateral bulge
	Hypoglossal nerve (XII) (ventral-lateral surface) • exits through ventral-medial surface	**Hypoglossal nerve roots & nucleus** • nerve roots emerge between the **medullary pyramid** and the **olive** • trace these nerve roots dorsally to their origin in the **hypoglossal nucleus**, located along the dorsal midline

Figure 6. (Next page). The caudal and middle pons (upper and lower sections, respectively; "7-pons" & "6-pons" in ***Sylvius4 Online***) look very similar at first inspection. We need two levels to represent the pons because there are different groups of cranial nerve nuclei at the two levels. These sections are attached to the cerebellum (a dead giveaway that we are in the pons) by the massive **middle cerebellar peduncles** (cut on the lateral edge of the sections). The base of the pons is made up of a mix of cells—the **pontine gray matter** and transversely coursing fibers—fibers that arise from the cells in the pontine gray matter and travel into the cerebellum via the middle cerebellar peduncle. Not all the fibers in the base of the pons are running transversely. Note that some appear to be traveling perpendicular to the plane of section. These will emerge on the base of the medulla as the medullary pyramids. The tegmentum of the pons looks similar at both levels, but the nuclei contained at each level are different.

Pons

With reference to **Figures 6 & 7** and the chart below, carefully inspect the internal features of the pons. Spend some time browsing these pontine sections (and the sections in ***Sylvius4 Online***), and find each of the internal features described in the chart below.


Superior cerebellar peduncle
Inferior cerebellar peduncle
Fourth ventricle
Middle cerebellar peduncle
axons that will form medullary pyramids
Pontine gray matter


Superior cerebellar peduncle
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Middle cerebellar peduncle
axons that will form medullary pyramids
Pontine gray matter

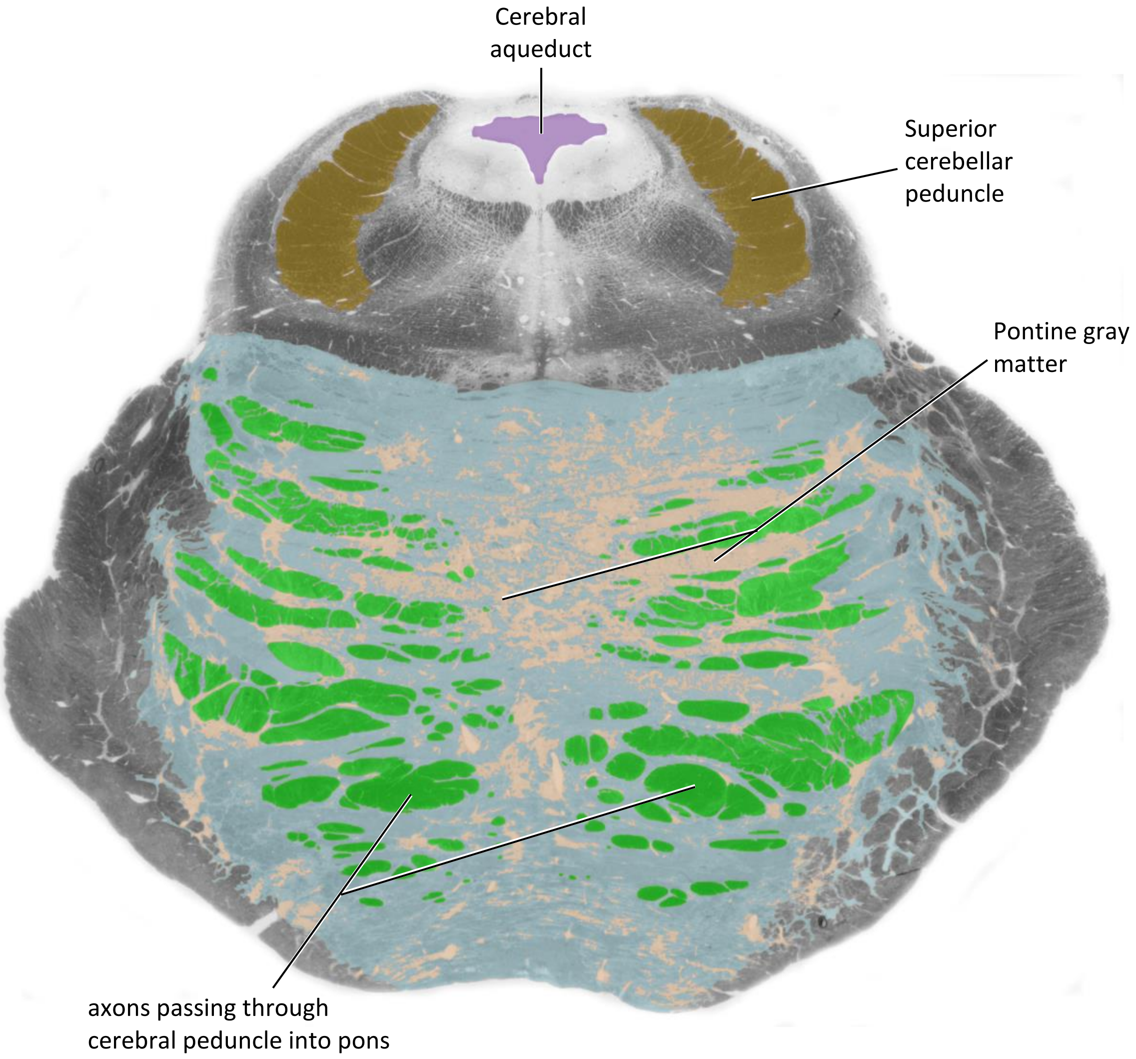

Figure 7. At the junction of the pons and midbrain, the brainstem looks relatively simple. The massive pontine base is about to give way to the cerebral peduncles. Dorsal to the base, the brainstem is reduced to the tegmentum. The fourth ventricle, which you saw in the sections through the pons, is disappearing to be replaced by the cerebral aqueduct. (Section is "4-pons" in ***Sylvius4 Onilne***)

Subdivision	Surface feature	Internal structure
Middle of pons (**Figure 6, lower**)	**Middle cerebellar peduncle** (ventral-lateral surface) • massive system of transverse fibers that "bridge" the longitudinal axis of the brainstem; these fibers originate in the basal region of the pons and continue around its ventral-lateral aspect to enter the cerebellum	**Pontocerebellar fibers & middle cerebellar peduncle** • the ventral half of the pons (also called the *basilar pons*) contains gray matter, longitudinal axons, and transverse fibers called the **pontocerebellar fibers** that decussate and form the *contralateral* middle cerebellar peduncle • these fibers arise from a scattering of gray matter in the basilar pons, called the **pontine nuclei**, and terminate in the *contralateral* cerebellum • also in the basilar pons are prominent fascicles of axons from the cerebral cortex that project to various nuclei of the brainstem and the spinal cord; collectively, these axons are the **corticobulbar/corticospinal fibers**
	Trigeminal nerve (V) (ventral-lateral surface) • enters/exits pons by penetrating the transverse, pontocerebellar fibers	**Trigeminal nerve roots & nucleus** • trace the nerve V roots dorsally to their origin in the trigeminal nuclear complex; at this level, note the location of the **trigeminal motor nucleus** and, just lateral to it, the **principal (chief sensory) nucleus** • now, keep your eye in this same general region and section caudally: in this same dorsal-lateral position in the caudal pons and throughout the medulla, the **spinal trigeminal nucleus** and the **spinal trigeminal tract** are present (the spinal nucleus can be further subdivided)
Caudal pons (**Figure 6, upper**)	**Abducens nerve (VI)** (ventral-medial surface) • enters/exits near the midline at the pontomedullary junction (most medial of the three that emerge from this junction)	**Abducens nerve roots & nucleus** • explore the medial tegmentum of the pons and locate nerve VI roots; note how they course through the basilar pons just lateral to the corticobulbar/corticospinal fibers • trace these nerve roots dorsally to their origin in the **abducens nucleus**, which is located along the dorsal midline
	Facial nerve (VII) (ventral-lateral surface) • enters/exits through ventral-lateral surface at pontomedullary junction (middle of the three that emerge from this junction, just medial to CN VIII)	**Facial nerve roots & nucleus** • explore the lateral tegmentum of the pons and locate nerve VII roots; note how they trace a most unusual trajectory around the dorsal aspect of the abducens nucleus (cf. **Figure 5.14**) • it may not be possible to trace these nerve roots all the way back to their origin in the **facial nucleus**, which is located just medial and ventral to the trigeminal nuclear complex • nerve VII roots exit the facial nucleus medially, then course dorsally around the abducens nucleus, and finally ventral-laterally toward a lateral exit (this is how CN VII ends up being lateral to CN VI)
	Vestibulocochlear nerve (VIII) (ventral-lateral surface) • enters through ventral-lateral surface at pontomedullary junction (most lateral of the three that emerge from this junction, just lateral to CN VII)	**Vestibular nuclear complex** • explore the lateral tegmentum of the pons and locate nuclei of the vestibular nuclear complex; you will find the vestibular nuclei dorsal to the trigeminal nuclear complex and spinal trigeminal tract • So what about the cochlear division of CN VIII? It terminates in a superficial nucleus of the dorsal-lateral upper medulla called the **cochlear nucleus**. Although not labeled in ***Sylvius4***, it is visible in the section labeled "8-Medulla" as the gray matter that wraps around the dorsal-lateral surface of the inferior cerebellar peduncle

Midbrain

With reference to **Figures 8 & 9** and the chart below, carefully inspect the internal features of the midbrain. Spend some time browsing these pontine sections (and the sections in ***Sylvius4 Online***), and find each of the internal features described in the chart below.

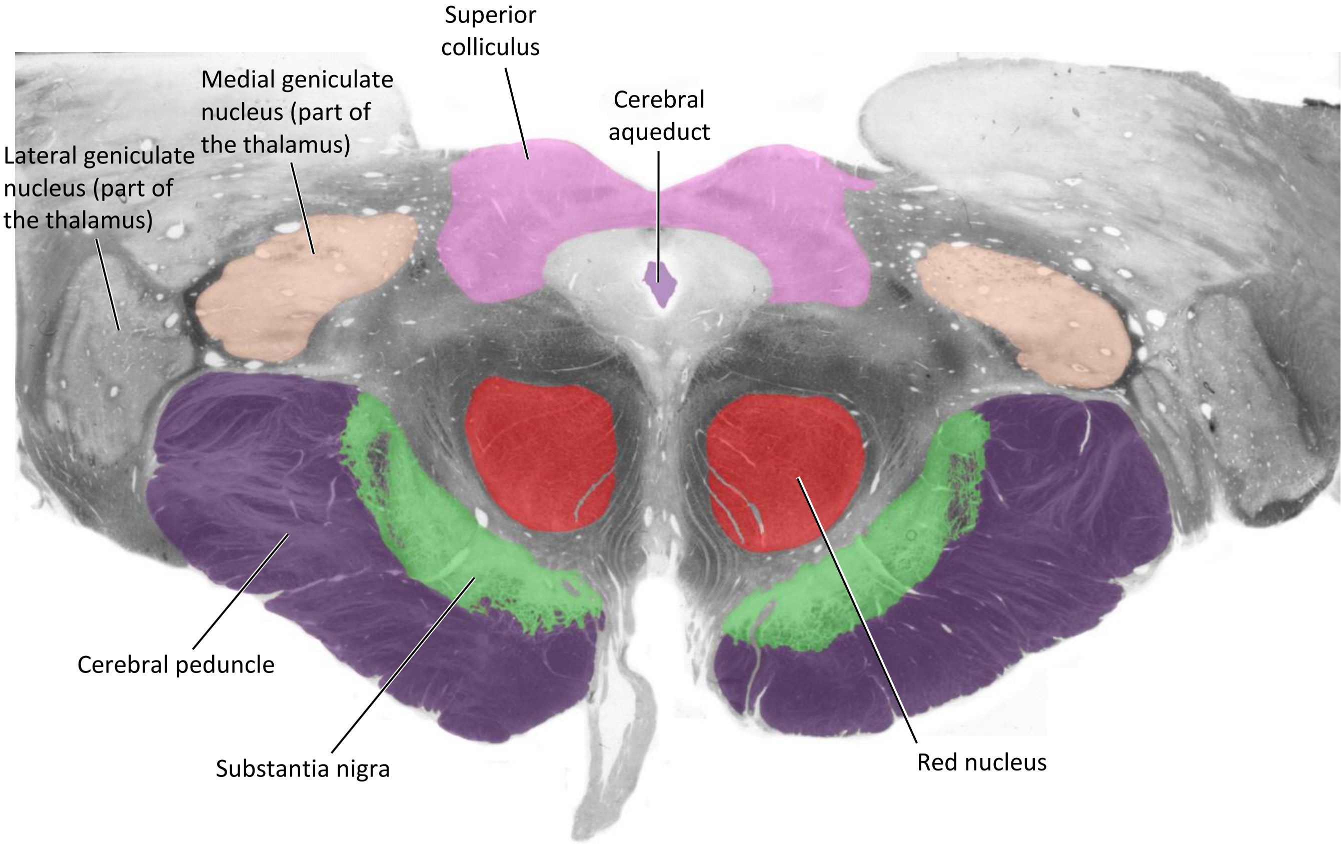

Figure 8. This section is through the rostral midbrain and so it cuts through the **superior colliculus**. The space between the colliculi is the **cerebral aqueduct**. The **cerebral peduncles** form the base of the midbrain. Two very large nuclei lie dorsal to them. These are the **substantia nigra** and the **red nucleus**; they are discussed in a later session. (A small part of the dorsal thalamus, including the medial and lateral geniculate nuclei, are also included in this section.) (Section is "2-midbrain" in ***Sylvius4 Online***)

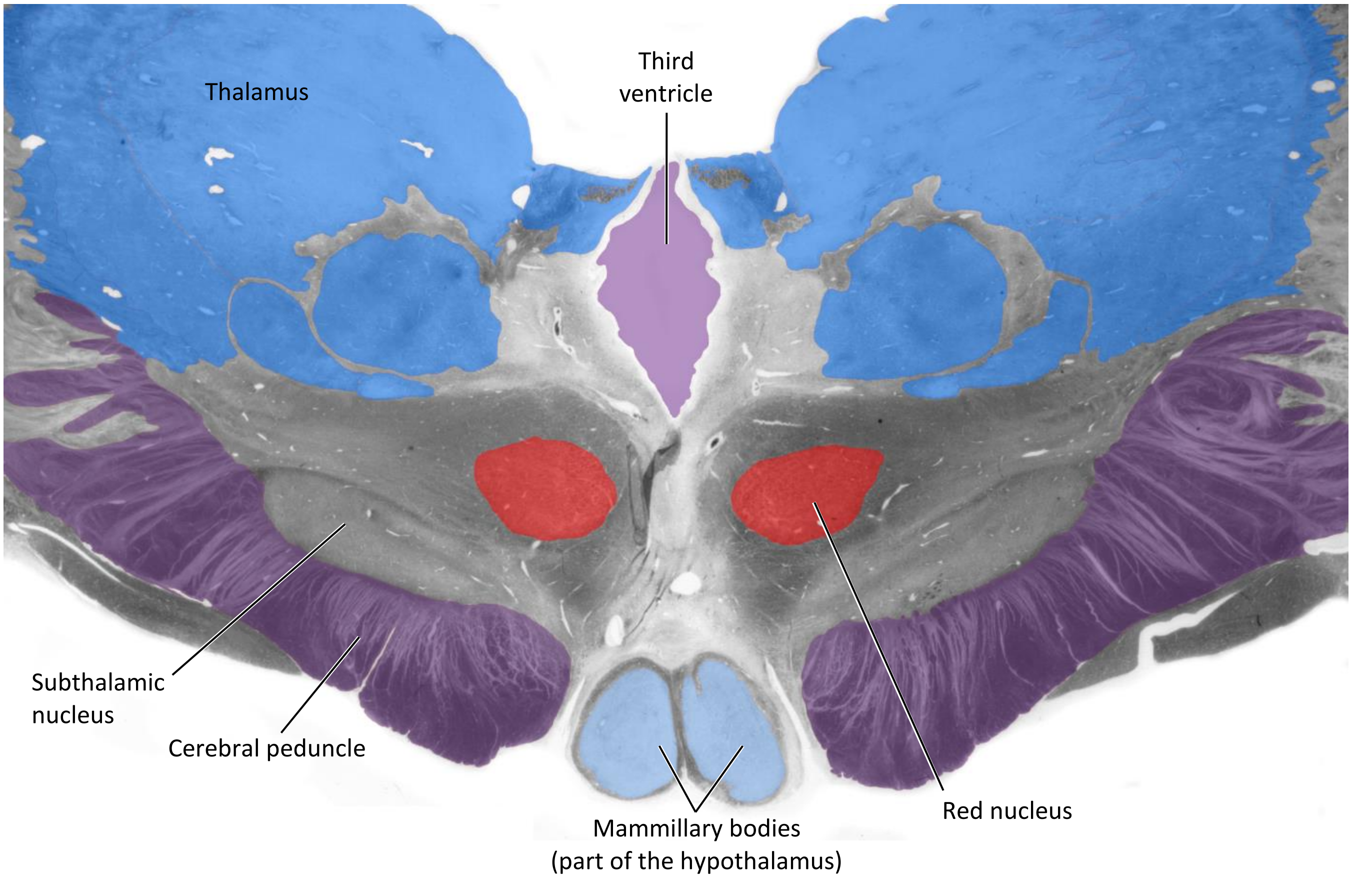

Figure 9. The last section in the series through the brainstem is cut through the junction of the midbrain and diencephalon. Structures of the midbrain are seen medially, but laterally the diencephalon has appeared. The cerebral peduncles will become continuous with the **internal capsule** a little rostral to this level. Likewise, the cerebral aqueduct will become continuous with the **third ventricle**. Note the presence of the subthalamic nucleus on the dorsal aspect of the cerebral peduncle (in the place where the substantia nigra is located a centimeter inferior to this level; cf. **Figure 8**). (Section is "1-midbrain-diencephalon junction" in ***Sylvius4 Online***)

