Brainstem – Part 1: Medulla

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Key Concepts:

1. On the ventral surface of the medulla are the pyramids, the pyramidal decussation, and the inferior olives.

2. At the pyramidal decussation 75 to 90 percent of descending corticospinal fibers cross to the opposite side and form the lateral corticospinal tract.

3. Dorsal column nuclei receive input from the ascending gracile and cuneate tracts. These nuclei project to the thalamus via the medial lemniscus.

4. The accessory cuneate nucleus is homologous to the nucleus dorsalis of Clarke in the spinal cord. Both provide unconscious input about position sense as part of the spinocerebellar system.

5. The inferior olives serve as relays between the brain and cerebellum.

6. The sensory (afferent) arc of the gag reflex is carried by CN IX and X, but the motor (efferent) arc is carried by the vagus nerve (CN X) alone.

7. Unconscious input from baro- and chemo-receptors of the carotid body and carotid sinus is provided by the glossopharyngeal nerve (CN IX).

8. Unconscious input from baro- and chemo-receptors of the aortic arch and other viscera in the chest and abdomen is provided by the vagus nerve (CN X).

9. The vagus nerve (CN X) has two motor nuclei (dorsal motor nucleus and nucleus ambiguous) and two sensory nuclei (nucleus solitarius and spinal trigeminal nucleus).

10. Sensation to the dura of the posterior cranial fossa is provided by the vagus nerve (CN X) and by upper cervical nerve roots.¹

¹ Sensation for the dura of the supratentorial region of the brain is provided by the trigeminal nerve (CN V).
INTERNAL STRUCTURE OF THE MEDULLA

A good understanding of the medulla comes from considering a cross-sectional (axial) view of three specific regions:

- **decussation of the pyramids** – the most caudal level where descending motor fibers cross to the opposite side
- **lemniscal decussation** – a higher level where ascending sensory fibers cross to the opposite side
- **nuclei of the inferior olives** – the most rostral level of three, where a half million neurons serve as an important relay center for the cerebellum

**Level of the pyramidal decussation.** There are three distinguishing features of the medulla at this lowest level:

- **decussation of the pyramidal tracts** – this is where 75 to 90% of corticospinal fibers cross to the opposite side to form the *lateral corticospinal tract*. Those fibers that do not cross continue as the *anterior corticospinal tract*. In the medulla prior to decussation descending corticospinal fibers to the legs are more lateral than fibers to the arms; fibers to muscles of the trunk are intermediate. The medullary pyramids also contain *corticobulbar fibers*, but these leave the pyramids to synapse on nuclei of cranial nerves and none remain at the level of the decussation.

- **dorsal column nuclei** -- this is where “first order” sensory neurons synapse on brainstem nuclei. Both nuclei are located slightly more centrally in the brainstem than their ascending pathways. These nuclei also receive descending input from the somatosensory cortex, as well as excitatory and inhibitory input from reticular formation interneurons. Efferent axons from dorsal column nuclei travel the *medial lemniscus* to reach the *thalamus*.
  - **nucleus gracilis** – this is the more caudal of the two nuclei. It receives axons traversing the gracile tract from neurons at spinal cord level T7 and below. It is the most medial structure in the dorsal medulla at this level.
  - **nucleus cuneatus** – this is more rostral in its position. It receives axons traversing the cuneate tract from the C1 to T7 spinal cord level. It is located lateral to the gracile tract but medial to the tract of the *spinal trigeminal nucleus*.

- **spinal trigeminal nucleus** – this is where exteroceptive sensory information (pain, temperature and light touch) from the ipsilateral face is received. This column of nuclei descends caudally to the level of C4 spinal cord, continuing on as the *substantia gelatinosa*. The column ascends rostrally where it becomes the *main sensory nucleus of V* in the pons. Sensory fibers from the jaw synapse at the lowest cervical level, while those around the mouth synapse at the lowest level of the medulla; fibers from elsewhere in the face synapse at higher levels of the nucleus.
Level of the lemniscal decussation. There are three distinguishing features of the medulla at this intermediate level, in addition to the pyramids which are prominent ventrally:

- **medial lemniscus** – this is where axons that originate in the *dorsal column nuclei* run ventrally and medially (as *internal arcuate fibers*) to cross the midline to form the *medial lemniscus*. This structure is the most medial of all in the tegmentum of the medulla. Its location is dorsal to the pyramids. The *medial lemniscus* carries axons of “second order” sensory neurons to the *ventral posterolateral nucleus* (VPL) of the thalamus.

- **medial longitudinal fasciculus (MLF)** – this is a descending pathway that carries axons from vestibular nuclei and the pontine reticular formation. At this level it is dorsal to the *medial lemniscus* and just about at the center of the brainstem.

