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

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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 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

[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]

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).

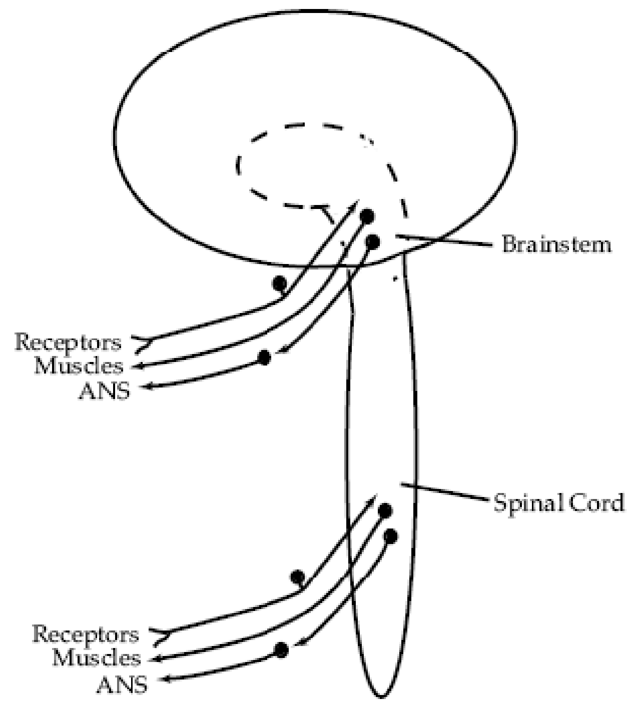


Fig. 1. Both the spinal cord and brainstem receive input from primary sensory neurons; the cell bodies of these neurons lie in sensory ganglia. In addition, both the spinal cord and brainstem give rise to motor output to striated muscles and to the autonomic ganglia (*ANS*, autonomic nervous system;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

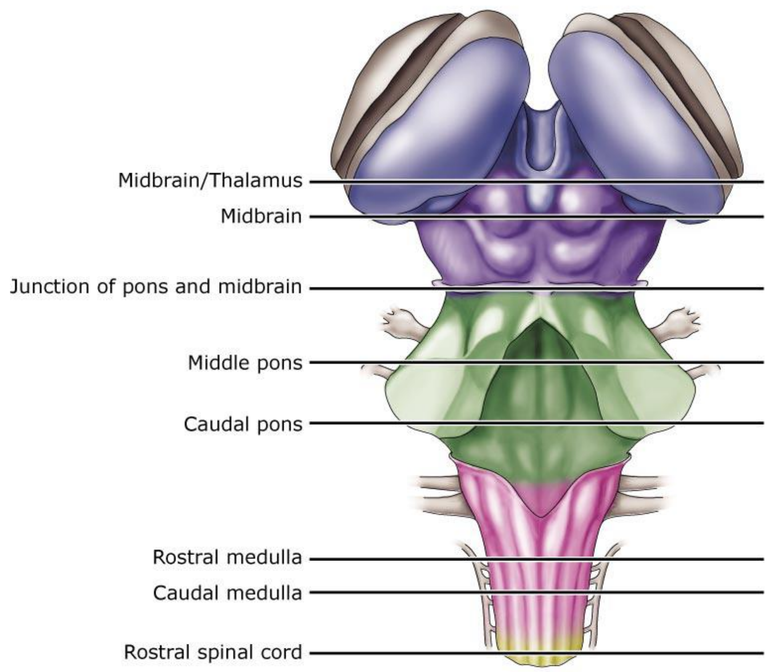


Figure 2. Drawing of the dorsal surface of the brainstem with lines to indicate the seven levels that will be illustrated in the following pages. These same sections are also annotated in the **Brainstem Cross Sectional Atlas** in ***Sylvius4 Online***. (Illustration courtesy of Pyramis Studios, Durham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