Subdivision	Surface feature	Internal structure
Midbrain (**Figure 8**)	**Cerebral peduncles** (ventral surface) • large, longitudinal “stalks” (peduncle means stalk) that occupy the ventral midbrain	**Cerebral peduncles** • technically, “cerebral peduncle” refers to the entire ventral midbrain, including the midbrain tegmentum and the fiber systems that run through the stalks; however, it is common to use the term “cerebral peduncle” to refer specifically to these fiber systems (the proper term for these ventral portions of the peduncles—where the fibers are—is *pes* or *basis pedunculi*) • the cerebral peduncles comprise efferent fibers of the cerebral cortex that terminate in the brainstem and spinal cord; these fibers are referred to collectively as the **corticobulbar/corticospinal fibers**; this compound terms indicates that the some of these fibers terminate among brainstem nuclei (“bulbar” refers to the brainstem and cranial nerve nuclei), while other fibers continue and terminate in the spinal cord • it is important to recognize the course of these fibers from their origin in the cerebral cortex through brainstem: cerebral cortex → subcortical white matter → **internal capsule** → **cerebral peduncle** → basilar pons → **medullary pyramids** → **lateral** and **anterior** (**ventral**) **corticospinal tract** • there are about 20 million axons in each cerebral peduncle; can you guess how many axons are present in medullary pyramid by simply noting the difference in size of these two structures?[3] (the majority of these axons never reach the spinal cord) • now consider the tegmentum of the midbrain; just dorsal to the cerebral peduncles (pes pedunculi) there is an important gray matter nucleus called the **substantia nigra**, and in a similar position but just a bit more rostral is the **subthalamic nucleus**; you will learn much more about these nuclei when we study the basal ganglia • just dorsal to the substantia nigra, is a spherical gray matter structure called the **red nucleus**, which modulates cerebellar function
	Oculomotor nerve (III) (ventral surface) • exits through ventral surface just medial to cerebral peduncles (in the interpeduncular fossa)	**Oculomotor nerve roots & nuclear complex** • trace these nerve roots dorsally to their origin in the nuclei of the oculomotor complex along the midline of the dorsal tegmentum; here you will find two divisions: the **oculomotor nucleus** and the **Edinger-Westphal nucleus** • this nuclear complex is embedded within gray matter that surrounds the **cerebral aqueduct**, termed the **periaqueductal** (or **central**) **gray**
	Inferior colliculi (dorsal surface) • inferior pair of the four bumps that are visible in brainstem model/illustration, but are normally covered by the cerebellum	**Inferior colliculi** • in the caudal midbrain, the inferior colliculi are gray matter structures that occupy a position just dorsal and lateral to the periaqueductal gray (see section “3 - Midbrain”) • together with the superior colliculi, they form the “roof” of the midbrain (above the cerebral aqueduct); for this reason, these four bumps are also called the **tectum** (*tectum* means *roof*) • the **trochlear nerve** exits the dorsal surface of the brainstem just caudal to the inferior colliculus (see **Brainstem Model** in **Surface Anatomy** module) • although that nerve is not visible in section 3 – Midbrain, you can see the small **trochlear nuclei** where you should expect to find somatic motor nuclei, along the midline of the dorsal tegmentum
	Superior colliculi (dorsal surface) • superior pair of the four bumps that are visible in brainstem model/illustration	**Superior colliculi** • in the rostral midbrain, the superior colliculi are laminated gray matter structures that occupy a position just dorsal and lateral to the periaqueductal gray matter (see section lableled “2 - Midbrain”) • together with the inferior colliculi, they form the “roof” (tectum) of the midbrain (above the cerebral aqueduct)

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[3] There are about one million axons in each medullary pyramid.

STUDY QUESTIONS

Q1. What is the **brainstem nucleus** that accounts for the outward bulge just lateral to the nerve roots of CN XII (hypoglossal nerve)?

A. gracile nucleus
B. cuneate nucleus
C. inferior olivary nucleus
D. facial motor nucleus
E. spinal trigeminal nucleus

Q2. Which of the following is a defining feature of the **pons**?

A. cedullary pyramids
B. cerebral peduncles
C. inferior olivary nucleus
D. pontocerebellar fibers forming the middle cerebellar peduncle
E. dorsal column nuclei

Q3. Which of the following cranial nerve nuclei is found in the **midbrain**?

A. abducens nucleus
B. hypoglossal nucleus
C. oculomotor nucleus
D. facial motor nucleus
E. red nucleus

Medical Neuroscience | Tutorial Notes

Cranial Nerve Nuclei

MAP TO NEUROSCIENCE CORE CONCEPTS[1]

NCC1. The brain is the body's most complex organ.

LEARNING OBJECTIVES

After study of the assigned learning materials, the student will:

1. Identify the major subdivisions of the brainstem and spinal cord, as seen in representative transverse cross-sections.
2. Discuss the relationship between the cranial nerves and the corresponding cranial nerve nuclei.

NARRATIVE

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Introduction

Of chief importance in understanding the organization of the brainstem is knowledge of what is localized in each embryological subdivision and in any transverse section. This is a significant challenge for every student of neuroanatomy and we will now turn our attention progressively to this challenge. You have already faced the first step toward competency with the essential knowledge: recognition of the external features of each brainstem subdivision, including the associated cranial nerves. After working through this tutorial, you should be able to recognize how the cranial nerves relate to gray matter structures in the brainstem that grew out the axons in the cranial nerves (motor axons) or receive synaptic input from ganglionic neurons associated with the nerves (sensory axons). Before proceeding, it will be worth reminding yourself of the basic layout of sensory and motor neurons in the brainstem and spinal cord.

The central nervous system interacts with the outside world through primary sensory neurons, which convey information from the body or its environment into the brain and spinal cord, and motor neurons, which activate striated muscles and modulate the activity of cardiac and smooth muscles and glands (see **Fig. 1** below and/or **Figure A1A**[2]). The cell bodies of primary sensory neurons lie in the **dorsal root ganglia** or the **cranial nerve ganglia**. Each neuron gives rise to a peripheral process, which receives information either directly or through association with receptors, and a central process, which enters

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[1] Visit **BrainFacts.org** for *Neuroscience Core Concepts* (©2012 Society for Neuroscience) that offer fundamental principles about the brain and nervous system, the most complex living structure known in the universe.

[2] Figure references to Purves et al., *Neuroscience, 5th Ed.*, Sinauer Assoc., Inc., 2012. [click here]

the central nervous system and forms synapses with second order neurons. The cell bodies of somatic motor neurons lie in clusters or **nuclei** within the central nervous system and give rise to axons that innervate striated muscles in the body or head. In this tutorial, you will be especially concerned with the organization of these second-order sensory neurons and somatic motor neurons. You will also be introduced to other motor neurons that are part of the visceral motor system (a.k.a., autonomic nervous system) and are indirectly responsible for governing cardiac muscle, smooth muscle or glands. By the conclusion of this learning experience, you will learn how to locate:

1. nuclei that are the destination of all primary somatic sensory, visceral sensory, and special sensory *input* into the CNS (i.e., the location of all of the second-order neuronal cell bodies that receive the primary sensory input), except for olfaction and vision. The olfactory nerve and the optic nerve are not included in this discussion; for several reasons they are atypical.
2. nuclei that are the origin of all of the somatic and visceral motor *output* of the CNS (i.e., the location of all of the alpha motor neurons and preganglionic visceral motor neurons).

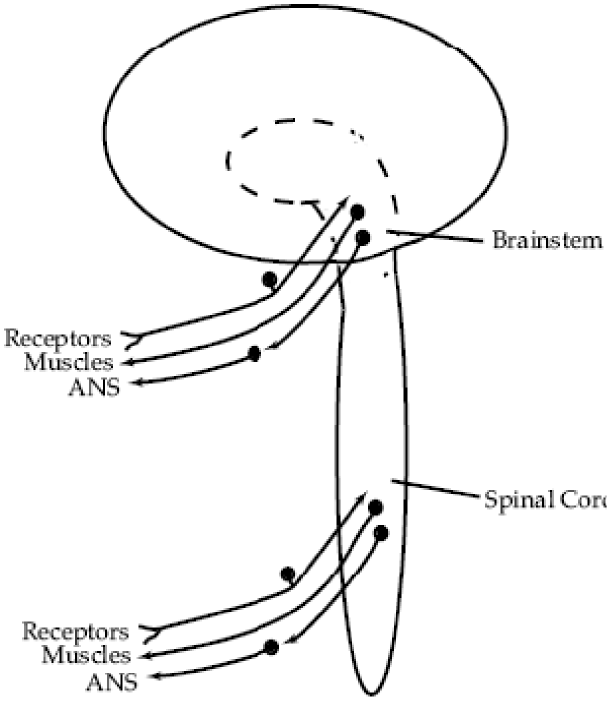


Fig. 1. Both the spinal cord and brainstem receive input from primary sensory neurons; the cell bodies of these neurons lie in sensory ganglia. In addition, both the spinal cord and brainstem give rise to motor output to striated muscles and to the autonomic ganglia (*ANS*, autonomic nervous system; synonymous with visceral motor system). (Illustration by N.B. Cant)

From the viewpoint of clinical practice, the most important general principle of organization in the central nervous system is that each ***CNS function*** (e.g., perception of sensory stimuli, control of motor behavior) ***involves groups of neurons—interconnected through synapses—that are spatially distributed throughout several CNS subdivisions***. Groups of neurons that together subserve a particular function are called a 'system'; for example, there are the visual, motor, and somatic sensory systems. The structures containing the neurons and axons of a particular system are collectively referred to as a 'pathway'. (The term 'system' has a functional connotation, whereas the term 'pathway' refers to the structures involved.) We will study several important sensory and motor pathways in detail in future tutorials.

If damage to the CNS at every level gave rise to exactly the same signs and symptoms, it would not be worthwhile for you to learn the details of neuroanatomy. However, as neurologists and neuroscientists recognized long ago, the neurons involved in specific functions occupy specific locations in the central nervous system. Even those systems that are represented in multiple subdivisions bear different physical relationships to one another from one subdivision to the next. Because neurons that subserve specific functions occupy specific locations, the combinations of neurological signs and symptoms exhibited by particular patients often provide detailed information about the location of damage in the CNS. These principals will guide our survey of the cranial nerve nuclei that are distributed across the three major subdivisions of the brainstem. Knowledge of their location and function will provide key information that will help you localize neurological injury and dysfunction in clinical patients.

An embryological framework for understanding the cranial nerve nuclei

The cranial nerve nuclei are made up of the neurons in the brainstem that receive primary sensory inputs or that give rise to motor outputs. Just as there are cell groups in the dorsal horn of the spinal cord that receive sensory information and cell groups in the ventral horn that contain motor neurons, there are separate sensory and motor nuclei in the brainstem.

The spinal cord receives sensory information from the body surface, muscles (via the muscle spindles) and the viscera, and sends motor axons to striated muscles and to the autonomic ganglia. These same inputs and outputs exist for the head. In addition, there are specialized sensory inputs in the head that do not have equivalents in the spinal cord. These include the inputs for hearing, balance and taste. The motor outputs are just a little more complicated as well. There are nuclei which innervate the extrinsic eye muscles and the tongue. Since the muscles that are innervated are derived from **somites**, these motor neurons are exactly equivalent to those in the ventral horn, which also innervate muscles derived from somites. In addition, there are nuclei in the brainstem that innervate the muscles derived from the **branchiomeres** of the embryonic pharyngeal arches (jaw muscles, muscles of facial expression, the pharynx and larynx). There is only one such cell group in the spinal cord; it innervates the trapezius and sternocleidomastoid muscles, which are also derived from branchiomeres. It is included with the cranial nerve nuclei, since it gives rise to the spinal part of cranial nerve XI. Finally, there are cell groups in the brainstem that form part of the visceral motor (autonomic) system and send axons to autonomic ganglia in organs throughout the body. Now, let’s appreciate the organization of these nuclei in each division of the brainstem.

The organization of the sensory and motor neurons in the spinal cord and brainstem are similar, for reasons that are clear when one considers the development of these two regions of the neural tube—as explained in **Fig. 2** (next page). Sensory neurons, which are located dorsally in the spinal cord, are located laterally in the medulla and pons. Motor neurons, which are located ventrally in the spinal cord, are located medially in the medulla, pons, and midbrain.

Ten sets of cranial nerves are associated with the brainstem. These nerves supply sensory inputs to or derive motor output from 16 sets of cranial nerve nuclei. In the following discussion, ways of grouping these nuclei to make them easier to remember are presented. Next, the way in which they match up with the nerves will be described. Finally, they will be located on the cross-sections of the brainstem.

One further point can be made from **Fig. 2**. In the medulla, the motor column that gives rise to somatic motor nuclei also gives rise to the motor neurons that will innervate the branchiomeric muscles. These motor neurons migrate from the midline into the ventral-lateral part of the tegmentum and send their axons out in nerves that exit the brain laterally (i.e., V, VII, IX, X, and XI). The somatic motor neurons, on the other hand, send their axons out ventrally (in a line with ventral roots of the spinal cord), except for the trochlear nucleus, which is the only motor nucleus to grow its axons out of the dorsal aspect of the CNS. Oddly, the parasympathetic preganglionic neurons (visceral motor neurons) in the medulla and pons also send their axons out laterally; in the spinal cord (and in the midbrain), the autonomic preganglionic axons leave in the ventral roots. All of the sensory inputs enter the brain laterally.

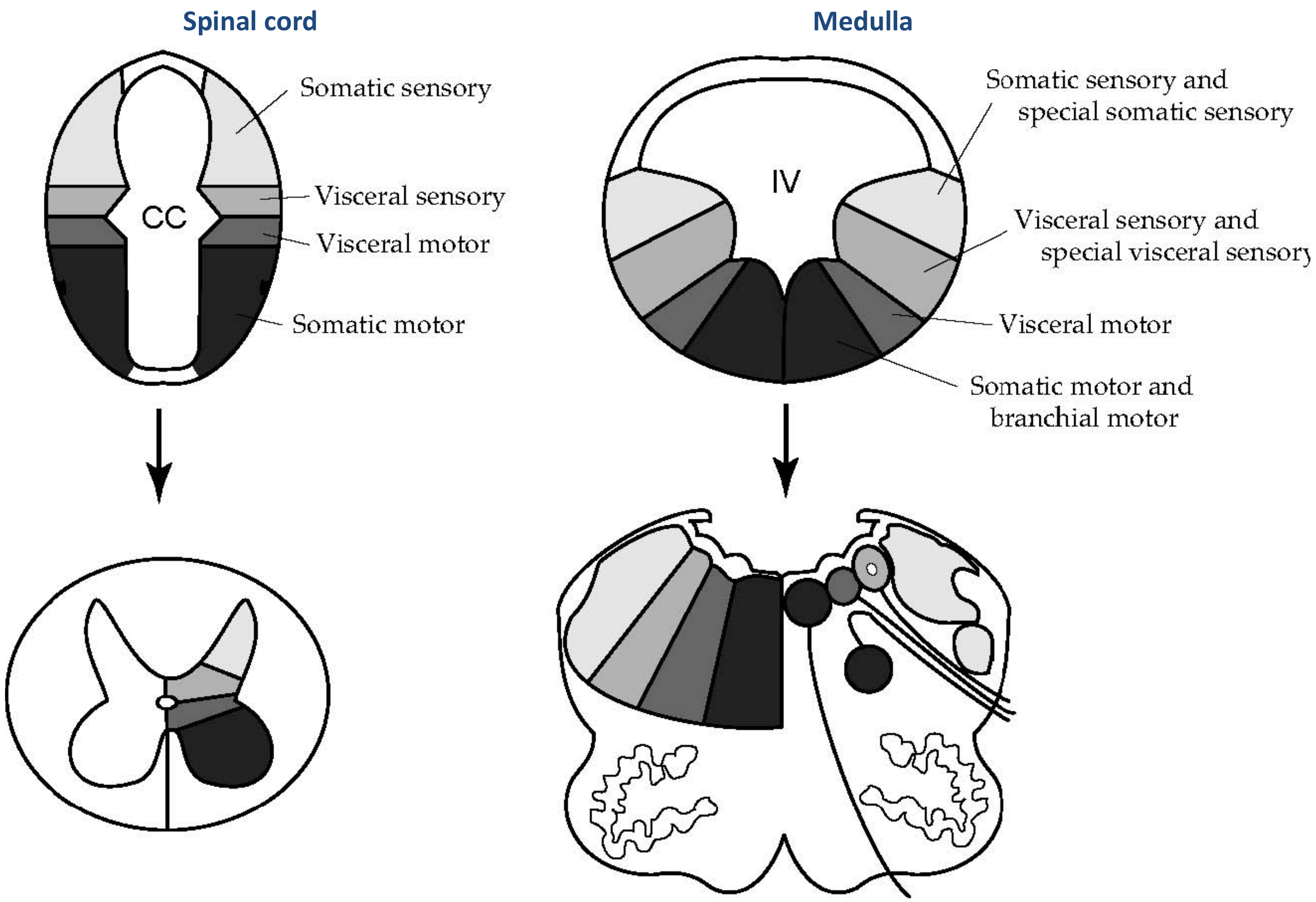


Fig. 2. Drawings of cross-sections through the embryonic (top panels) and adult (bottom panels) spinal cord and medulla. In the embryo, four columns of dividing neurons can be identified which give rise to somatic and visceral sensory and motor cell groups in the adult. (Indicated in different shades of gray.) Because the medulla has a much wider roof than the spinal cord, the cell columns that are located dorsally in the spinal cord get pushed out laterally in the medulla. The cell columns that are located ventrally in the spinal cord are located medially in the medulla. The same relation holds true for the sensory and motor cell groups in the adult. (CC, central canal of the spinal cord; IV, fourth ventricle) (Illustration by N.B. Cant)

Location and function of the cranial nerve nuclei

The sixteen cranial nerve nuclei can be most easily remembered if they are assembled into functional groups and anatomical location (see **Table** on the next page— **Table A3** from Purves et al., *Neuroscience, 5th Ed.*; and **Fig. 3**). Three of the groups are motor nuclei: a **somatic motor** group, a **branchial motor** group, and a **parasympathetic preganglionic** group (the corresponding sympathetic preganglionic group is in the thoracic segments of the spinal cord). The other three groups are sensory nuclei: **general sensory**, **special sensory**, and **visceral sensory**.