- **accessory cuneate nucleus** – this is a small nucleus in a position dorsolateral to the *cuneate nucleus*. Despite the name, it has nothing to do with the cuneate nucleus. It is the nucleus for axons which originates in the spinal cord above the level of C8 from an area homologous to the *dorsal nucleus of Clarke* (which does not extend above C8). Axons from “second order” neurons leave the *accessory cuneate nucleus* and travel to the *cerebellum* via the *cuneocerebellar tract*. This tract, like the *dorsal spinocerebellar tract* arising from dorsal nuclei of Clark, has a role in unconscious position sense.

Level of the *inferior olives*. There are three distinguishing features of the medulla at this highest level:

- **inferior olivary nuclei** – this is the most distinctive finding in the medulla: convoluted, ribbon-shaped gray matter located in the ventral medulla, dorsal to the pyramids. The olivary nuclear complex serves as an important relay center, and it receives input from a variety of sources;
  - cerebral cortex via the corticospinal tract
  - basal ganglia and red nucleus via the central tegmental tract
  - dorsal column nuclei

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^2 Tracts are typically names by their nucleus of origin and their destination. Note that there is no *cuneothalamic* tract arising from the *nucleus cuneatus*. Instead, these fibers constitute the *medial lemniscus*. 


- vestibular nuclei
- deep cerebellar nuclei
Efferent signals from the olives travel to the cerebellum, primarily the contralateral cerebellum, via the olivocerebellar tract.

- **restiform body (inferior cerebellar peduncle)** – this is the most caudal of the connections between the brainstem and cerebellum. In axial views of the medulla at this level, the *restiform bodies* are positioned ventrolaterally. The ascending pathways which traverse the peduncle are:
  - olivocerebellar tract from the inferior olivary complex
  - dorsal spinocerebellar tract from the dorsal nuclei of Clarke
  - reticulocerebellar tract from the reticular formation in the medulla

- **floor of the fourth ventricle** – this is another distinctive feature of the medulla at this level: batwing shaped floor of the ventricle, created by rotation of the alar plate to a position adjacent to the basal plate. The medial and lateral bumps of the tegmentum forming this distinctive shape are:
  - hypoglossal nucleus – discussed below
  - medial vestibular nucleus – this is part of the complex of vestibular nuclei which participate in ongoing postural control. Only the *medial and inferior vestibular nuclei* are seen at the level of the upper medulla; the *lateral and superior vestibular nuclei* are seen in the pons. Fibers from the *medial vestibular nucleus* ascend in the *medial longitudinal fasciculus* and mediate head reflexes in response to activation of semicircular canals in the inner ear. Axons from the *medial and lateral vestibular nuclei* descend to the spinal cord and mediate the *vestibular-cervical reflex* and the *vestibular-spinal reflex*, which move the head and body for postural stability in walking.

In addition, there is one unseen but important group of nuclei. These are the *arcuate nuclei*, which actually sit on the ventral (anterior) aspect of the pyramids. Progressing rostrally these nuclei become large until they become continuous with the *pontine nuclei* at the level of the pons. These nuclei receive input from the contralateral cerebral cortex, and they send axons to the ipsilateral and contralateral cerebellum via the *restiform body*. 
CRANIAL NERVES OF THE MEDULLA

The medulla gives rise to CN VIII through XII, although some arise from multiple nuclei. The vestibulocochlear nerve is CN VIII. Reviewing the others from caudal to rostral:

Hypoglossal nerve (CN XII). This nerve contains efferent motor fibers to the muscles of the tongue. The column of cells that serves as the nucleus of CN XII extends throughout the medulla, just short of its rostral and caudal ends. These columns are located close to the midline in the tegmentum, just below the ventral floor of the fourth ventricle. From the nucleus hypoglossal nerve fibers travel anteriorly (medial to the inferior olives but lateral to the midline medial lemnisci) and at the ventral side of the brainstem swing laterally to exit immediately lateral to the pyramids. Examination of the tongue is therefore of localizing value in suspected lesions of the medial lemniscus or the pyramids.

Accessory nerve (CN XI). This nerve contains efferent motor fibers to the sternomastoid and upper trapezius muscles. It also partners with the vagus nerve (CN X) to innervate muscles of the larynx. The portion of CN XI that supplies sternomastoid and trapezius arises from the accessory nucleus, which is located among the anterior horn cells of C1-C6. The accessory nerve enters the skull through the foramen magnum and to innervate the muscles leaves the skull through the jugular foramen. The portion of CN XI that supplies muscle to the larynx arises from the nucleus ambiguus. The nerve joins with a branch of the CN X to form the recurrent laryngeal nerve. For all practical purposes, this part of the nerve may be considered part of the vagus nerve.