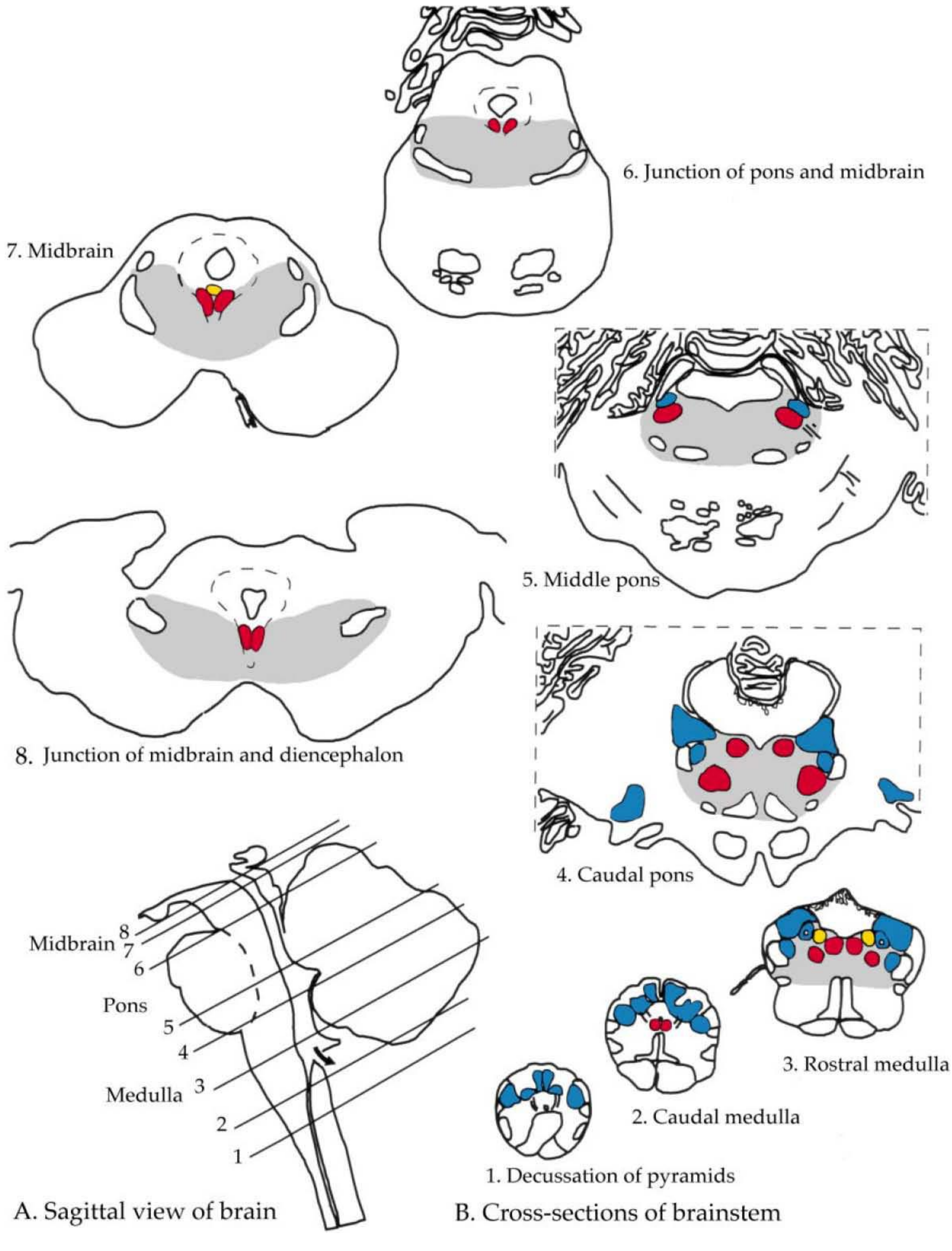

6. Junction of pons and midbrain
7. Midbrain
5. Middle pons
8. Junction of midbrain and diencephalon
4. Caudal pons
Midbrain
8
7
6
Pons
5
4
Medulla
3
2
1
3. Rostral medulla
2. Caudal medulla
1. Decussation of pyramids
A. Sagittal view of brain
B. Cross-sections of brainstem

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]