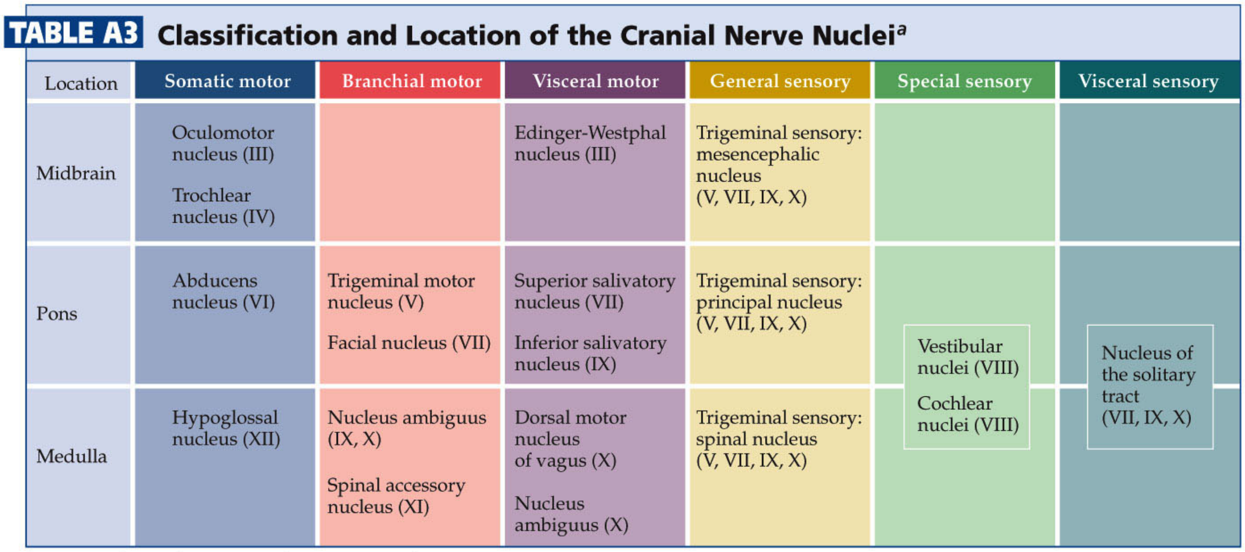


TABLE A3 Classification and Location of the Cranial Nerve Nuclei[a]

Location	Somatic motor	Branchial motor	Visceral motor	General sensory	Special sensory	Visceral sensory
Midbrain	Oculomotor nucleus (III) Trochlear nucleus (IV)		Edinger-Westphal nucleus (III)	Trigeminal sensory: mesencephalic nucleus (V, VII, IX, X)		
Pons	Abducens nucleus (VI)	Trigeminal motor nucleus (V) Facial nucleus (VII)	Superior salivatory nucleus (VII) Inferior salivatory nucleus (IX)	Trigeminal sensory: principal nucleus (V, VII, IX, X)	Vestibular nuclei (VIII) Cochlear nuclei (VIII)	Nucleus of the solitary tract (VII, IX, X)
Medulla	Hypoglossal nucleus (XII)	Nucleus ambiguus (IX, X) Spinal accessory nucleus (XI)	Dorsal motor nucleus of vagus (X) Nucleus ambiguus (X)	Trigeminal sensory: spinal nucleus (V, VII, IX, X)		

[a] Associated cranial nerves are shown in parentheses.

How do these nuclei relate to the components of the cranial nerves that you studied in a previous tutorial? **Table A2** (from Purves et al., *Neuroscience, 5th Ed.*) lists the cranial nerve nuclei from which the sensory and motor components of each nerve arise.

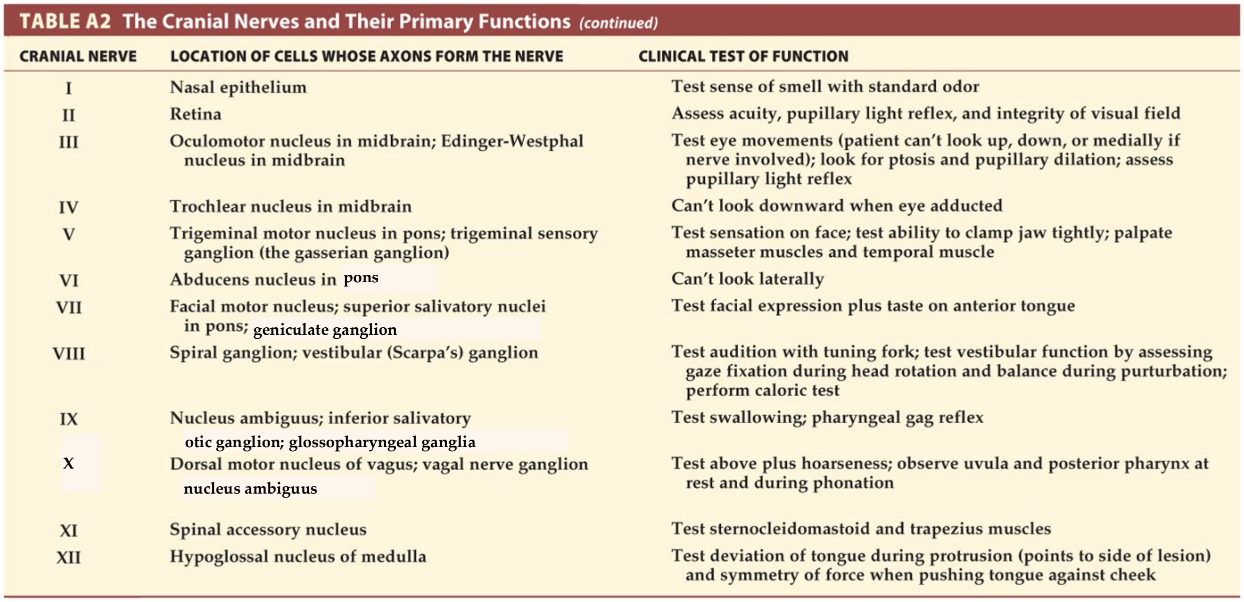


TABLE A2 The Cranial Nerves and Their Primary Functions *(continued)*

CRANIAL NERVE	LOCATION OF CELLS WHOSE AXONS FORM THE NERVE	CLINICAL TEST OF FUNCTION
I	Nasal epithelium	Test sense of smell with standard odor
II	Retina	Assess acuity, pupillary light reflex, and integrity of visual field
III	Oculomotor nucleus in midbrain; Edinger-Westphal nucleus in midbrain	Test eye movements (patient can't look up, down, or medially if nerve involved); look for ptosis and pupillary dilation; assess pupillary light reflex
IV	Trochlear nucleus in midbrain	Can't look downward when eye adducted
V	Trigeminal motor nucleus in pons; trigeminal sensory ganglion (the gasserian ganglion)	Test sensation on face; test ability to clamp jaw tightly; palpate masseter muscles and temporal muscle
VI	Abducens nucleus in pons	Can't look laterally
VII	Facial motor nucleus; superior salivatory nuclei in pons; geniculate ganglion	Test facial expression plus taste on anterior tongue
VIII	Spiral ganglion; vestibular (Scarpa's) ganglion	Test audition with tuning fork; test vestibular function by assessing gaze fixation during head rotation and balance during purturbation; perform caloric test
IX	Nucleus ambiguus; inferior salivatory otic ganglion; glossopharyngeal ganglia	Test swallowing; pharyngeal gag reflex
X	Dorsal motor nucleus of vagus; vagal nerve ganglion nucleus ambiguus	Test above plus hoarseness; observe uvula and posterior pharynx at rest and during phonation
XI	Spinal accessory nucleus	Test sternocleidomastoid and trapezius muscles
XII	Hypoglossal nucleus of medulla	Test deviation of tongue during protrusion (points to side of lesion) and symmetry of force when pushing tongue against cheek

***NEUROSCIENCE 5e*, Table A2 (Part 2)**

Taken together, these tables illustrate the point that most of the cranial nerves are connected to only one or two cranial nerve nuclei. Only three nerves carry components from more than two nuclei. These nerves—VII, IX, and X—each carry five components: a branchial motor component, a parasympathetic component, a somatic sensory component, a special visceral sensory component (taste), and a general visceral sensory component. These three nerves lack a somatic motor component.

Location of the cranial nerve nuclei in brainstem cross-sections

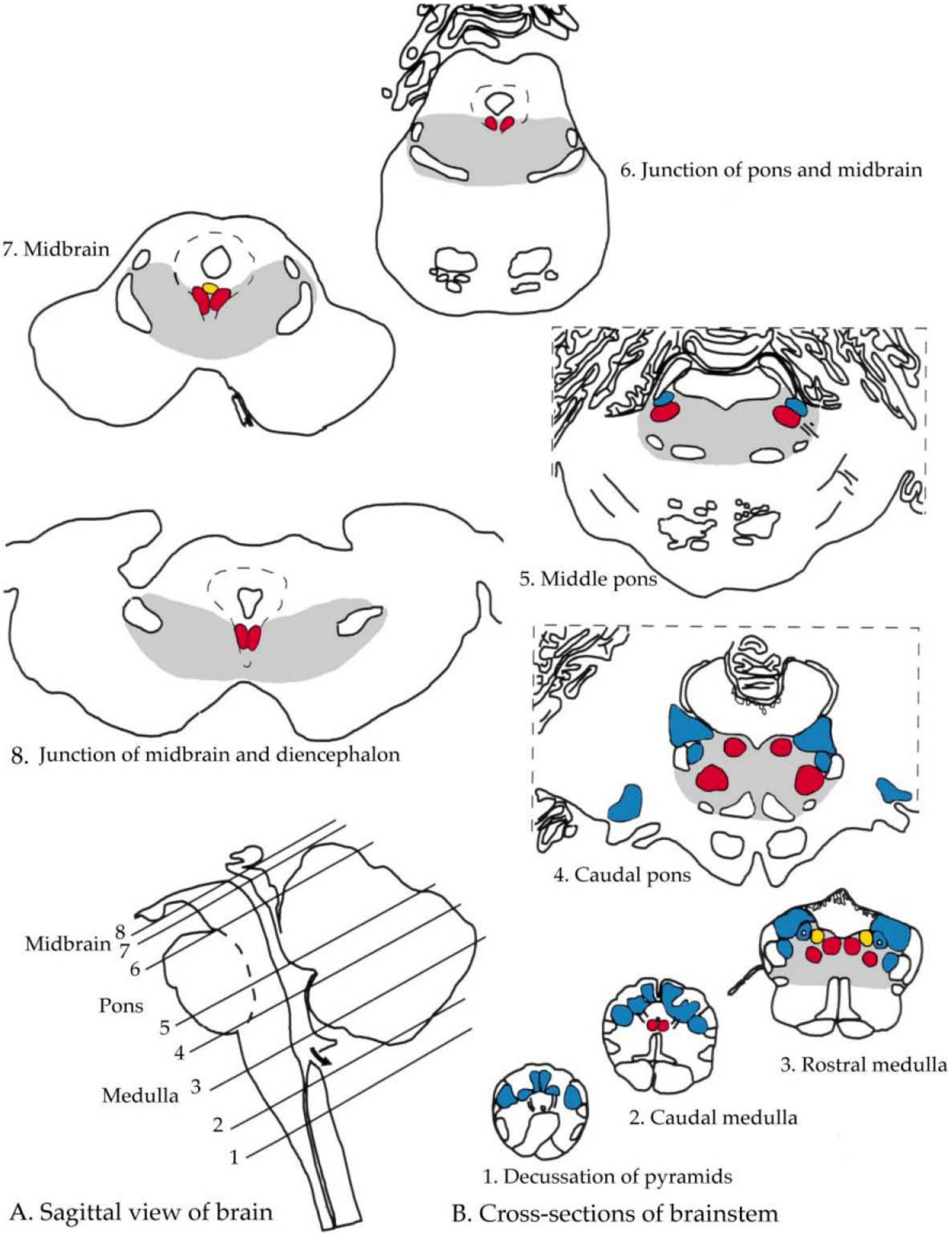
The internal organization of the brainstem is complicated (there is no point avoiding that reality!). However, two factors work in your favor as you study its features. First, important general principles of embryology will help you understand the basic plan for the brainstem (and spinal cord). Second, much of the complexity of the brainstem is contributed by cell groups and axon tracts that will not be considered in this course (now, that comes as good news!). In the following discussion, the general plan of organization of the brainstem is presented first. Then, the cranial nerve nuclei are discussed in some detail. An understanding of their functions and locations is essential for diagnosing (and treating) neurological injury, dysfunction and disease.

It would be convenient if each subdivision of the brainstem were sufficiently homogeneous along its length that one cross-section could serve as a 'typical' representative for the entire subdivision. However, the brainstem changes continuously along its length—the subdivision into three parts is somewhat arbitrary. As a compromise between examining three sections (one for each subdivision) and hundreds, eight sections of the brainstem are sketched (to scale) in **Fig. 3**. At this stage, it is not important to study the details; we will come back to them. For now, three points should be taken from the figure.

1. All of the sections are shown at the same magnification (a little less than two times actual size). In most atlases (including ***Sylvius4 Online***), the smaller sections are magnified more than the larger ones, and it is easy to lose sight of the relative proportions of the different subdivisions.
2. The cranial nerve nuclei lie in the tegmentum of the brainstem (gray region in figure), as do many of the major ascending and descending tracts.
3. Just as in the spinal cord, the nuclei that receive sensory inputs via the cranial nerves are spatially separate from those that give rise to motor output. The sensory nuclei are located laterally in the brainstem, whereas the motor nuclei are located medially.

Also take note in the figure that although the sections themselves vary greatly in size, the tegmentum is approximately the same size in all of them. Much of the effort in this course will be spent on learning the organization of the structures in the tegmentum. The positions of the cranial nerve nuclei (and also the sensory nuclei known as the dorsal column nuclei, which will be covered in a later tutorial) are indicated in the figure. Motor nuclei are represented in red and yellow, indicating somatic motor and visceral motor nuclei, respectively; sensory nuclei are represented in blue; important tracts are represented in unfilled outline. Note that the tracts are external to the sensory and motor nuclei, as is the case in the spinal cord.

Fig. 3. (next page) A. Sagittal view of the brainstem to show the level of the sections in part B. (The small curved arrow indicates the location of the median aperture through which cerebrospinal fluid escapes from the ventricular system.) B. Sections through the brainstem. (Only a portion of the cerebellum is included in the drawings of sections 4, 5 and 6). (Illustration by N.B. Cant)



A. Sagittal view of brain B. Cross-sections of brainstem

Now, let's look at the location of the cranial nerve nuclei in actual transverse sections through the brainstem. In the sections shown in the remaining figures, the photographs of the sections were prepared according to standard conventions for viewing brainstem sections: gray matter is light gray and white matter is in darker shades of grade. The important cranial nerve nuclei are colorized and labeled. The locations of most of the cranial nerve nuclei listed in **Tables A2** & **A3** are indicated on these sections.

The rostral medulla is a good place to start because a representative of each motor column is present (labeled on right side of section), and most of the sensory nuclei are also present (labeled on left side of section). Of the motor nuclei, the **hypoglossal nucleus** is closest to the midline. Next to it is the **dorsal motor nucleus of the vagus nerve**. The **nucleus ambiguus**—true to its name—is difficult to delineate in the myelin-stained human brain. The **nucleus of the solitary tract** is easy to spot, because it is associated with an isolated myelinated tract (the **solitary tract**, of course) that terminates in the nucleus. (The fibers in the tract come from nerves VII, IX, and X.) The **vestibular nuclei** (a collection of discrete nuclei) are large and can be seen in sections through much of the medulla and pons. The trigeminal nucleus in the medulla is known as the **spinal trigeminal nucleus**. Axons travel into it via the **spinal trigeminal tract**, which is just lateral to the nucleus.