Nucleus ambiguus. The nucleus ambiguus serves as a motor nucleus for three cranial nerves:
- Accessory nerve (CN XI) -- discussed above
- Glossopharyngeal nerve (CN IX) -- sending a few axons to innervate the stylopharyngeus muscle, which lifts the pharynx during swallowing and talking.
- Vagus nerve (CN X) -- where the nucleus ambiguus is known as the ventral motor nucleus of X. This column of nuclei is located about halfway between the inferior olivary nuclei and the spinal tract of V. Axons basically course laterally to exit the brainstem between the inferior olives and the inferior cerebellar peduncle. These axons innervate the majority of muscles of the pharynx and larynx.

Nucleus solitarius. The nucleus solitarius serves as a sensory nucleus for five cranial nerves. It is oval in shape with one superior-lateral end and another inferior-medial end; it parallels a line drawn from the heart to the shoulder. It is functionally divided in half, with the lateral devoted to taste and the medial portion devoted to cardio-respiratory function. The gustatory (taste) region receives input from three cranial nerves:
- Facial nerve (CN VII) -- with sensory input from the anterior 2/3 of the tongue
- Glossopharyngeal nerve (CN IX) -- with sensory input from the posterior 1/3 of the tongue and the pharynx.
- Vagus nerve (CN X) -- with sensory input from the epiglottis. Axons carrying this information have their cell bodies located in the nodose ganglion.

Efferent signals from the gustatory region travel to the ventral posterior medial nucleus (VPMN) of the thalamus and then on to the cerebral sensory cortex. The visceral (cardio-respiratory) region receives input from two cranial nerves:
- CN IX
- CN X

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3 This is sometimes called the spinal accessory nucleus because of its location.
Efferent signals from this medial region of the nucleus solitarius project to the *nucleus ambiguus* and the *dorsal motor nucleus of X*, and centers in the medulla (see below).

**Vagus nerve (CN X).** This is a mixed nerve which contains both motor and sensory fibers. It relates to four nuclei in the brainstem:

- Efferent (motor)
  - *Nucleus ambiguus* – discussed above
  - *Dorsal motor nucleus of X* – this column of nuclei is parallel but slightly lateral to the hypoglossal column of nuclei. Like fibers from the *nucleus ambiguus*, the axons emerge from the lateral brainstem between the inferior olive and inferior cerebellar peduncle. These axons are **preganglionic parasympathetic** fibers that carry impulses to the organs of the chest and abdomen.
- Afferent (sensory)
  - *Nucleus solitarius* – discussed above
  - *Nucleus of the spinal tract of V* – neurons in this nucleus receive sensory signals from ear, auditory canal, and outside of the tympanic membrane. Like sensory nerves at the spinal level, these few sensory fibers have their cell bodies outside the central nervous system in the **jugular ganglion**.

The vagus nerve exits the brainstem via multiple rootlets lateral to the inferior olives. Like a spinal nerve, the rootlets combine to form a single nerve, which leaves the skull through the *jugular foramen*.

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4 These axons do not synapse directly on the organs. Instead they synapse on the parasympathetic ganglia which are often located within or on the organs. These are the source of **postganglionic parasympathetic** fibers which actually innervate the organs.

5 The nodose ganglion is sometimes called the *inferior ganglion of X*, while the jugular ganglion is called the *superior ganglion of X*. 
Glossopharyngeal nerve (CN IX) – This is also a mixed nerve which contains motor and sensory fibers. Like the vagus nerve, it is associated with four nuclei in the brainstem:

- **Efferent (motor)**
  - Nucleus ambiguus – discussed above
  - Inferior salivatory nucleus – this is a poorly defined group of neurons which are preganglionic parasympathetic fibers which stimulate the parotid gland.

- **Afferent (sensory)** – identical to the vagus nerve
  - Nucleus solitarius – discussed above, but carrying signals from the posterior tongue, tonsils and Eustachian tube
  - Nucleus of the spinal tract of V – discussed above, but carrying sensation from a small region behind the ear

CN IX also has a special afferent branch which innervates the carotid body and carotid sinus. Particularly in older individuals, manipulating or massaging the neck can stimulate CN IX axons, activate the dorsal motor nucleus of X, and stimulate ganglion cells in the wall of the heart to slow the pulse and reduce the blood pressure.

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6 A dry mouth in response to fear is the inferior salivatory nucleus’s response to stimulation from the hypothalamus. Increased salivation in response to the smell of food is the nucleus’ response to stimulation from the olfactory nerve.