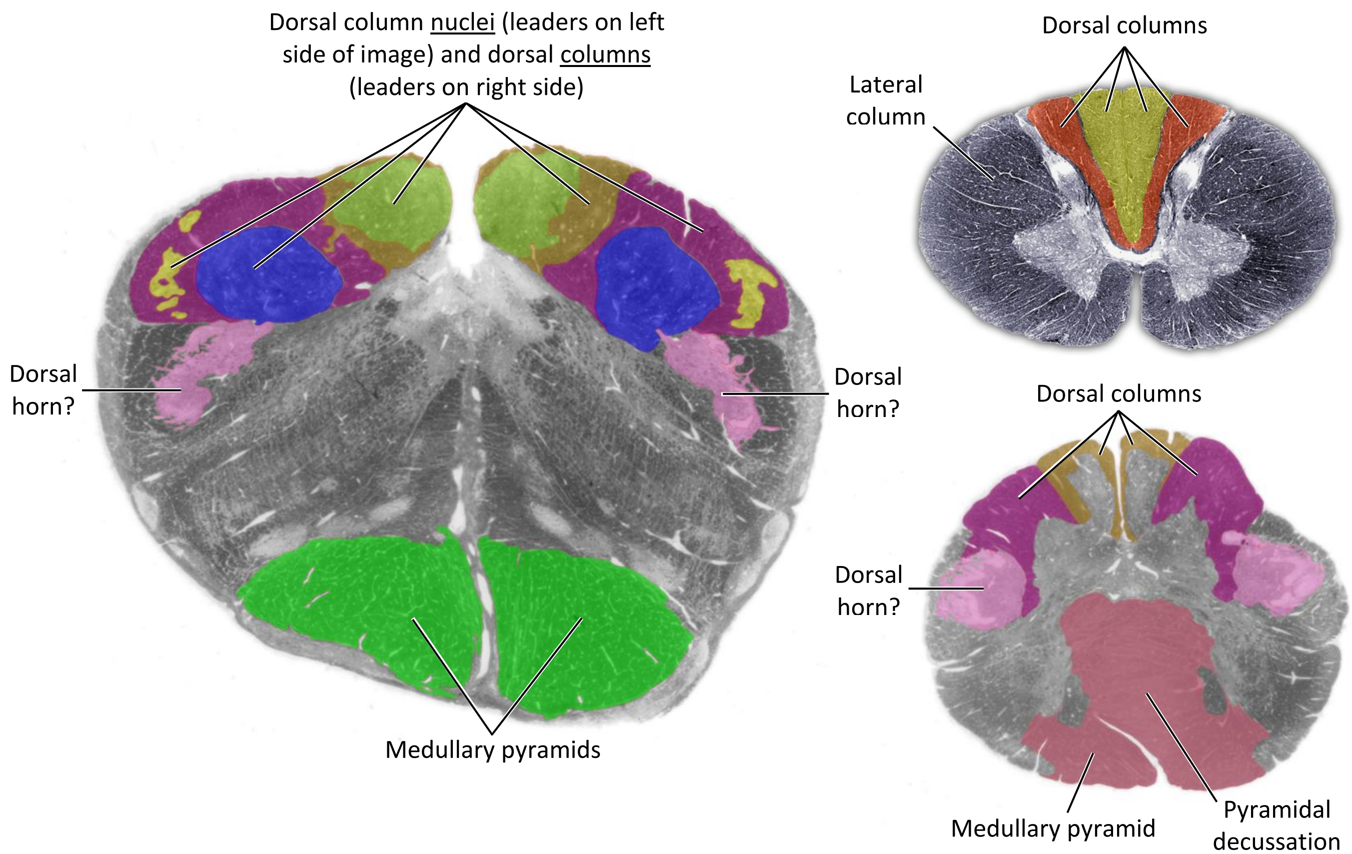


Figure 4. Section through the caudal medulla (left picture; "11-medulla" in ***Sylvius4 Online***). The shape is similar to that of the spinal cord (a section through the cervical cord is shown in top right picture; "14-Spinal Cord-cervical" in ***Sylvius4***). But, although the internal organization 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.