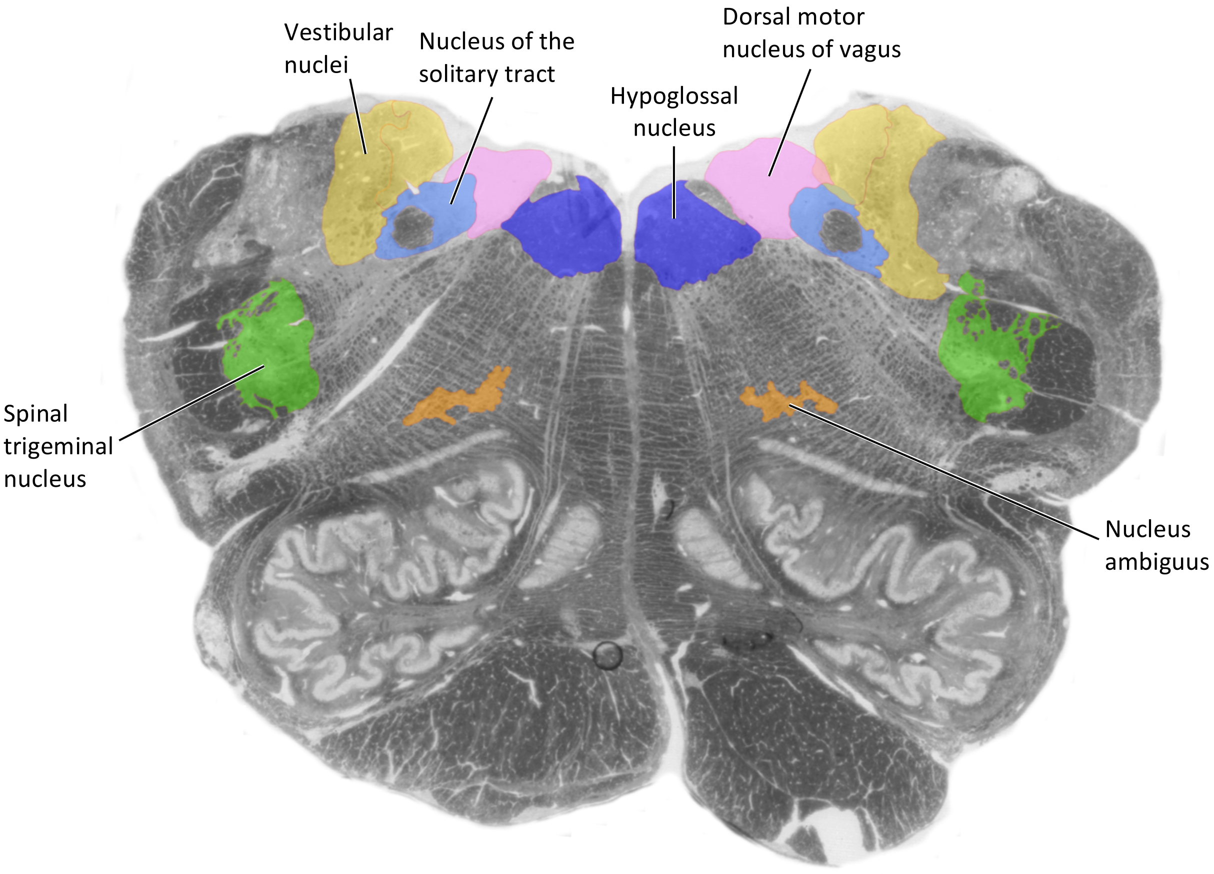


Fig. 4. Cranial nerve nuclei in the rostral medulla. (Section shown is "9-medulla" in ***Sylvius4 Online***)

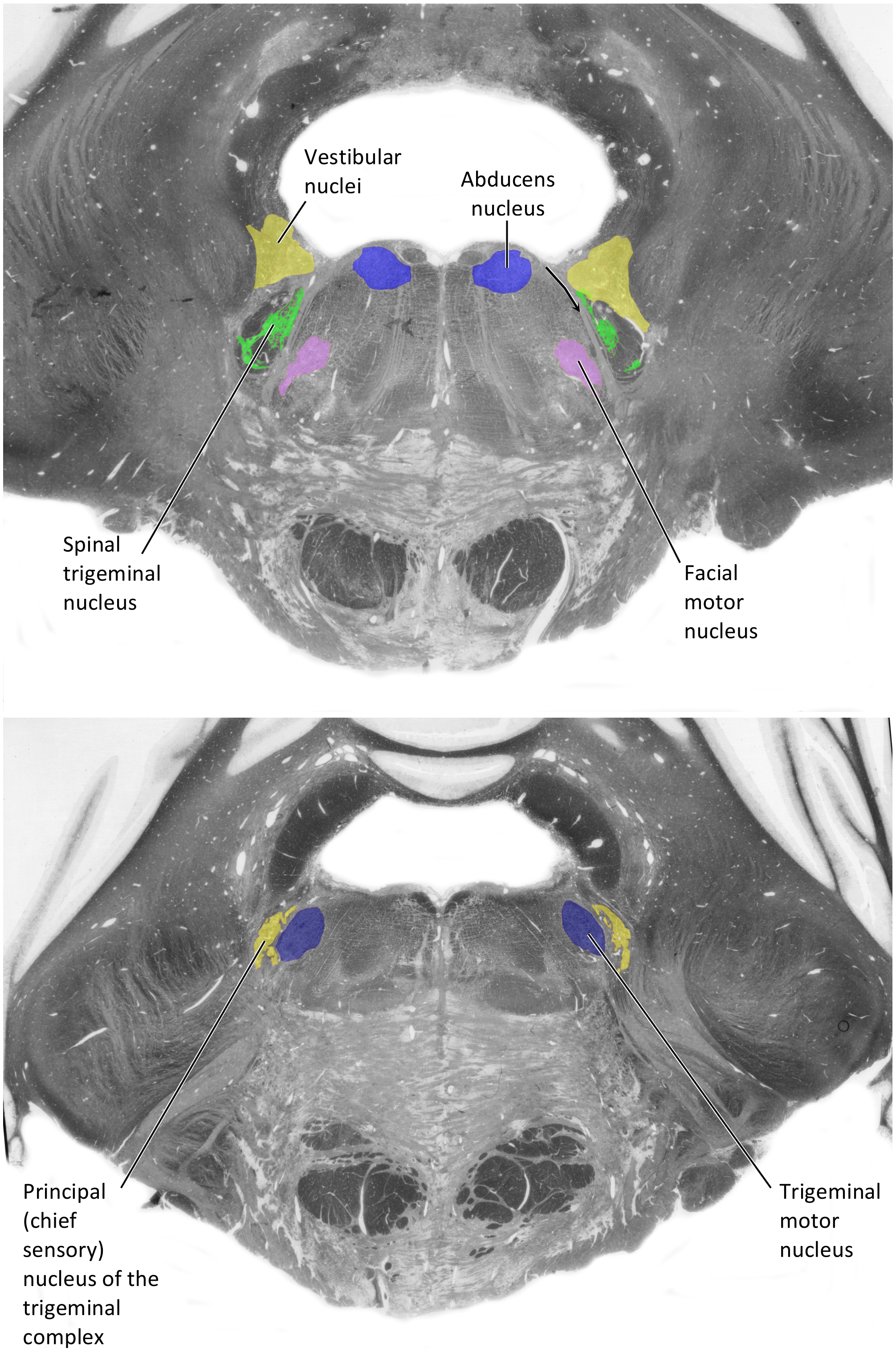


Fig. 5. Cranial nerve nuclei in the lower pons (top section; “7-pons” in ***Sylvius4 Onilne***) and upper pons (bottom section; “6-pons” in ***Sylvius4 Onine***).

Three motor nuclei can be identified in the pons. In the caudal pons, the **abducens nucleus** occupies the location next to the midline, and the **facial motor nucleus** is located ventral-laterally in the tegmentum. The myelinated axons indicated by the arrow are the axons that are leaving the seventh motor nucleus to enter the seventh nerve. These axons loop over the abducens nucleus before they exit laterally, forming what is known as the 'genu' of the seventh nerve. Parts of two nuclei that could be seen in the medulla are also seen here in the caudal pons—the **spinal trigeminal nucleus** and the **vestibular nuclei**. The final motor nucleus in the pons is the motor nucleus of the fifth nerve, also known as the **trigeminal motor nucleus**, which is rostral to the seventh motor nucleus. It is separated from the **chief sensory nucleus of the trigeminal nerve** by a bundle of myelinated fibers which are either entering or leaving via the fifth nerve (which gets to these nuclei by plunging through the middle cerebellar peduncle).

Three motor nuclei can be identified in the midbrain. The **trochlear nucleus** is the most caudal and is very small, as is evident in the section shown below in **Fig. 6**. The other two motor nuclei of the midbrain are present near the middle of the midbrain. There, the **oculomotor nucleus** occupies a medial position in the dorsal tegmentum (**Fig. 7**). You can see some of the myelinated axons that are forming the third nerve medial to the substantia nigra and the cerebral peduncle in **Fig. 7**. The **Edinger-Westphal nucleus** lies immediately dorsal to the oculomotor nucleus and is also located next to the midline.

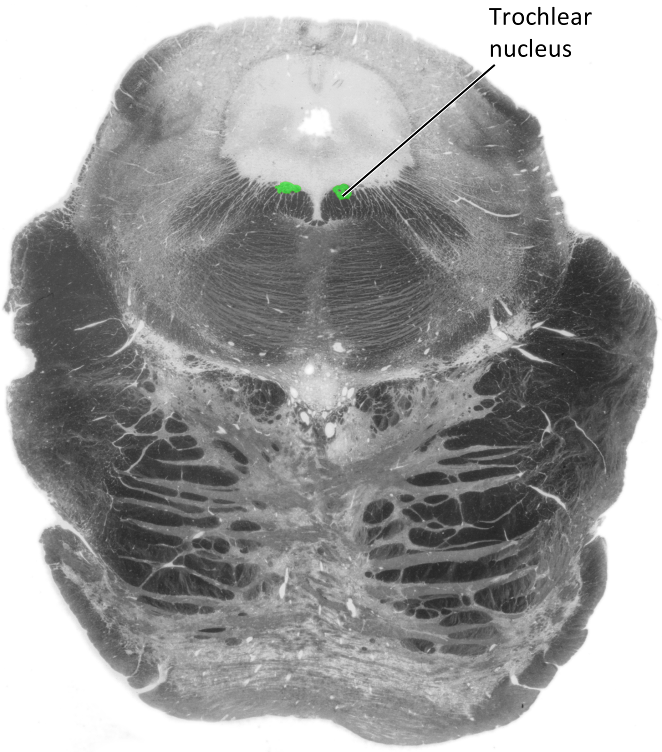


Fig. 6. Cranial nerve nuclei in the caudal midbrain. (Section shown is "3-midbrain" in ***Sylvius4 Online***)

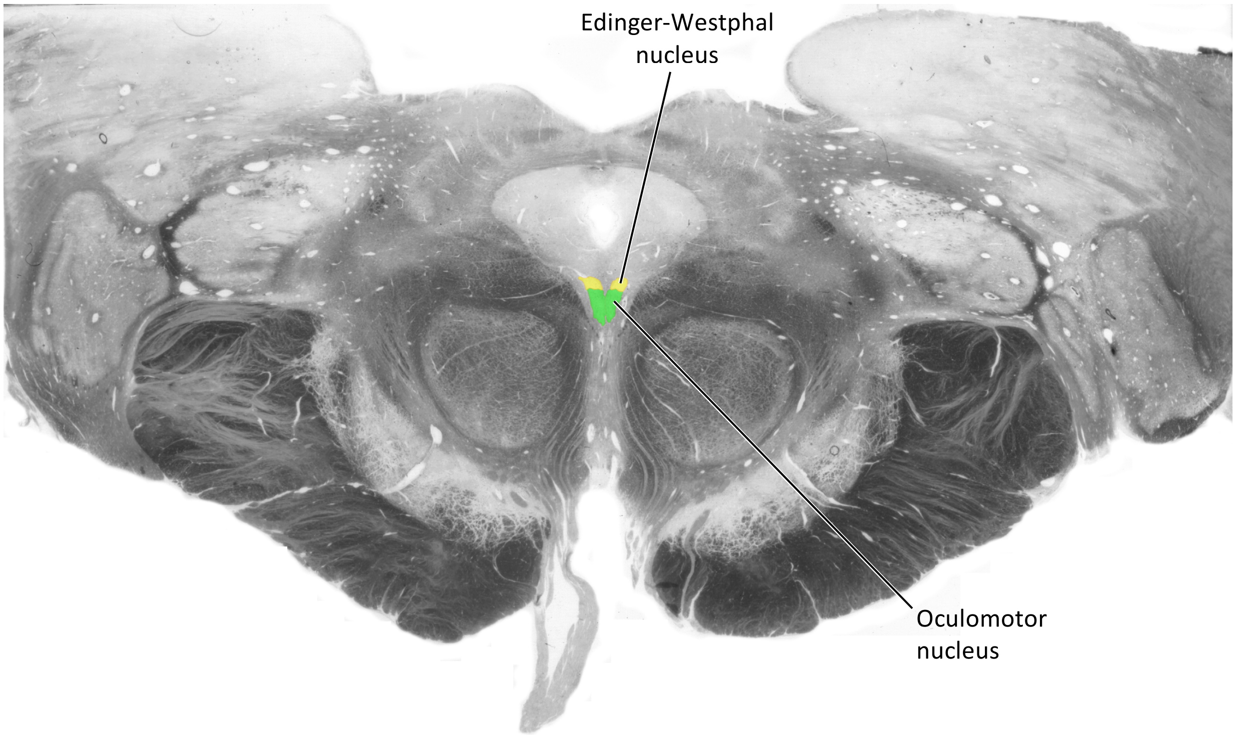


Fig. 7. Cranial nerve nuclei in the middle of the midbrain. (Section shown is "2-midbrain" in ***Sylvius4 Online***)

Only four of the cranial nerve nuclei are not identified in the preceding figures. The spinal accessory nucleus is found at the junction of the caudal medulla and the spinal cord and continues caudally into the first few cervical segments. Very few people in the world know just where the superior and inferior salivatory nuclei are located (somewhere in the dorsal tegmentum of the rostral medulla/caudal pons). The cochlear nucleus is located just at the junction of the medulla and pons, where this nucleus wraps around the lateral aspect of the inferior cerebellar peduncle (visible, but unlabeled in ***Sylvius4 Online***, section "8 – Medulla").

You should now be able to identify the brainstem subdivisions from which each section is taken. You should also be able to identify each of the cranial nerve nuclei (except for the four mentioned in the preceding paragraph). To consolidate your understanding of the surface anatomy of the brainstem and of sections through it, identify the point at which each cranial nerve enters or leaves the brain, and determine the approximate trajectory of the axons as they travel to or from this point to the cranial nerve nuclei with which they are connected. By the end of this learning experience, you should be able to view a cross section through the brainstem and identify the landmarks that characterize the subdivision, the level of the brainstem from which it was taken and the locations of the cranial nerves and nuclei that are present. Make sure that you can identify all of the structures (in **bold**) discussed in this tutorial and identified in the figures.

STUDY QUESTION

People can experience "hemiparesis" (unilateral weakness) for many reasons. For example, hemiparesis can result from damage to the precentral gyrus, the internal capsule, the cerebral peduncles, the medullary pyramids or the spinal cord (all structures that you should now know something about!).

If you saw a patient that was weak on one side of his body and you began to consider the location of the lesion, which of the following actions would be, arguably, the BEST option to investigate because the resulting action, if abnormal, could tell you most precisely where the lesion was located?

A. ask the patient to point to your nose with the index finger of his weak hand
B. ask the patient to follow your finger tip with his gaze as you moved your finger from side to side in front of him
C. ask the patient to stick his tongue straight out at you
D. ask the patient to point to your nose with the index finger of his strong hand
E. ask patient to stand using only his strong leg

Medical Neuroscience | Tutorial Notes

Internal Anatomy of the Spinal Cord

MAP TO NEUROSCIENCE CORE CONCEPTS[1]

NCC1. The brain is the body's most complex organ.

LEARNING OBJECTIVES

After study of the assigned learning materials, the student will:

1. Discuss the organization of gray matter in the spinal cord and the general functions associated with the dorsal horn, ventral horn and intermediate gray matter.
2. Discuss the organization of white matter in the spinal cord and the general functions associated with each column.

NARRATIVE

by **Leonard E. White** and **Nell B. Cant**
Duke Institute for Brain Sciences
Department of Neurobiology
Duke University School of Medicine

Introduction

After working through this tutorial, you should be able to discuss the organization of the various components of gray matter and white matter in the spinal cord. Let's begin by making sure that you understand the basic layout of sensory and motor neurons in the spinal cord.

The central nervous system interacts with the outside world through primary sensory neurons, which convey information from the body or its environment into the brain and spinal cord, and motor neurons, which activate striated muscles and modulate the activity of cardiac and smooth muscles and glands (see **Fig. 1** below and/or **Figure A1A**[2]). The cell bodies of primary sensory neurons lie in the **dorsal root ganglia** or the **cranial nerve ganglia**. Each neuron gives rise to a peripheral process, which receives information either directly or through association with receptors, and a central process, which enters the central nervous system and forms synapses with second order neurons. The cell bodies of somatic motor neurons lie in clusters or **nuclei** within the central nervous system and give rise to axons that innervate striated muscles in the body or head. You will also be introduced to other motor neurons that are part of the visceral motor system (a.k.a., autonomic nervous system) and are indirectly responsible for governing cardiac muscle, smooth muscle or glands.

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[1] Visit **BrainFacts.org** for *Neuroscience Core Concepts* (©2012 Society for Neuroscience) that offer fundamental principles about the brain and nervous system, the most complex living structure known in the universe.