7 This is called the glossopharyngeal-vagal reflex.
SPECIAL FUNCTIONS OF THE MEDULLA

Swallowing. Deglutition is a reflex that requires coordination of more than 25 muscles. The human fetus is capable of swallowing by twelve weeks following conception, before cortical or subcortical pathways of the brain are functioning. Swallowing is therefore considered a “primitive” reflex. There are three functionally distinct phases of swallowing, the last two of which are controlled by the medulla:

- **oral phase** – this is a voluntary and reversible phase in which food is moved to the back of the pharynx
- **pharyngeal-laryngeal phase** – this is an involuntary phase in which the epiglottis is closed to protect the airway, the palate is closed to protect the nasopharynx, breathing stops, the larynx constricts, and food is moved into the esophagus
- **esophageal phase** – this is an involuntary phase in which both smooth and striated esophageal muscles move food towards the stomach

There are two regions in the medulla that coordinate this complex process. The neurons which trigger, organize and sequence the process are located in the **dorsal swallowing group**, which is located in the nucleus solitarius and adjacent reticular formation. Neurons which distribute the swallowing drive to various motor neurons the carry out the process are located in the **ventral swallowing group**, which is located in the ventrolateral medulla, next to the nucleus ambiguous. Together the dorsal and ventral swallowing groups are called a central pattern generator.

Vomiting. Emesis is a somatic and autonomic reflex that is integrated in the medulla, in response to a wide variety of triggers. A chemoreceptor trigger zone is located on the ventral floor of the fourth ventricle in a region called the **area postrema**. This area is not protected by the blood-brain barrier so that chemoreceptors can respond to triggers in the blood. Signals then travel to the adjacent **nucleus solitarius**, which also receives input from:

- taste receptor via CN VII, IX and X
- autonomic input from GI tract: parasympathetic input via CN X, and sympathetic input via splanchnic nerves
- **vestibular system**

There is no true “vomiting center” in the medulla. The nucleus solitarius projects to the central pattern generator that sends signals to:

- nuclei that control jaw, mouth, and tongue movements (CN V, VII, XII)
- nuclei that control respiratory and abdominal muscles (dorsal motor n. of X, nucleus ambiguous, anterior horn cells)
- hypothalamus

Yawning. Neurons responsible for this stereotypic event which occurs across many species are located in the region of the respiratory and vasomotor centers. It occurs alone, or in combination with stretching or erection of the penis. Hypothalamic neurons releasing oxytocin are responsible for triggering the yawn, and they may be activated by dopamine or excitatory amino acids; they are inhibited by opioids.

Sneezing. Sneezing is a reflex controlled by a “sneezing center,” which is located at the margin of the spinal nucleus and descending tract of CN V; it also includes the nucleus solitarius and the reticular formation. There are a variety of triggers that are usually mechanical (tickle) or chemical; however, bright light or blue light and male orgasm can also be triggers. The afferent arc of the reflex includes the

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8 These neurons are located in the paraventricular nucleus of the hypothalamus.
olfactory nerve (CN I) and the ethmoidal nerve (CN V). The efferent arc includes preganglionic fibers to the greater petrosal nerve and the sphenopalatine ganglion (both CN VII). Stimulation of the ganglion leads to increased nasal secretion and edema, further stimulating the nasal mucosa and intensifying the impulse to sneeze.

**Breathing.** There are two regions of the medulla that contribute to control of respiration, both of which project to spinal cord neurons that innervate the diaphragm (C3-5):
- dorsal respiratory group – neurons in the **nucleus solitarius** control **inspiration**
- ventral respiratory group – neurons in the **nucleus ambiguous** control **expiration** and to a lesser degree **inspiration**.

**Blood pressure.** Neurons in the **nucleus solitarius**, together with those in the dorsal motor nucleus of X and neurons in the ventrolateral medulla, regulate blood pressure. They receive descending input from sensory and motor cortex of the brain, which alters sympathetic vasomotor tone and the baroreceptor reflex.

**BLOOD SUPPLY TO THE MEDULLA**

The medulla received blood from the following arteries:
- vertebral arteries
- anterior spinal artery
- posterior spinal arteries
- posterior inferior cerebellar artery (PICA)
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9 Arterioles in the body have smooth muscle which constrict with sympathetic stimulation, thereby raising blood pressure. There is no parasympathetic innervation of blood vessels.
The arterial network creates four longitudinal vascular regions of blood distribution in the medulla:

- **paramedian territory**, which includes pyramids, medial lemniscus, medial longitudinal fasciculus (MLF), and hypoglossal nucleus and nerve (CN XII)
  - supplied by the anterior spinal artery and short branches of the vertebral arteries

- **olivary territory**, which includes the inferior olive complex
  - supplied by AICA (anterior inferior cerebellar artery), typically the first large branch of the basilar artery

- **dorsolateral territory**, which includes dorsal motor nucleus of X, nucleus solitarius and tract, vestibular nuclei, nucleus ambiguous, spinal trigeminal nucleus and tract, lateral spinothalamic tract, restiform body, olivocerebellar pathway, and dorsal column nuclei and tracts
  - supplied by vertebral artery and PICA
  - with contribution in most caudal regions by posterior spinal arteries