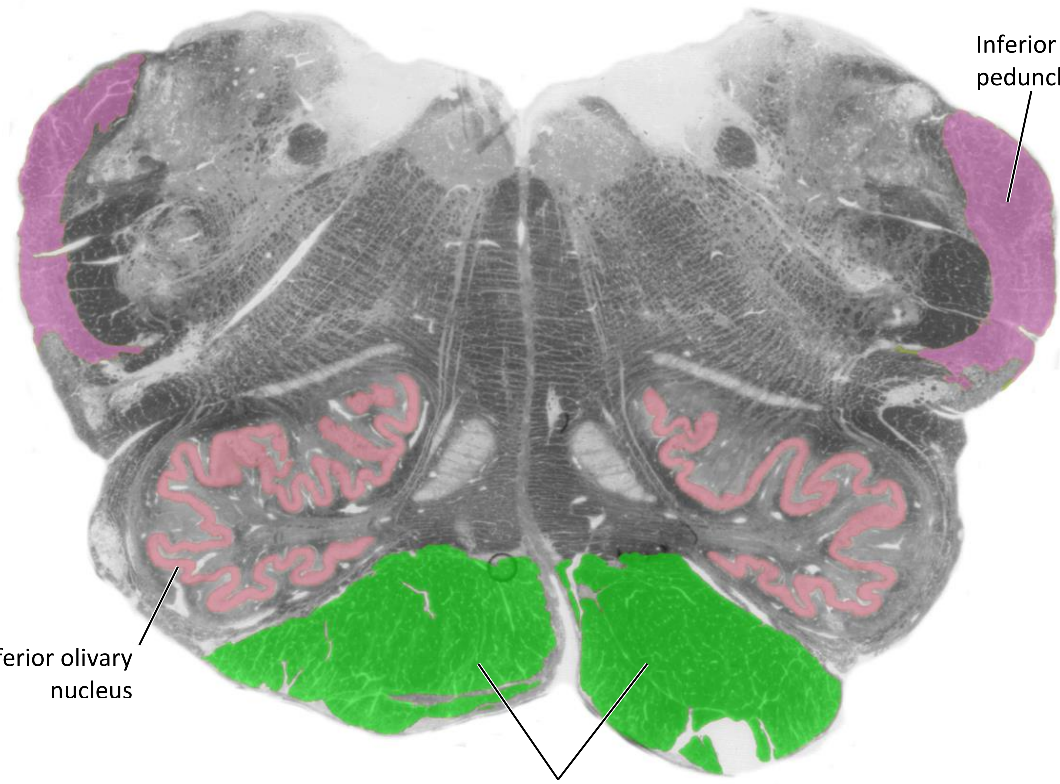


Figure 5. The rostral medulla is easy to identify and is not likely to be confused with any other part of the brain (section shown is "9-medulla" in ***Sylvius4 Online***). It features the large nuclei known as the paired **inferior olivary nucleus** (this is what accounts for the outward bulging seen 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.

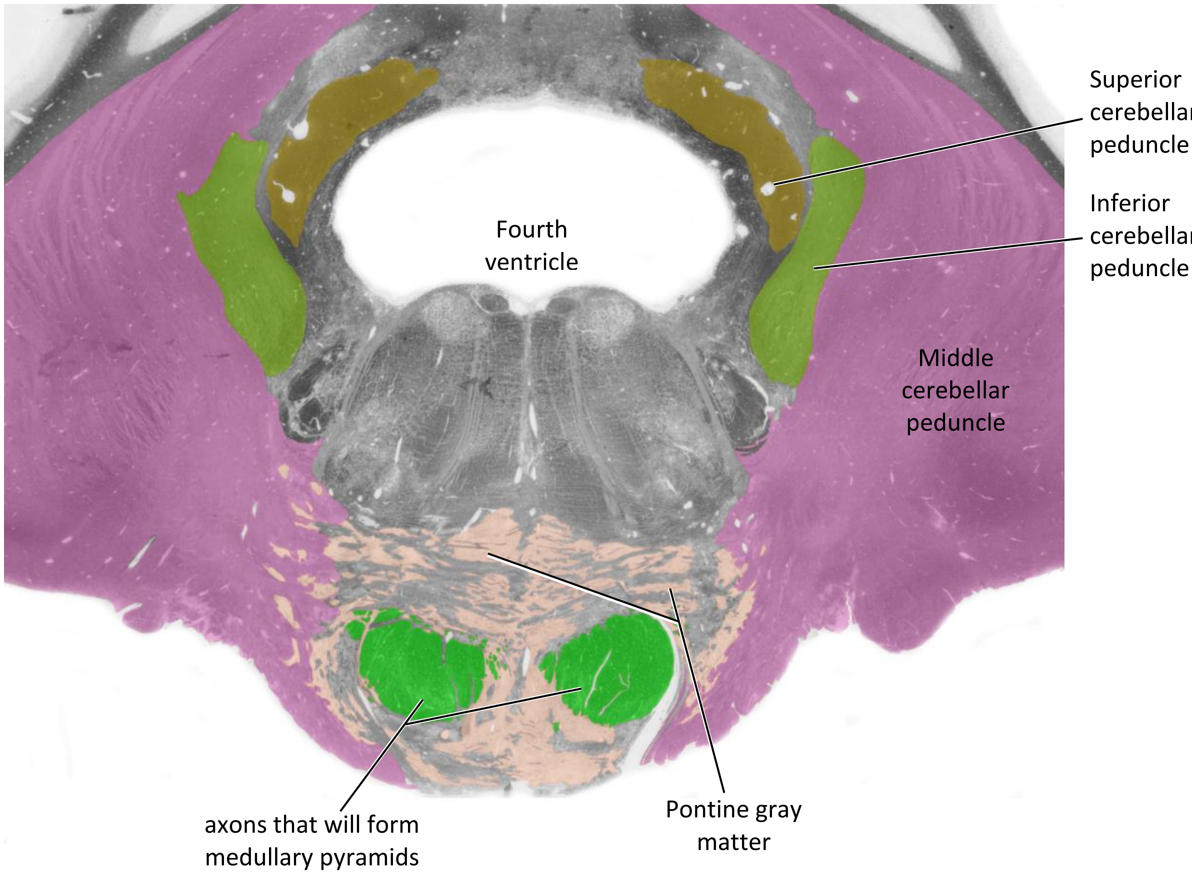
With reference to **Figures 4 & 5** and the chart below, carefully inspect the internal features of the medulla from its caudal union with the spinal cord to the pons. Spend some time browsing these medullary sections (and the sections in ***Sylvius4 Online***), and find each of the internal features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