[2] Figure references to Purves et al., *Neuroscience, 5th Ed.*, Sinauer Assoc., Inc., 2012. [click here]

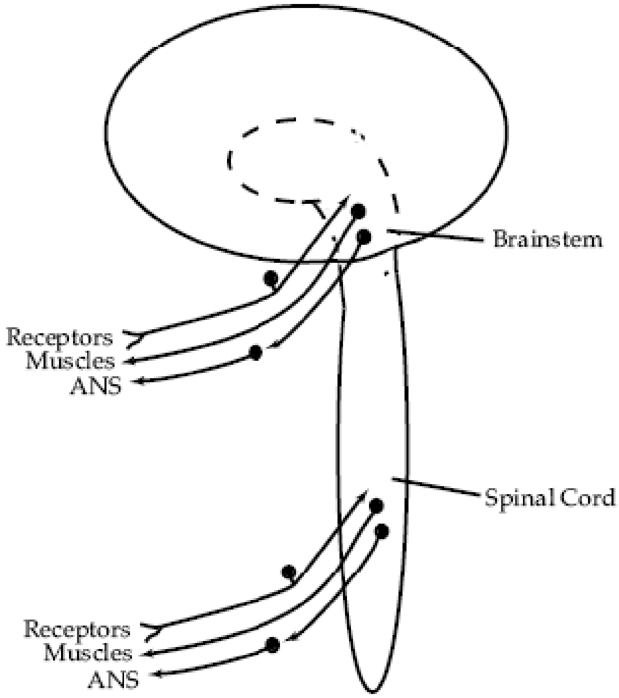

Fig. 1. Both the spinal cord and brainstem receive input from primary sensory neurons; the cell bodies of these neurons lie in sensory ganglia. In addition, both the spinal cord and brainstem give rise to motor output to striated muscles and to the autonomic ganglia (*ANS*, autonomic nervous system; synonymous with visceral motor system). (Illustration by N.B. Cant)

The internal anatomy of the spinal cord

The following brief discussion of the internal anatomy of the spinal cord will introduce some of the general principles of organization that also hold true for the brainstem. A cross-section through the spinal cord is illustrated schematically in **Fig. 2**. The gray matter forms the interior of the spinal cord; it is surrounded on all sides by the white matter. The white matter is subdivided into **dorsal** (or posterior), **lateral**, and **ventral** (or anterior) **columns**. Each of these columns contains bundles of axons related to specific functions. For example, the lateral columns are made up partly of axons that travel from the cerebral cortex to form synapses with motor neurons in the ventral horn. The dorsal columns carry much of the ascending sensory information from mechanoreceptors (more on these long pathways in later sessions).

The gray matter of the spinal cord is divided into **dorsal** and **ventral** (or posterior and anterior) '**horns**.' The dorsal horn is the part of the gray matter that receives sensory information entering the spinal cord via the dorsal roots of the spinal nerves. (Not all sensory fibers terminate in the dorsal horn of the spinal cord; axons carrying sensory information from mechanoreceptors travel to the medulla before making their first synapse in the pathway to conscious perception; they will be covered later.) The ventral horn contains the cell bodies of motor neurons that send their axons out via the ventral roots to terminate on striated muscles. Thus, one important general rule of organization is that neurons in the spinal cord that process sensory information are spatially separate from motor neurons. (See **Fig. 3** below and **Table A1** of *Neuroscience, 5th Ed.*, for more detail on the internal organization of spinal gray matter.)

As seen in a previous tutorial, the inputs and outputs of the spinal cord are arranged segmentally into the 31 spinal nerves. However, the gray matter of the spinal cord is not obviously segmented. It can be thought of as continuous columns (ventral horn) and layers (dorsal horn) of cells that run the length of the cord, with important differences in the size of the dorsal and ventral horns at different levels. The dorsal and ventral horns are largest where they supply the upper and lower limbs, because there are significantly greater numbers of outgoing and incoming nerve fibers at those levels. There is also variation along the length of the cord in the number of fibers in the columns of white matter (and, therefore, in their relative size). The amount of white matter is greatest at cervical levels and least at sacral levels. This is because ascending and descending fibers from and to all levels must pass through the cervical cord. Such variations in the organization of specific gray matter and white matter components along the length of the spinal cord are outlined in the chart on the next below.

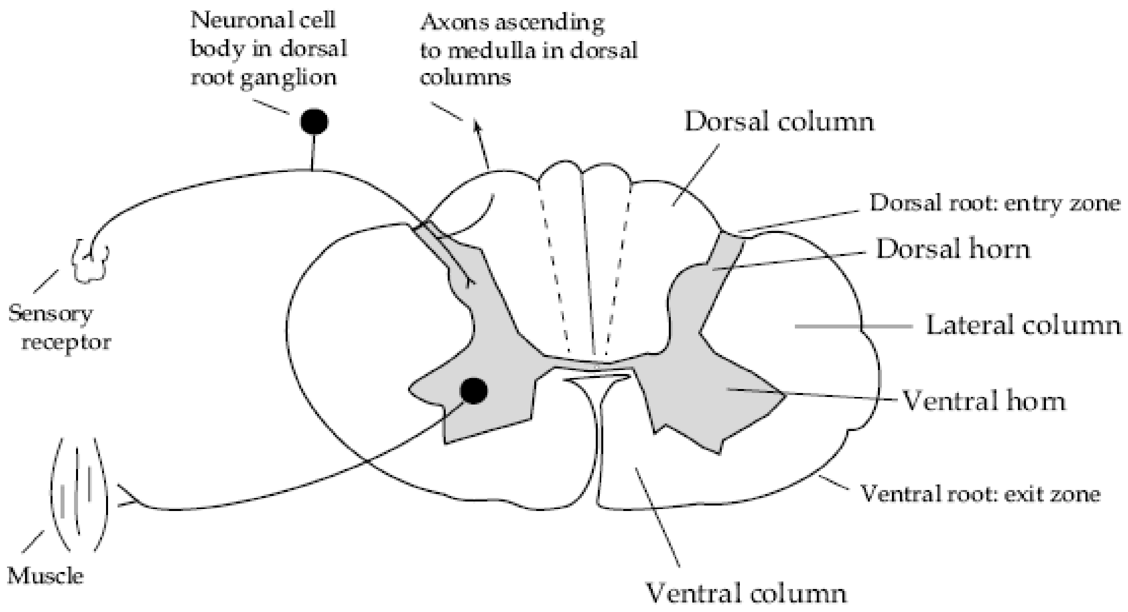

Fig. 2. Cross-section of the spinal cord at the cervical level. The general layout is the same at all levels of the cord, although specific details differ from one level to the next (see chart below). (Illustration by N.B. Cant)

	Internal features								
Spinal cord segment	**Dorsal horn**	**Lateral horn**	**Ventral horn**	**White matter**	**Gracile tract**	**Cuneate tract**	**Lateral corticospinal tract**	**Ventral corticospinal tract**	**Anterolateral system**
Cervical segments (8)	✓	--	✓	+++++	+++	+++	+++	+	+++
Thoracic segments (12)	✓	✓	✓	++++	+++	+ --	++	+	++
Lumbar segments (5)	✓	--	✓	+++	+++	--	++	+	++
Sacral segments (5)	✓	--	✓	++	++	--	+	+	+
Coccygeal segment (1)	✓	--	✓	+	+	--	--	+	+

Legend: ✓ indicates the structure's presence; -- indicates the structure's absence; +'s indicate the tract's relative abundance across segments.

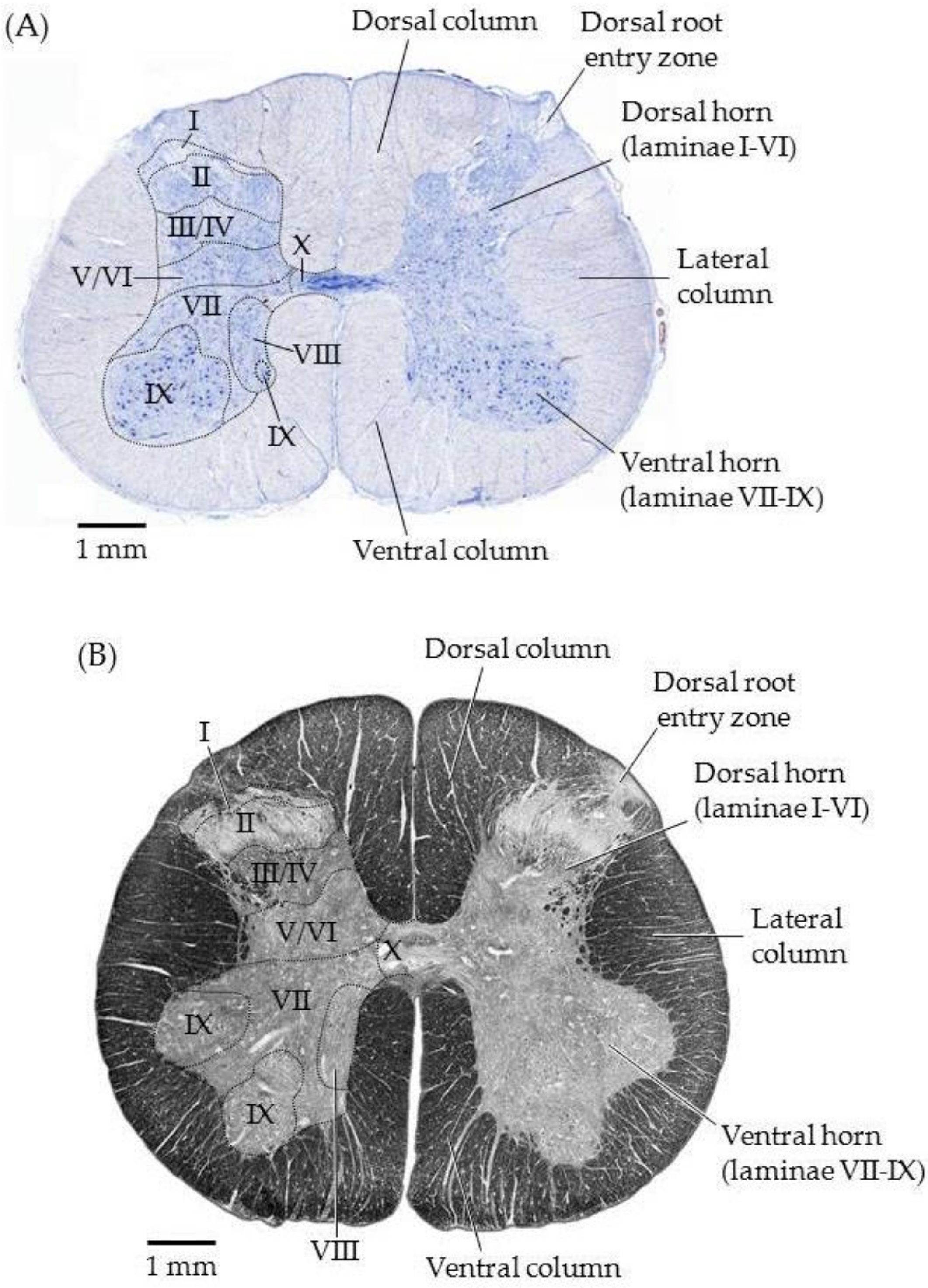

Fig. 3. Cross-sections through a lumbar segment of the human spinal cord. (A) Nissl stain highlighting cell bodies. (B) Facsimile of a myelin stain highlighting (in dark tones) white matter. (images by L.E. White)

STUDY QUESTION

Identify the MOST ACCURATE statement regarding the longitudinal organization of the spinal cord.

A. In the thoracic segments of the spinal cord, the volume of gray matter is greater than the volume of white matter.
B. The sympathetic preganglionic neurons are localized to the thoracic segments of the spinal cord.
C. There is progressively more white matter in the spinal cord from one segment to the next in a caudal progression.
D. The ventral horns achieve their greatest size in the thoracic segments of the spinal cord.
E. There is more neural circuitry in the gray matter of the thoracic segments than in the cervical or lumbosacral enlargements of the spinal cord.

Medical Neuroscience | Tutorial Notes

Ventricles

MAP TO NEUROSCIENCE CORE CONCEPTS[1]

NCC1. The brain is the body's most complex organ.

LEARNING OBJECTIVES

After study of the assigned learning materials, the student will:

1. Describe the distribution of the ventricular spaces in the forebrain and brainstem.

NARRATIVE

by Leonard E. WHITE and Nell B. CANT
Duke Institute for Brain Sciences
Department of Neurobiology
Duke University School of Medicine

Overview

Now that you have acquired a framework for understanding the regional anatomy of the human brain, as viewed from the surface, and some understanding of the blood supply to both superficial and deep brain structures, you are ready to explore the internal organization of the brain. In the next set of tutorials from the brain anatomy lab, we will focus on the internal anatomy of the forebrain (recall that the forebrain includes the derivatives of the embryonic prosencephalon). Given the complexity of the brainstem and its importance for diagnosis and clinical practice, that portion of the brain will be addressed in a separate set of tutorials. Here, the focus will be on the ventricular system of the human central nervous system—the system of fluid-filled spaces in the human brain derived from the lumen of the embryonic neural tube.

The ventricular system

As a point of emphasis for this tutorial, remember that the ventricles are the product of the morphogenic events that bent, pinched and expanded the lumen of the embryological neural tube and greatly increased the thickness and complexity of its walls (now that's an understatement!). The objective of this tutorial is to recognize the various compartments that constitute the ventricular system of the adult brain. This will entail recognizing four principal ventricles, the paired **lateral ventricles**, the **third ventricle**, and the **fourth ventricle**, as well as three narrow channels, the paired **interventricular foramina**, and the single (midline) **cerebral aqueduct**.

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[1] Visit **BrainFacts.org** for *Neuroscience Core Concepts* (©2012 Society for Neuroscience) that offer fundamental principles about the brain and nervous system, the most complex living structure known in the universe.

If you have a copy of *Neuroscience, 5th Ed.*, begin by becoming familiar with **Figure A23**[2]. If you have access to a digital brain atlas, such as ***Sylvius4 Online***, then open the atlas views in the coronal plane and be prepared to step through the brain from anterior to posterior.

Begin passing through the brain from anterior to posterior and note the appearance of the frontal horn of the lateral ventricle as it first appears. With your attention on the lateral ventricle, continue sectioning and note the appearance of the temporal horn of the lateral ventricle in the medial temporal lobe. Finally, note the caudal extension of the lateral ventricle as it penetrates the occipital lobe as the occipital horn of the lateral ventricle.

Now, re-slice the forebrain in the axial (horizontal) plane from dorsal to ventral. Look for these same compartments within the lateral ventricle. Do you notice how the lateral ventricle opens widely in its central part or body, then appears more posteriorly in a region called the atrium before appearing more anteriorly in the temporal lobe?

To appreciate the third ventricle, look for the narrow slit-like space along the midline at the medial base of the diencephalon The **interventricular foramina** (of Monroe) provide the means for cerebrospinal fluid (CSF) flow to from each lateral ventricle, where it is synthesized by **choroid plexus**, into the third ventricle. Note that the two lateral ventricles are separated by a thin wall called the **septum pellucidum**. Thus, CSF produced in the lateral ventricles first mixes in the third ventricle.

The third ventricle communicates with the fourth ventricle by means of a narrow channel through the dorsal midbrain (mesencephalon) called the **cerebral aqueduct**. The cerebral aqueduct is a principal landmark that will always help you identify transverse sections through the midbrain. From here, continue sectioning through the brainstem in the caudal direction and note the gradual expansion of the cerebral aqueduct as you enter the pons. By the middle of the pons, the cerebral aqueduct has fully opened up into the **fourth ventricle**. This most caudal ventricle in the adult brain lies between the dorsal surface of the pons and the large stalks of white matter (the cerebellar peduncles; “peduncle” means stalk) that connect the cerebellum to the brainstem.

The circulation of CSF

From the foregoing account, it should be clear that CSF flows from the lateral ventricles, through the interventricular foramina, into the third ventricle, through the cerebral aqueduct and into the fourth ventricle. Actually, there is choroid plexus in each ventricle so some CSF is produced in each; but given the large size of the lateral ventricles, these are the major produces of CSF. This may be surprising, but the choroid plexus produces 2-3 times as much CSF every day as can be contained in the brain, the cranial vault, and the spinal column. Thus, the entire volume present in the system is turned over several times a day. Thus, obstruction of CSF flow results in an excess of cerebrospinal fluid in the intracranial cavity, a dangerous condition called hydrocephalus (literally, “water head”) that can lead to enlargement of the ventricles and compression of the brain. But how does the CSF leave the brain and ultimately return to the venous vascular system?

Cerebrospinal fluid percolates through the ventricular system and flows into the subarachnoid space through perforations in the thin covering of the fourth ventricle (through a midline foramen of Magendie and two lateral foramena of Luschka). Once outside of the fourth ventricle, CSF flows in between the pia mater and the arachnoid mater in the **subarachnoid space**. CSF eventually passes through specialized structures called **arachnoid villi** or **arachnoid granulations** along the dorsal midline of the forebrain (see **Figure A21**). These granulations are essentially one-way valves that communicate

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[2] Figure references to Purves et al., *Neuroscience, 5th Ed.*, Sinauer Assoc., Inc., 2012. [click here]

between the subarachnoid space and a prominent, midline dural sinus, called the **superior sagittal sinus**. Thus, CSF is returned to the venous circulation via the system of dural sinuses that eventually form the jugular veins in the base of the cranium.

STUDY QUESTIONS

Q1. Which structure produces **cerebrospinal fluid**?

A. choroid plexus
B. pineal gland
C. arachnoid granulations
D. cisterna magna
E. pituitary gland

Q2. Which statement below most accurately describes the components of the **ventricular system** and/or the circulation of cerebrospinal fluid (CSF)?

A. CSF flows directly from one lateral ventricle through an aperture in the septum pellucidum into the other lateral ventricle.
B. The third ventricle is lies posterior to the fourth ventricle.
C. The lateral ventricle is associated with the midbrain.
D. CSF circulates around the entire central nervous system in the subarachnoid space.
E. CSF flows into the subarachnoid space via apertures in the third ventricle.

Medical Neuroscience | Tutorial Notes

Internal Capsule and Deep Gray Matter

MAP TO NEUROSCIENCE CORE CONCEPTS[1]

NCC1. The brain is the body's most complex organ.

NCC3. Genetically determined circuits are the foundation of the nervous system.

LEARNING OBJECTIVES

After study of the assigned learning materials, the student will:

1. Identify major white matter and gray matter structures that are apparent in sectional views of the forebrain, including the structures listed in the chart and figures in this tutorial.
2. Describe and sketch the relations of the deep gray matter structures to the internal capsule in coronal and axial sections of the forebrain.
3. Describe the distribution of the ventricular spaces in the forebrain and brainstem.