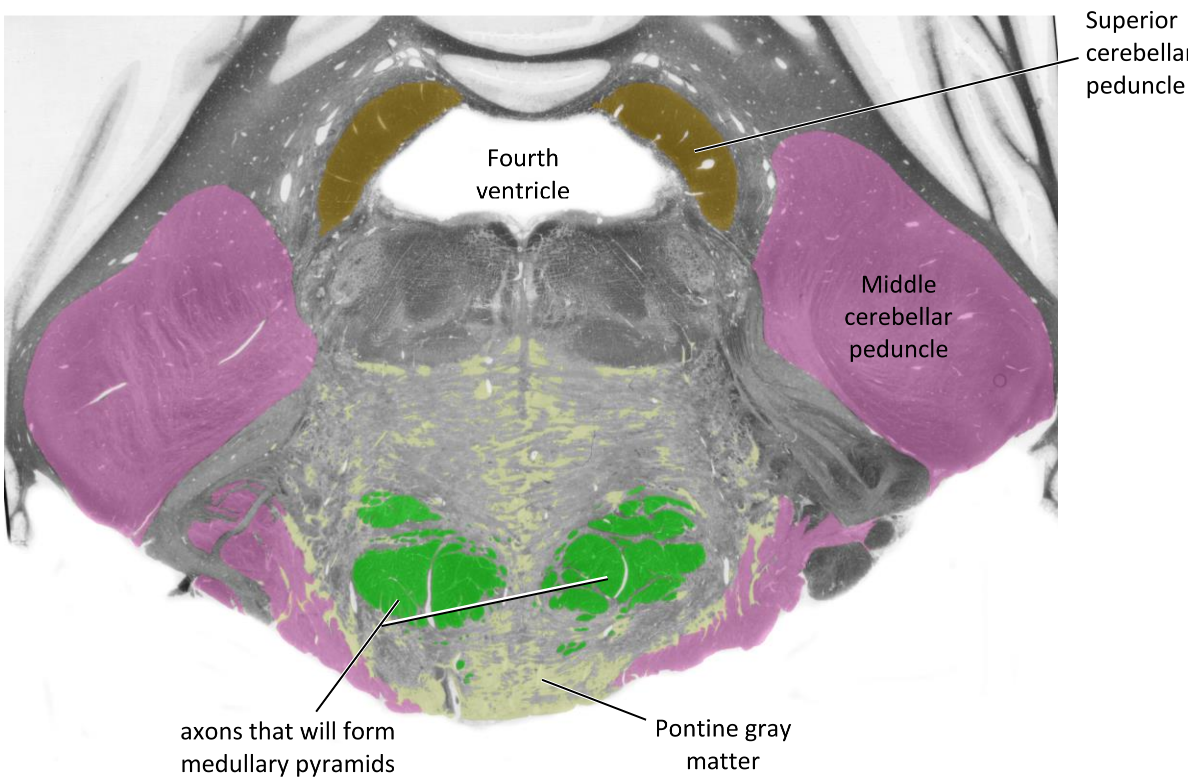
Figure 6. (Next page). The caudal and middle pons (upper and lower sections, respectively; "7-pons" & "6-pons" in ***Sylvius4 Online***) look very similar at first inspection. We need two levels to represent the pons because there are different groups of cranial nerve nuclei at the two levels. These 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
Fourth ventricle
Middle cerebellar peduncle
axons that will form medullary pyramids
Pontine gray matter