NARRATIVE

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Overview

Now that you have acquired a framework for understanding the regional anatomy of the human brain, as viewed from the surface, and some understanding of the blood supply to both superficial and deep brain structures, you are ready to explore the internal organization of the brain. This tutorial will focus on the sectional anatomy of the forebrain (recall that the forebrain includes the derivatives of the embryonic prosencephalon). As you will discover, much of our framework for exploring the sectional anatomy of the forebrain is provided by the **internal capsule** and the deep gray matter, including the **basal ganglia** and the **thalamus**. But before beginning to study this internal anatomy, it will be helpful to familiarize yourself with some common conventions that are used to describe the deep structures of the central nervous system.

Some terminology and general principles

The next few pages contain definitions and illustrations of some commonly used neuroanatomical

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[1] Visit **BrainFacts.org** for *Neuroscience Core Concepts* (©2012 Society for Neuroscience) that offer fundamental principles about the brain and nervous system, the most complex living structure known in the universe.

terminology. They may be useful for reference as you study the material in this and the related neuroanatomical tutorials.

The simplest classification of central nervous tissue is **white matter** and **gray matter** (Figure 1). The gray matter (so-named because it looks grayish in fresh specimens) is made up of neuronal cell bodies, their dendrites, and the terminal arborizations of both local axons and those from distant sources. The dendrites and the axons that form synapses with them are sometimes referred to as “neuropil.” The white matter is made up of the axons that connect separated areas of gray matter. The myelin that ensheathes many of these axons gives the white matter its glistening white appearance. Note that an individual neuron can contribute to both gray and white matter. Axons projecting from one part of the brain to another usually group together in bundles. Likewise, neurons that serve similar functions often form clusters.

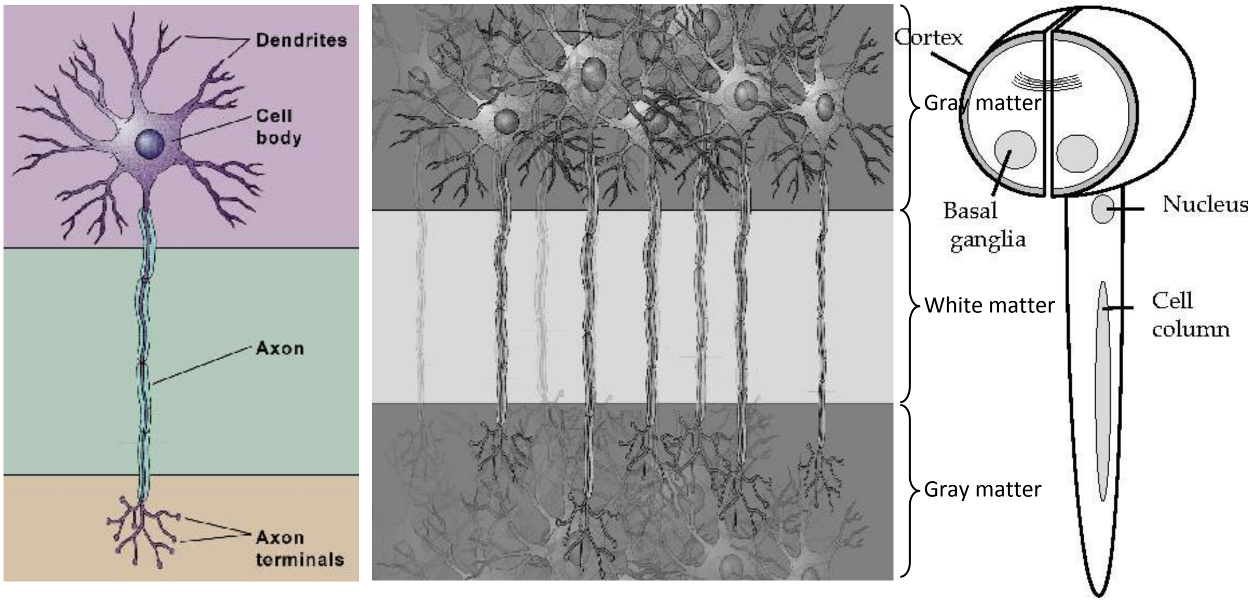

Figure 1. Gray and white matter in the central nervous system. *Left*, Drawings depicting the composition of both types of neural tissue (Illustration courtesy of Pyramis Studios, Durham NC). *Right*, Drawing of the organization of gray and white matter in the brain and spinal cord; cortex, basal ganglia, nucleus and cell column are all examples of gray matter in the central nervous system. (Illustration by N.B. Cant)

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

Terms used to refer to gray matter

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

Terms used to refer to white matter

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

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

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

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

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

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

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

You will also encounter the following terms used to refer to general regions of the central nervous system:

tectum (L., roof)—used to refer to brainstem structures located dorsal to the ventricular system. In mammals, this term has become synonymous with the dorsal midbrain.

tegmentum—this term refers to structures that form the core of the brainstem (**Figure 2**). It can be thought of (very loosely) as the part of the brainstem that is most like the spinal cord in the sense that the cell groups in the tegmentum have functions similar to those of cell groups in the spinal cord. For the most part, the structures that lie outside the tegmentum have no counterparts in the spinal cord.

base—the ventral aspect of the brain. The term ‘basal’ is synonymous with ‘ventral.’

floor, *wall*—usually used with respect to structures that bound the ventricles (e.g., the floor of the fourth ventricle corresponds to the part of the pons and medulla that forms the ventral boundary of the ventricle).

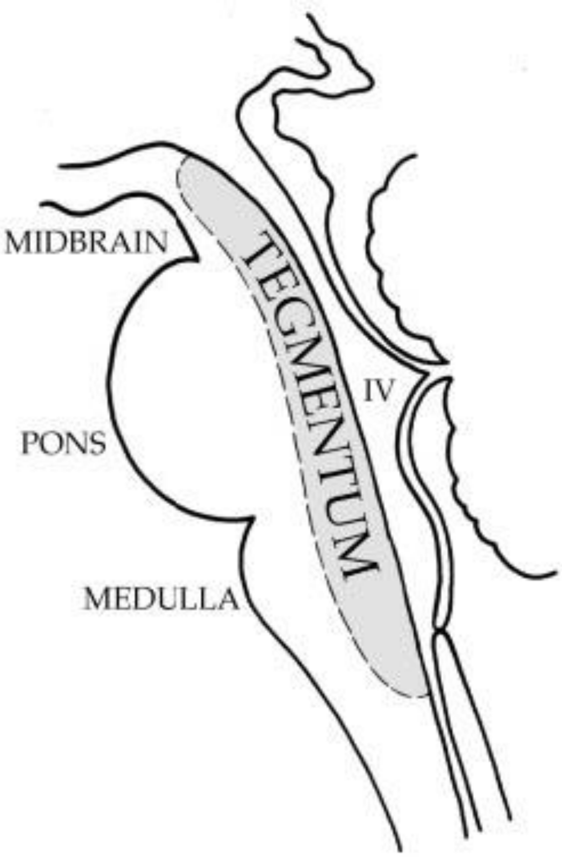

Figure 2. Structures in the core of the brainstem make up the tegmentum. It includes the cranial nerve nuclei, most long tracts, and loosely arranged groups of neurons known collectively as the reticular formation. (Illustration by N.B. Cant)

The large number of terms used to refer to similar structures may seem annoying, but it is not unlike the case in non-medical English usage. Consider, for example, the many terms that refer to roadways (street, avenue, boulevard, interstate, path, road, highway, etc.).

Internal anatomy of the forebrain

For the rest of this tutorial, we will discuss the appearance of sections through the forebrain, so that you can learn to identify the structures that are not visible on a surface view. The anatomy of the forebrain as seen in sections is relatively simple; however the geometry of some of these deep structures can be a challenge to appreciate. For an example, if you have *Neuroscience 5th Ed.*, note the locations of the **hippocampal formation** and the **lateral ventricle** in the illustration of a partially dissected hemisphere in **Figure A13**[2]. You will soon learn why these structures appear where they do. In brief, the hippocampus and other deep forebrain structures follow the course of the lateral ventricle into the temporal lobe. The hippocampus (one component of the hippocampal formation) lies in the 'floor' of the lateral ventricle in the temporal lobe. The fornix is a bundle of axons that arises mainly in the hippocampus and essentially travels to the diencephalon along this same path (i.e., following the course of the lateral ventricle).

As you work through the remainder of this tutorial—and hopefully, as you explore the brain on your own in a digital brain atlas such as ***Sylvius4 Online***, be sure to recognize and locate the following structures on sections cut in any of the three standard anatomical planes:

	Gray Matter	White Matter	Ventricle
Telencephalon (cerebral hemispheres)	**Cortical/corticoid structures:** **cerebral cortex; hippocampus; amygdala** **Basal ganglia (deep structures):** **caudate nucleus, putamen, nucleus accumbens, globus pallidus**	**Corpus callosum** **Anterior commissure** **Fornix** **Internal capsule**	**Lateral ventricle**
Diencephalon	**Thalamus** **Hypothalamus**	**Fornix**	**Third ventricle**

Let's approach our study of internal forebrain anatomy with the **cerebral cortex**. The cerebral cortex is a thin layer of gray matter that covers the entire surface of the hemispheres. Most of the cortex that is visible from the surface in humans is known as **neocortex**, cortex which is made up of six layers of neurons. Phylogenetically older cortex, which has fewer cell layers, is found on the inferior surface of the temporal lobe, separated from neocortex by the rhinal fissure (**Figure 3**). The cortex with the fewest layers (three) is known as the **hippocampus** (paleocortex of the parahippocampal gyrus). The hippocampus is the medial edge of temporal cortex that becomes double-folded into the medial aspect of the temporal lobe; it is visible only in dissected brains or in sections. It is worth remembering that the entire cerebral cortex is derived from the walls of the largest and most anterior swelling of the embryonic brain, the prosencephalon. Thus, despite its deep sulci and fissures and phylogenetic divisions, the entire cerebral cortex in one hemisphere is a continuous sheet of neural tissue.

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[2] Figure references to Purves et al., *Neuroscience, 5th Ed.*, Sinauer Assoc., Inc., 2012. [click here]

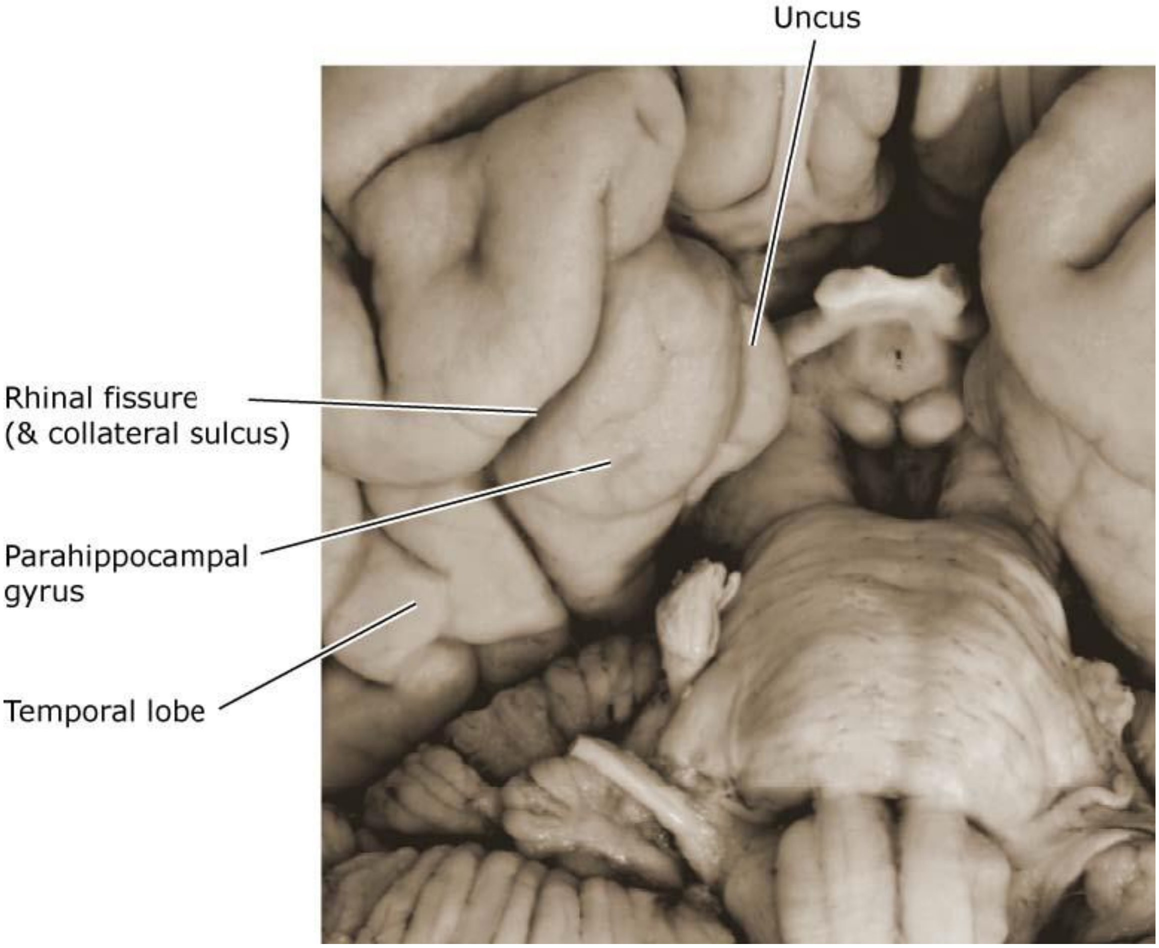

Figure 3. Close-up view of the ventral-medial surface of the temporal lobe to show the parahippocampal gyrus and related sulci. The rhinal fissure separates the lateral neocortex from the medial paleocortex. The medial protuberance in the parahippocampal gyrus is called the uncus, which is cortical division of the posterior amygdala.

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

Buried deep within the hemispheres are the **basal ganglia** (**Figure 4**), which are large gray matter structures concerned with modulating thalamic interactions with the frontal lobe. (The term ‘ganglion’ is *not* usually used for clusters of neurons inside the central nervous system; this is an exception.) The basal ganglia lie partly rostral and partly lateral to the diencephalon (refer to the chart on page 1 for their embryonic relations). They can be divided into four main structures: the **caudate**, the **putamen**, the **nucleus accumbens**, and the **globus pallidus**.

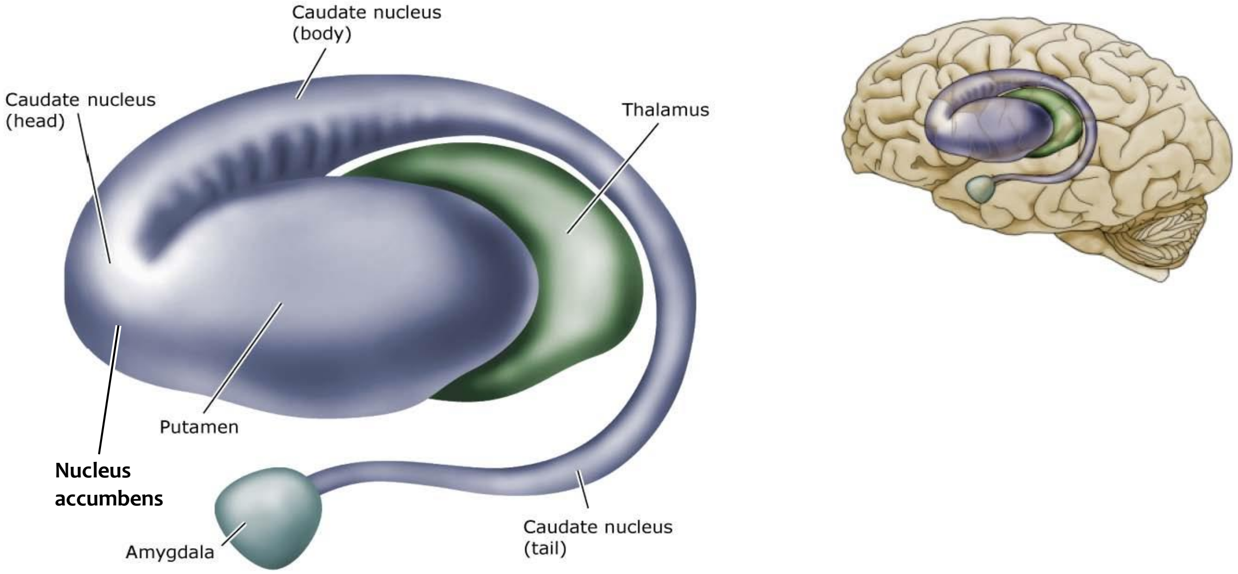

Figure 4. The basal ganglia and thalamus drawn with all of the cortex and white matter of the hemispheres stripped away; viewed from the side (refer to the inset for orientation). The head of the caudate is in the frontal lobe; its body lies just dorsal to the thalamus, and its tail descends into the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

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

These three divisions of the striatum receive inputs from different portions of the telencephalon that define the functional roles of each striatal division. In general terms, the striatum (and the circuits through the basal ganglia that begin here) regulates *movement*, with the three divisions of the striatum governing different domains of movement. Thus, it should be instructive to remember that:

- the **putamen** is concerned with the regulation of *bodily movement*;
- the **caudate nucleus** (especially its large anterior 'head') regulates *movement of the mind* and *eyes* (which often indicate what we are thinking about); and
- the **nucleus accumbens** is concerned with *movement of emotion* or *motivated behavior*.

Obviously, we are speaking of the concept of movement in loose terms. Nevertheless, it is important to recognize that each striatal division (and the distinct circuits through the basal ganglia that derive from each) share common structural and functional motifs that help explain their contribution to the modulation of behavior. Each circuit is involved in the *initiation* or *suppression* of some program for behavior. To accomplish these functions, each division of the striatum projects to some division of the **pallidum**; the **globus pallidus** is the largest division of the pallidum and it receives input mainly from the putamen. The pallidum in turn regulates thalamo-cortical interactions. A full consideration of basal ganglia circuitry is beyond the scope of this tutorial; but these important circuits will be considered elsewhere in the course when we explore in some depth the functions of the basal ganglia.