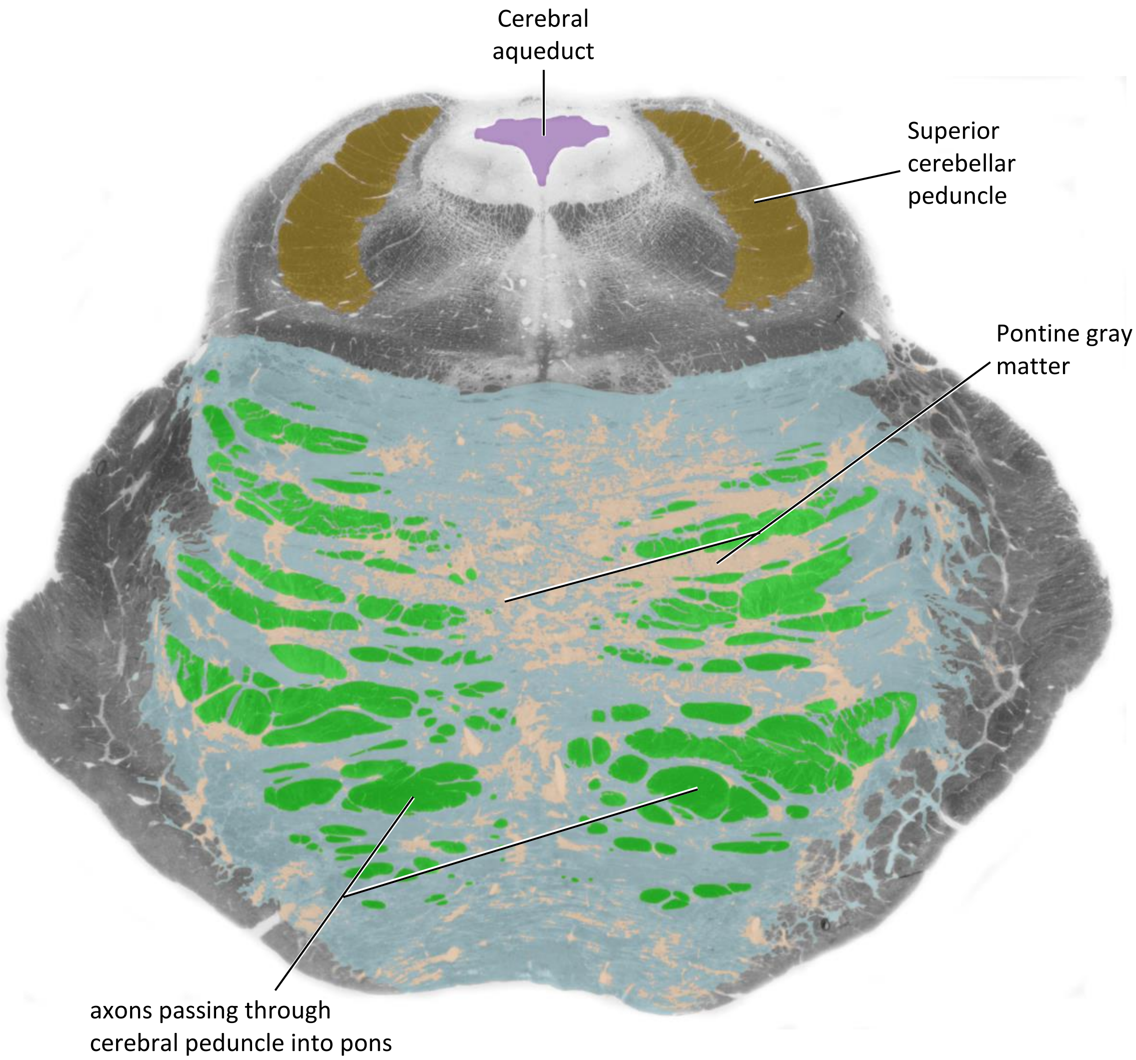


Figure 7. At the junction of the pons and midbrain, the brainstem looks relatively simple. The massive pontine base is about to give way to the cerebral peduncles. Dorsal to the base, the brainstem is reduced to the tegmentum. The fourth ventricle, which you saw in the sections through the pons, is disappearing 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.

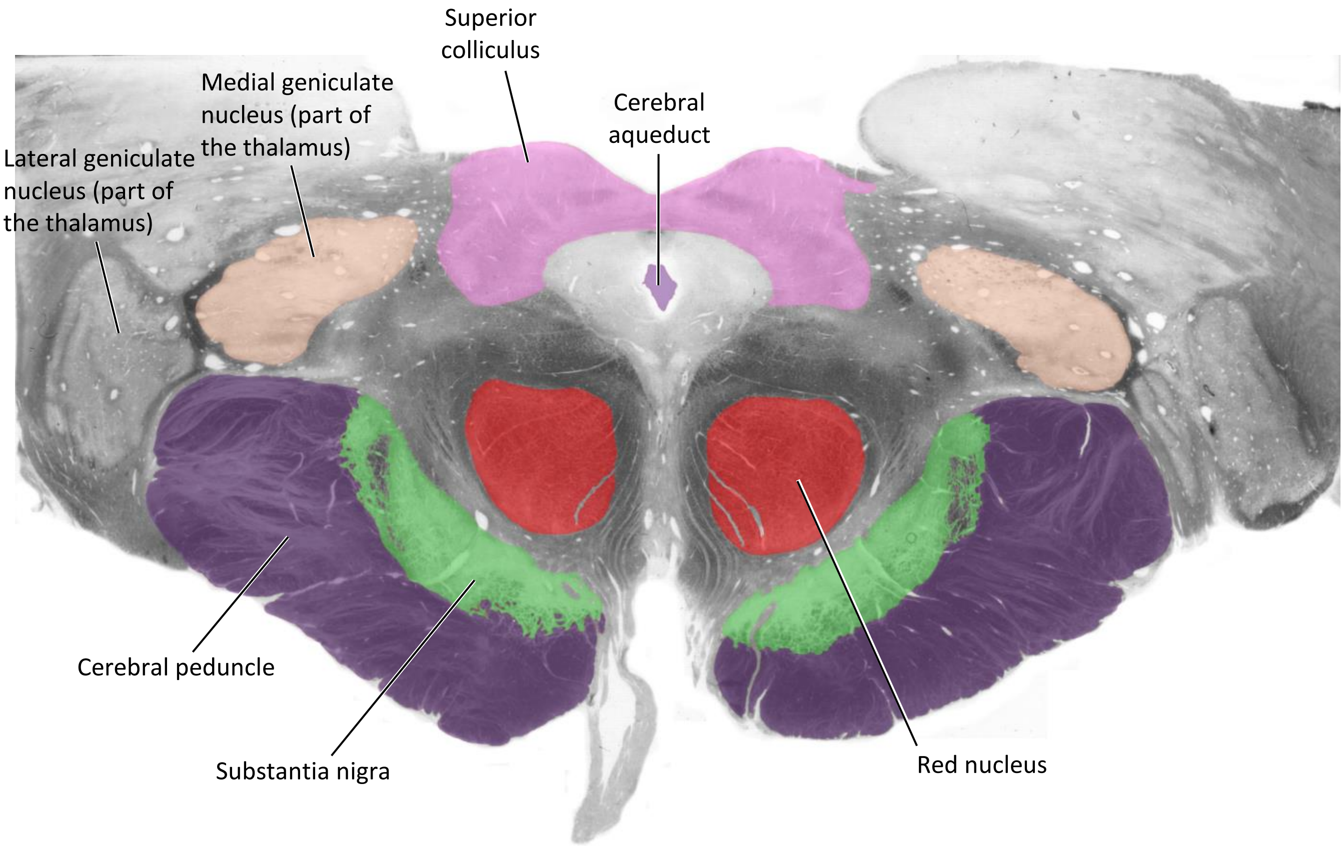


Figure 8. This section is through the rostral midbrain and so it cuts through the **superior colliculus**. The space between the colliculi is the **cerebral aqueduct.** The **cerebral peduncles** form the base of the midbrain. Two very large nuclei lie dorsal to them. These are the **substantia nigra** 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***)