Now let's turn our attention from gray matter to white matter. There are three bundles of axons in the hemisphere that have already been identified on mid-sagittal views: the corpus callosum, anterior commissure and fornix (see the tutorial, *Medial Surface of the Brain*). One additional system of axonal fibers should now be appreciated. Many of the axons entering or leaving the cortex do not assemble into compact bundles, except in the vicinity of the thalamus and the basal ganglia, where they form a structure known as the **internal capsule**. The internal capsule lies just lateral to the diencephalon, and as mentioned briefly above, a portion of it separates the caudate from the putamen. Many of the axons in the internal capsule terminate or arise in the thalamus. Other systems of axons descending from the cortex, course through the internal capsule, and continue past the diencephalon to enter the **cerebral peduncles** of the midbrain. Between the cortex and the internal capsule, the axons of the white matter are not so tightly packed; they are sometimes called the 'corona radiata', a reference to the way they appear to radiate out from the compact internal capsule to reach multiple areas of cortex. (Individual groups of axons may also be indicated in this way. For example, you will hear reference to the visual radiations or the auditory radiations, axons that travel from the thalamus to the visual and auditory cortices, respectively.) We will return to the internal capsule in relation to the important deep gray matter structures as we consider cross-sectional views through the forebrain.

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

That is almost it for structures in the cerebral hemispheres!

There are two other gray matter structures you should know. One is a group of complex nuclei, known as the **basal forebrain nuclei**, which have become associated with the signs and symptoms of diseases such as Alzheimer's disease (see **Figure 8**). Like the basal ganglia, the basal forebrain nuclei are made up of clusters of cells (rather than layers); but unlike the basal ganglia, these clusters are much smaller and typically much less compact. They are located ventral to the anterior commissure and below the basal ganglia, between the ventral striatum and the hypothalamus.

The other structure you should know is the **amygdala**, which is a large mass of gray matter buried in the anterior-medial part of the temporal lobe, anterior to the lateral ventricle and the hippocampus (see **Figure 9**). The amygdala is an important component of ventral-medial forebrain circuitry and it is involved in the experience and expression of emotion. It was once classified as part of the basal ganglia; however, it is structurally and functionally heterogeneous, with systems of neurons and intrinsic connections that are comparable to those in striatum and the cerebral cortex. We will discuss the amygdala and its connections within the limbic forebrain in some depth in later tutorials (see *The Amygdala and Hippocampus* and *Neurobiology of Emotion*).

There is one slight complication that you will encounter as you begin to identify the structures of the forebrain in sections. Sometimes you see the same structures twice in the same section in the same hemisphere. To understand why this is so, refer to **Figures 5** & **6**.

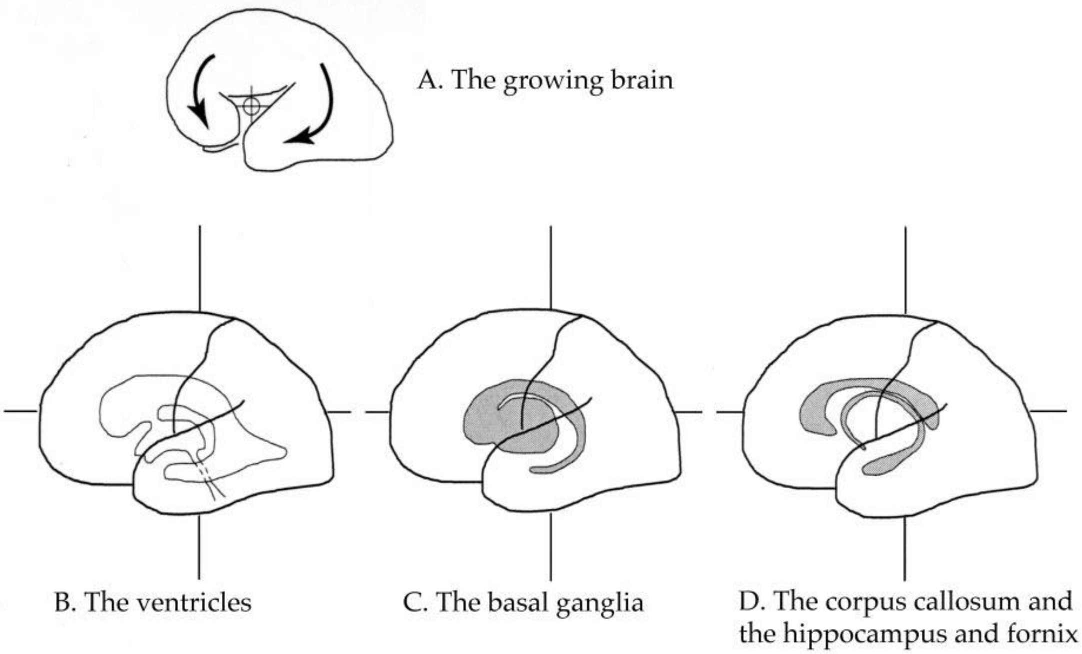

Figure 5. A. During development, the human cerebral hemispheres grow markedly in the posterior and ventral directions, forming the temporal lobe. As the temporal lobe grows, the hemisphere appears to rotate forward, beginning to form a shape something like a horseshoe. Deeper structures in the hemispheres follow this pattern of growth so that in the adult brain they also form an arch or horseshoe shape. B. The lateral ventricle curves into the temporal lobe. (The part in the temporal lobe is referred to as the inferior or temporal horn.) C. The caudate nucleus of the basal ganglia has a 'tail' which curves into the temporal lobe (cf. Figure 4). D. The corpus callosum curves slightly but does not continue into the temporal lobe. The hippocampus is located in the temporal lobe and gives rise to the fornix which arches over the diencephalon to enter it at its anterior end. The lines in B-D indicate planes of section (coronal and horizontal) that cut twice through the structures shown. (Illustration from N.B. Cant)

The diencephalon comes to lie medial to the hemispheres. The **thalamus** is the largest subdivision of the diencephalon (see **Figure 6**). It is egg-shaped and is made up of many subdivisions, some of which we shall identify later. The hypothalamus lies ventral to the thalamus. Anterior to the hypothalamus is the optic chiasm. (Clinically, the close physical proximity of the chiasm to the pituitary gland is very important, since a combination of visual and endocrine problems is a strong indication of a pituitary tumor.) The mammillary bodies are a part of the hypothalamus lying in its caudal part just at its junction with the midbrain.

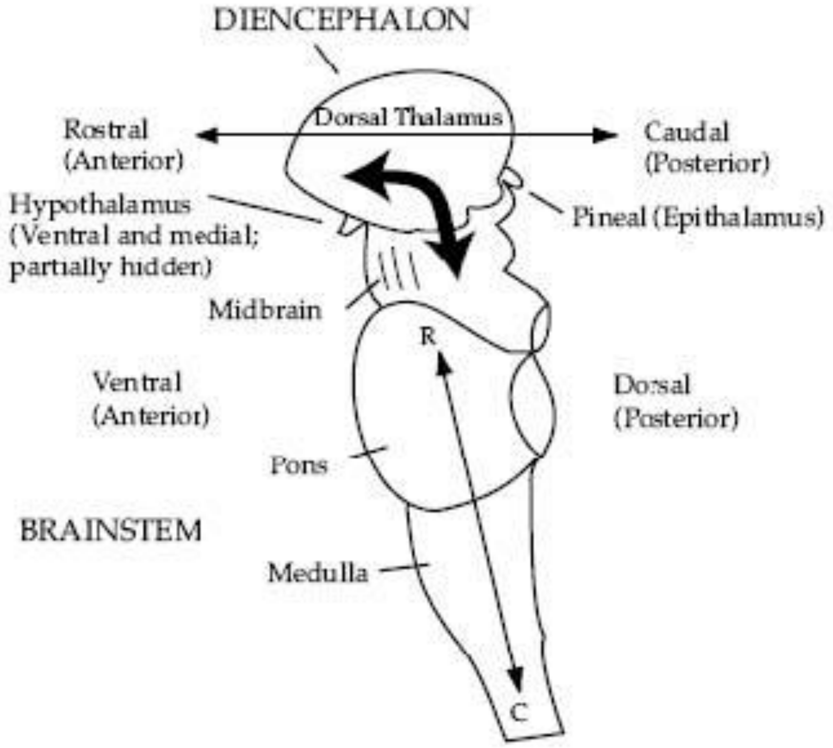

Figure 6. Brainstem and thalamus drawn with the cerebral hemispheres and cerebellum removed. This figure highlights the sharp bend in the long axis of the central nervous system that occurs at the junction of the midbrain and diencephalon. This causes the dorsal diencephalon to lie almost at a right angle to the dorsal midbrain. (The epithalamus, represented here by the pineal gland, is the most dorsal part of the diencephalon, but when the brain is viewed from the side as here, it appears to lie deep, since the lateral parts of the dorsal thalamus expand greatly in size. (Illustration from N.B. Cant)

Internal capsule and deep gray matter

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

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

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

These relations reflect the course of the outgrowing axons that formed the internal capsule in fetal development as they navigated through the anlage of deep gray matter in the embryonic brain. As you carefully inspect sections through the forebrain (in the next few pages and in ***Sylvius4 Onilne***), note the appearance of the internal capsule and the deep gray matter. There are several additional details to observe and learn:

(1) the **caudate nucleus**, **putamen** and **nucleus accumbens** become continuous around the rostral margin of the internal capsule;

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

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

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

(5) the **caudate nucleus** has a long “tail” that follows the course of the lateral ventricle into the temporal lobe (see again **Figures 4 & 5**).

(6) the anterior limb of internal capsule separates the head of the caudate from putamen and globus pallidus, and the posterior limb of internal capsule mainly separates thalamus from globus pallidus

So now that you are primed to interpret the internal anatomy of the forebrain, careful inspect the images of coronal sections on the following pages (and in the video tutorial) and ***identify each of the structures and relations numbered (1) to (6) above***.

Coronal sections through the brain

The five coronal sections through the brain shown, beginning on the next page (**Figures 7–11**), were taken from ***Sylvius4 Online*** and should resemble the brains that were shown in the tutorial. Remember, areas with little or no myelin appear dark and are considered gray matter, and areas containing myelinated axons appear light and are called white matter.

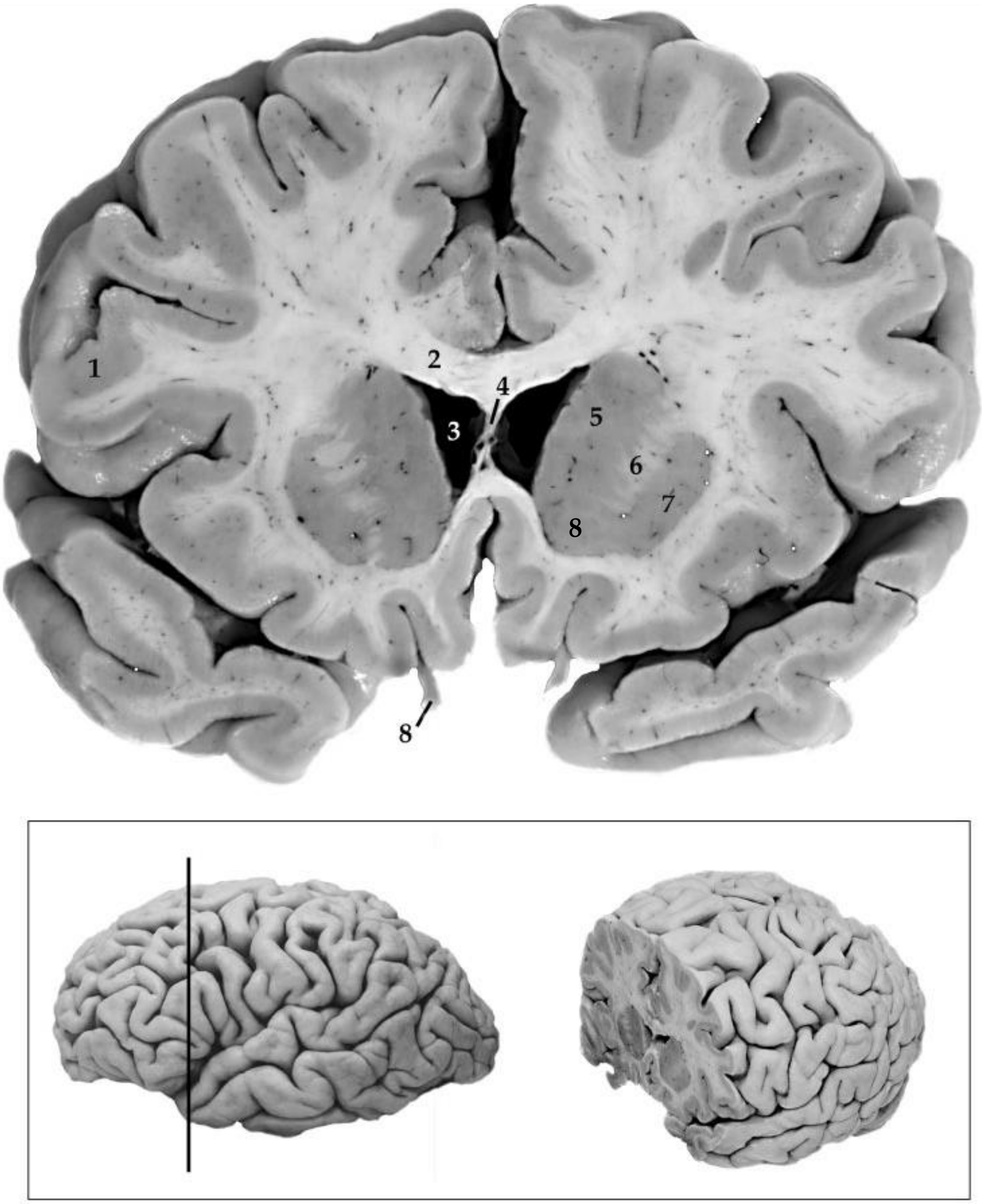

Figure 7. This first section is anterior to the region where the anterior commissure crosses the midline so only the hemispheres are present, and the diencephalon is not seen. The basal ganglia, which form part of the hemispheres, are very large here in the frontal lobes. Key: 1. Cerebral cortex of the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

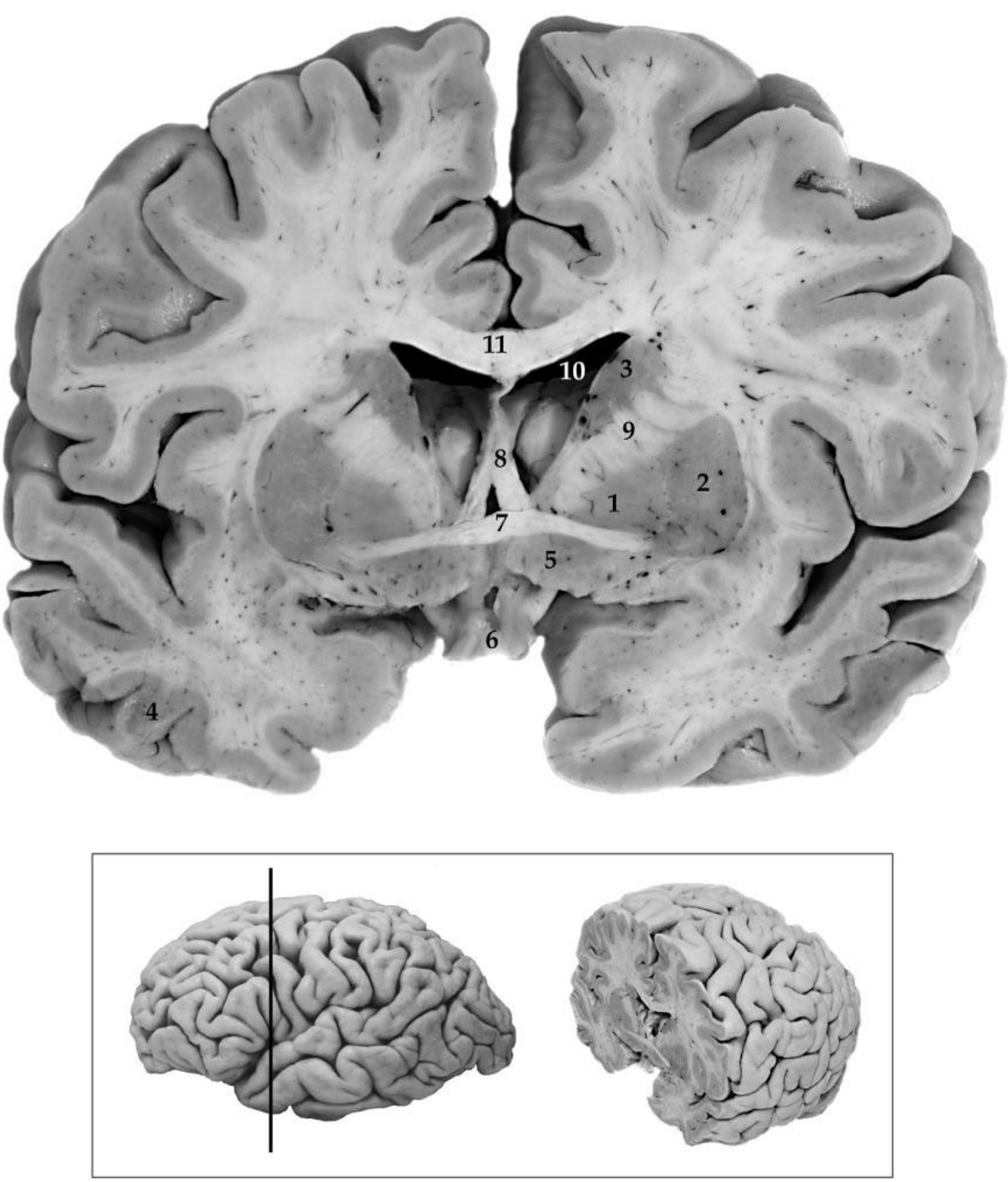

Figure 8. The second section in the series is at the level where the anterior commissure crosses the midline. Locate the caudate and putamen and the globus pallidus. Also find the internal capsule, the lateral ventricles, the corpus callosum, and the fornix. (You see the fornix only once on each side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