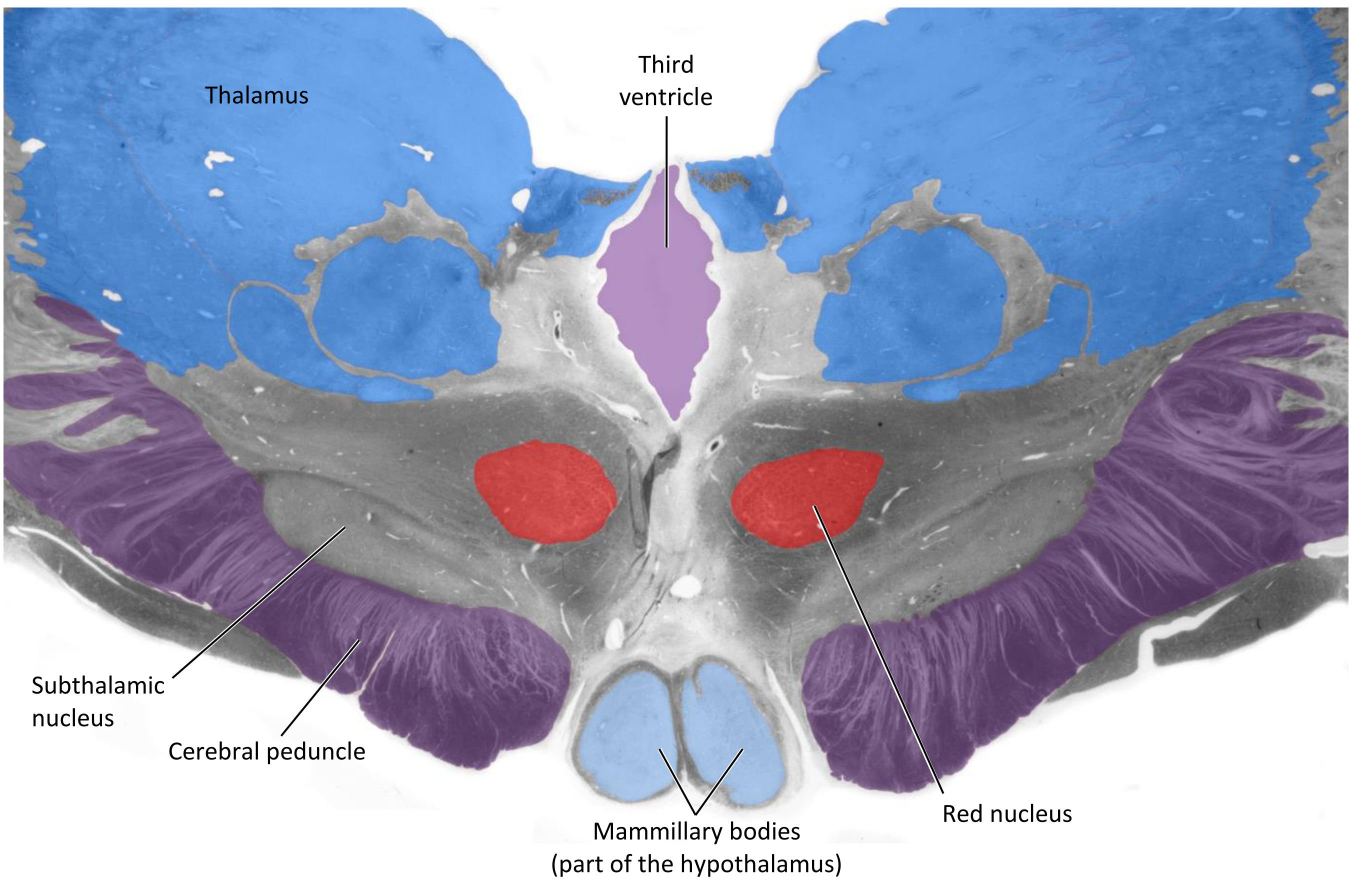


Figure 9. The last section in the series through the brainstem is cut through the junction of the midbrain and diencephalon. Structures of the midbrain are seen medially, but laterally the diencephalon has appeared. The cerebral peduncles will become continuous with the **internal capsule** a little 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)

[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