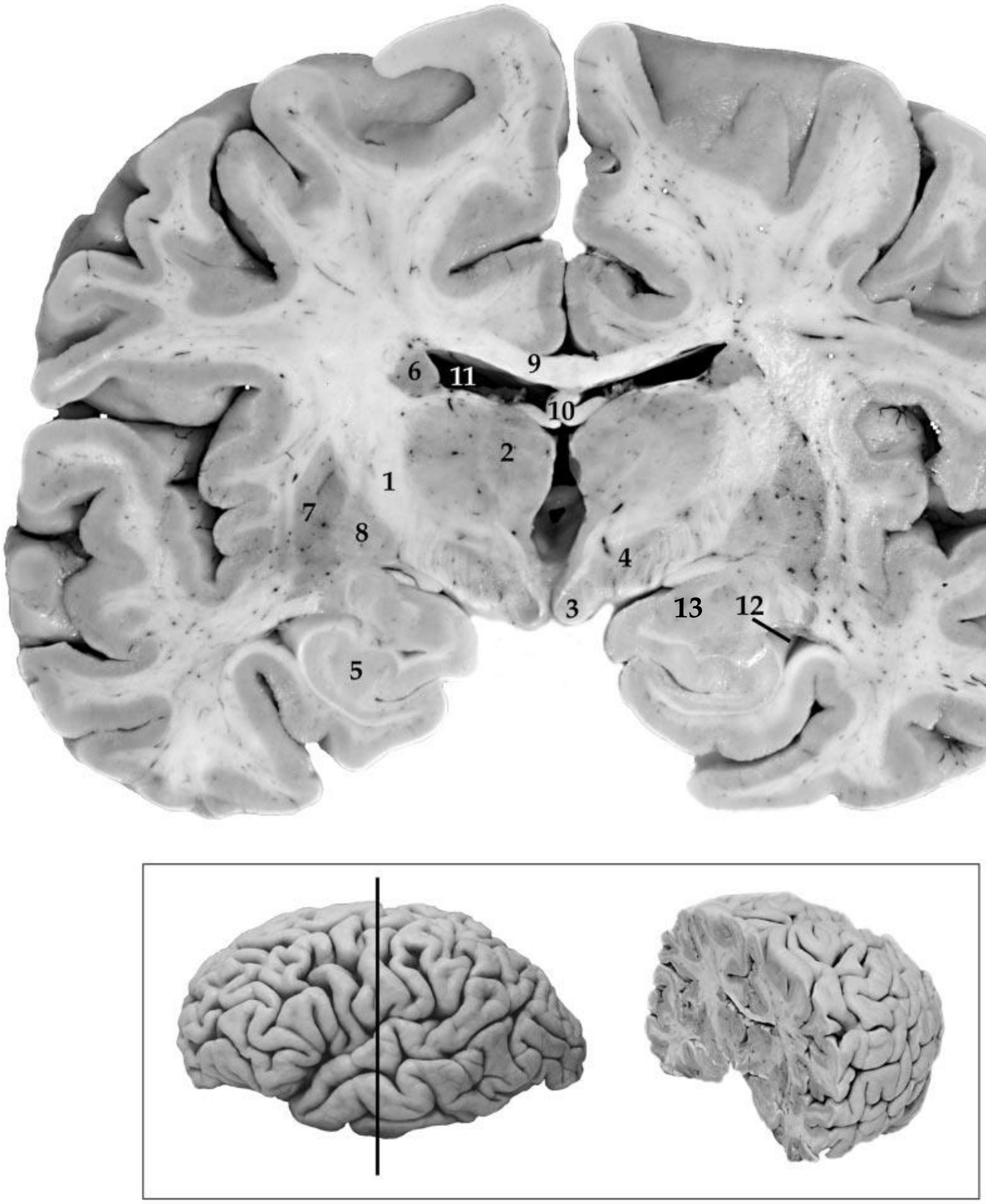

Figure 9. The third section in the series lies about halfway through the brain. Since this section lies posterior to the anterior commissure, the diencephalon appears next to the midline. The thalamus is separated from the putamen and globus pallidus by the internal capsule. The hypothalamus lies ventral to the thalamus. Lateral to the hypothalamus is the area known as the subthalamus. The cortex in the medial aspect of the temporal lobe is known as the hippocampus, which is emerging just inferior to the posterior portion of the amygdala. Key: 1. Internal capsule; 2. Thalamus; 3. Hypothalamus (mammillary body); 4. Subthalamus; 5. Hippocampus; 6. Caudate; 7. Putamen, 8. Globus pallidus; 9. Corpus callosum; 10. Fornix; 12. Lateral ventricle; 13 (posterior) amygdala. (Image is "Coronal 5" from ***Sylvius4 Online***)

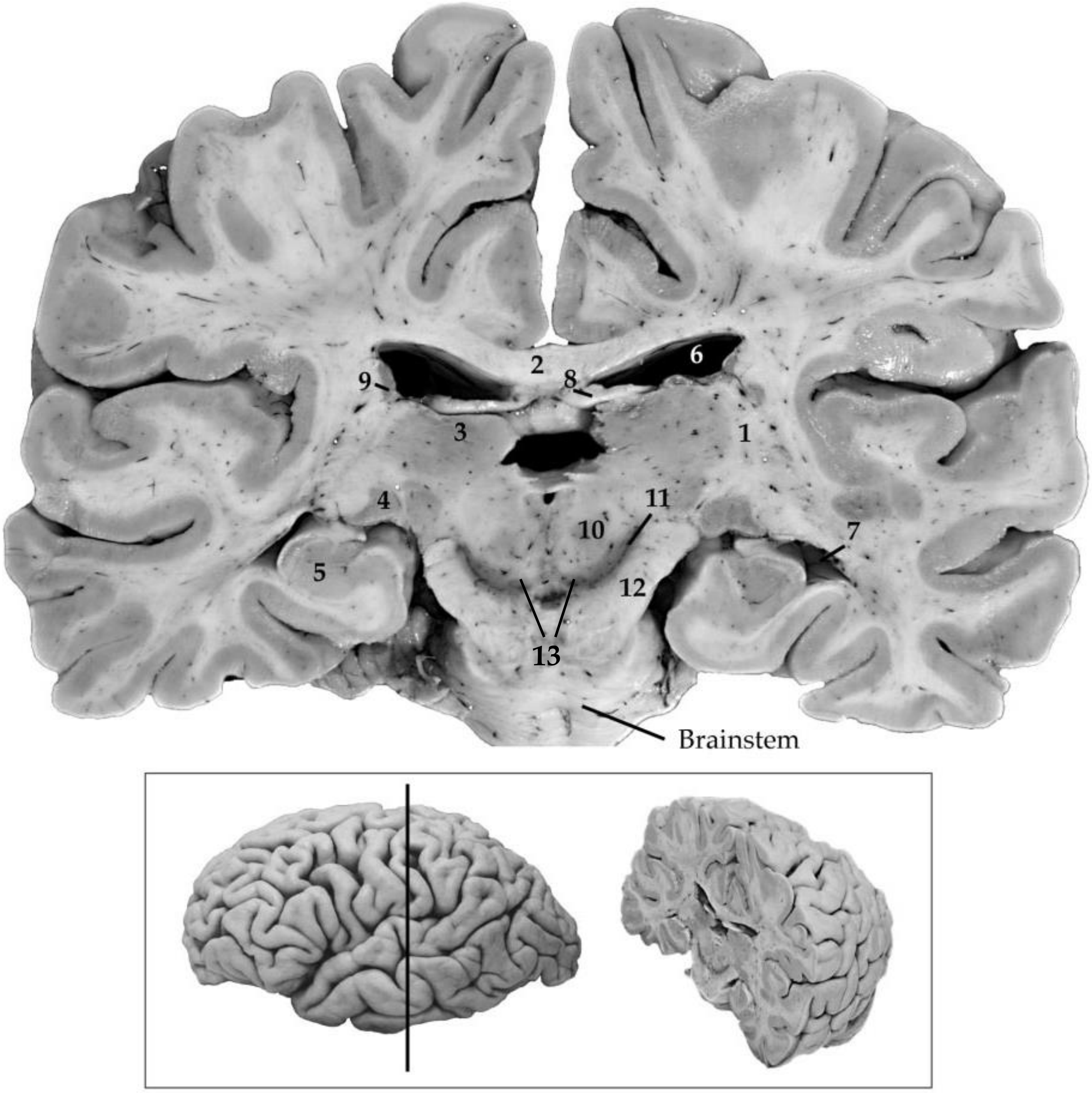

Figure 10. In this section, you can see the transition from the diencephalon to the midbrain of the brainstem. (Some of the structures of the midbrain are labeled in the figure.) In the forebrain, some of the same structures that were seen in more anterior sections can still be identified, although the basal ganglia have almost disappeared. Only a small portion of the caudate nucleus can still be seen. One important part of the thalamus, the lateral geniculate nucleus, is seen. Key: 1. Internal capsule; 2. Corpus callosum; 3. Thalamus; 4. Lateral geniculate nucleus (part of the thalamus); 5. Hippocampus; 6 & 7. Lateral ventricle; 8. Fornix; 9. Caudate; 10. Midbrain; 11. Substantia nigra (pars compacta); 12. Cerebral peduncle; 13. Ventral tegmental area. (Image is "Coronal 5" from ***Sylvius4 Onilne***)

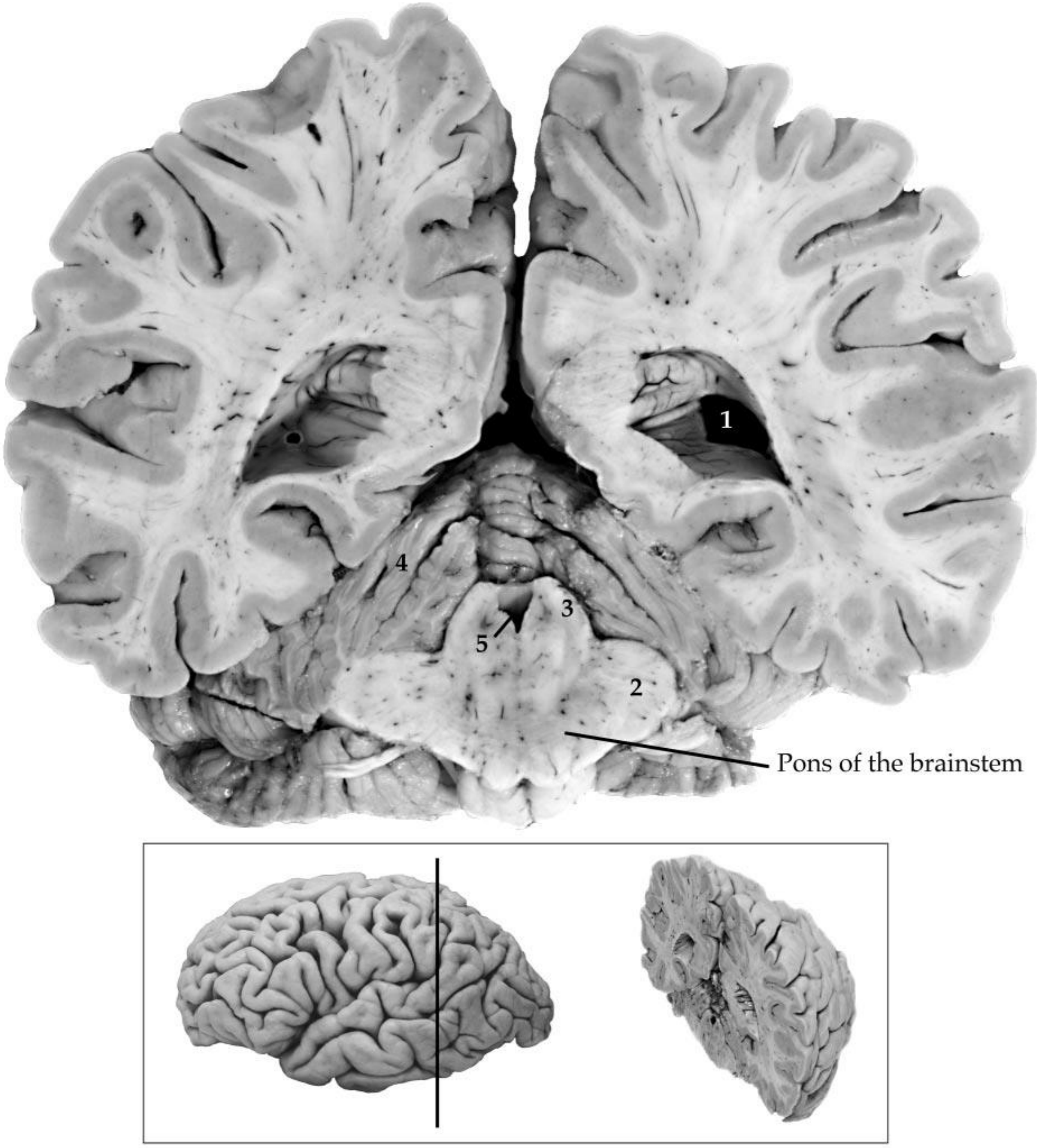

Figure 11. The most posterior section in the series is cut through the parietal lobes. Since the cut is posterior to the corpus callosum, the two hemispheres are not connected to each other. In the forebrain, only the gray and white matter and the posterior horn of the lateral ventricle are seen; none of the deep gray matter structures are present. The section also passes through the brainstem. This part of the brainstem is known as the pons; it lies ventral to the cerebellum. Key: 1. Lateral ventricle (posterior or occipital horn); 2. Middle cerebellar peduncle; 3. Superior cerebellar peduncle; 4. Cerebellum (cerebellar cortex); 5. Fourth ventricle (most rostral recess continuous with the cerebral aqueduct). (Image is "Coronal 5" from ***Sylvius4 Online***)

Optional exercise—modeling deep gray matter

Now that you have some experience with the sectional anatomy of the forebrain and a growing appreciation for the relations of deep gray matter structures in brain-space, you are ready to get your hands dirty. No sequence of neuroanatomical study is complete until learners are challenged to build or model their own brain. Obtain a set of colored modeling clay or make your own (several simple recipes are available on the www); five colors would be best, with one being white. Your goal will be to construct a simple, but accurate model of the spatial relations in the brain that you discovered in working through this tutorial. In particular, ***construct a clay (dough) model of the major components of the basal ganglia, thalamus and internal capsule***, as described on pp. 10-11, with special attention to the six numbered points of detail.

How to start? Begin by constructing the internal capsule: flatten out a white (for white matter, of course) lump of clay into an elongated fan shape. In the brain, the wide end of the fan (called the corona radiata) penetrates into the subcortical white matter and the narrow end penetrates the diencephalon and brainstem, where it forms the cerebral peduncle and, eventually, the medullary pyramid; the basal ganglia and thalamus reside near the middle of the fan. Next, add a colored lump of clay for the globus pallidus (but on what side of the internal capsule, lateral or medial?). Then, encompass your 'faux' globus pallidus with the putamen and fashion at least the rostral and dorsal portions of the caudate nucleus. When ready to be more ambitious, try creating a more complete caudate nucleus that includes its temporal tail. Finally, add an egg-shaped lump for the thalamus (remember its position relative to the internal capsule?). How does it look … anything like **Figure 4**? Don't worry if your first attempt(s) are less than edifying. What is most important about this exercise is the visualization of spatial relations that comes from wrestling with both substance (modeling clay) and abstraction (imagined brain-space).

One additional tip for this modeling exercise: ***Sylvius4 Online*** contains illustrations and an interactive virtual model of a standard brainstem model that is often used in neuroanatomical laboratories (including ours). This model includes the diencephalon, basal ganglion and internal capsule; refer to this model and interact with the "Atlas extras" feature (available via the folder in the navigation window in the upper left) for additional views of the relation among these structures.

Now that you have in front of you a clay model of the deep gray matter of the human brain, ***try actually sectioning your model in one of the three standard neuroanatomical planes*** (the coronal plane is a good starting plane for deconstruction). This should be easily done with a standard kitchen knife or a thin wire. Assuming the clay (dough) is of the proper consistency and has survived sectioning, do you recognize the spatial relations among your modeled gray matter structures that you discovered in the human brain? Try comparing different planes of section through your model with sectional views of the digital brain in ***Sylvius4 Online***. You might even try re-attaching your sections with a little gentle kneading and then re-sectioning in an orthogonal plane (try axial next).

With some persistence and patience, working through this exercise will foster a more cogent understanding of ***3D*** relations within the deepest substratum of the human forebrain. ***You might even want to snap a photograph of your model and post it to the Discussion Forum!***

STUDY QUESTIONS

Q1. Which pair of structures is located on the **medial** side of the internal capsule?

A. caudate nucleus & thalamus
B. nucleus accumbens & putamen
C. putamen & globus pallidus
D. amygdala & hippocampus
E. putamen & insula

Q2. Which pair of structures is located on the **lateral** side of the internal capsule?

A. globus pallidus & caudate nucleus
B. pineal gland & mammillary body
C. third ventricle & body of lateral ventricle
D. caudate nucleus & thalamus
E. putamen & globus pallidus