Neuroanatomy 4: Brainstem

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General View:

The brainstem is a term used to describe the midline mass of nervous tissue consisting of the midbrain, pons, & medulla oblongata. The brainstem connects the spinal cord to the cerebrum & cerebellum (like a stem of tree connecting its leaves). Note the following:

- The brainstem is a mass of white matter, with grey matter (nuclei) situated inside.
- Brainstem white matter consists of longitudinally & horizontally running nerve fibers (tracts), with many of them crossing the midline forming "decussations".
- Brainstem gre1y matter includes cranial nerves nuclei & specific nuclei. Reticular formation exists throughout the whole brainstem.
- Like the spinal cord, the brainstem mediates some reflexes. The afferent & efferent pathways of brainstem reflexes are formed mainly by the cranial nerves, not the spinal nerves.
- Like the other parts of the CNS, the brainstem has a longitudinal cavity containing CSF. This cavity is represented by the cerebral aqueduct (in the midbrain), forth ventricle (in the pons & upper medulla), & the central canal of the medulla (in the lower medulla).

Medulla Oblongata

The medulla oblongata is the most caudal part of the brain. It is a bulb-like structure continuous with the spinal cord caudally & the pons cephalically. The medulla is 3 cm long & 2 cm in its largest diameter superiorly. It gives rise to a number of cranial nerves, & has the median foramen (of Magendie) on its posterior aspect, through which the CSF in the 4th ventricle drains into the subarachnoid space.

Location & Relations:

The medulla oblongata lies in the midline of posterior cranial fossa, just above foramen magnum. It is slightly tilted anteriorly, & has the following structures related to it:

- Anteriorly: the basilar part of the occipital bone (separated from it by meninges & occipito-axial ligament), with the 2 vertebral arteries running on its anterolateral sides to meet each other at the upper border of the medulla. The anterior spinal artery forms in the midline of upper medulla, & runs along its anterior fissure.
- Posteriorly: The upper half of the medulla is related posteriorly to the 4th ventricle (forming its floor). Below this, the medulla is situated in the notch between the cerebellar hemispheres.
- Laterally: lateral to the medulla are the cranial nerves emerging from it & their rootlets. In addition, the anterior inferior & posterior inferior cerebellar arteries (AICA & PICA) run on the lateral surface of medulla before reaching the cerebellar hemispheres.

External Features:

The upper part of the medulla oblongata is larger than its lower part. Note the following:

- Anteriorly, 2 columns of nervous tissue extend vertically next to the midline, separated from each other by the anterior median fissure of the medulla, these are the "pyramids". At the lower half of the medulla, fibers of the pyramids decussate (the pyramidal decussation), causing the median fissure to disfigure or disappear.
- Just lateral to the pyramids, 2 oval masses are seen at the uppermost part (the olives), separated from the pyramids by the ventrolateral sulcus, from which the rootlets of hypoglossal nerves (CN XII) emerge.
- Posterior to the olive, the posterolateral sulcus exists. It gives rise to the rootlets of the following cranial nerves (from superior to inferior): glossopharyngeal (IX), vagus (X), & accessory (XI)-cranial part.
- The medulla is separated from the pons by a horizontal groove. This groove gives rise to the following cranial nerves (from medial to lateral): abducent (VI) above the pyramid, fascial (VII) above the olive, & vestibulocochlear (VIII) above the rootlets of CN IX.

- Posterior to the cranial nerve rootlets, the lateral surface of medulla is continuous with the lateral column (funiculus) of the spinal cord. Superiorly, this turns posteriorly becoming the inferior cerebellar peduncle & enters the cerebellum.
- From the inferior cerebellar peduncle to the posterior midline of medulla, 3 columns can be seen: (1) the spinal tract of trigeminal nerve (CN V), (2) the cuneate fascicle, & (3) the gracile fascicle.
- Posteriorly, the medulla is divided into a closed part (lower 2/3rd), & an open part (upper 1/3rd) that makes the floor of the lower half of the 4th ventricle.
- The closed part has the posterior media sulcus (a continuation of that of the spinal cord), with gracile & cuneate fascicles next to it. Each of those 2 fascicles ends superiorly with a bulge, the gracile & cuneate tubercles, respectively.
- The open part of medulla (= the lower half of the 4th ventricle floor) is separated by a wide V-shaped line from the closed part. This line extends between the inferior cerebellar peduncles, representing the attachment of the lower roof of the 4th ventricles (the inferior medullary velum). The posterior median sulcus extends also in the open part, with 2 lateral sulci (the right & left sulcus limitans) on each side.
- Medial to the sulcus limitans, 2 triangular elevations are seen: the **vagal triangle** (laterally) & the inverted **hypoglossal triangle** (medially).
- Lateral to the sulcus limitans, lies the vestibulocochlear area.
- At the upper border of the posterior surface of medulla, a horizontal band of fibers is seen running from the median sulcus to the inferior cerebellar peduncles, these are the "stria medullaris".
- See the below table to know the inner medullary structures corresponding to external structures:

External Structure	Corresponding internal structure
Pyramids	Corticospinal (pyramidal) tracts
Olive	Inferior olivary nucleus
Gracile tubercle	Gracile nucleus
Cuneate tubercle	Cuneate nucleus
Vagal trigon	Dorsal vagal nucleus
Hypoglossal trigon	Hypoglossal nucleus
Stria medullaris	Efferent fibers of arcuate nuclei to the cerebellum
Vestibular area	Vestibular nuclei

Internal Structure:

The medulla oblongata is a mass of white matter, in which grey mater nuclei are buried. The upper part of the medulla (open part) provides the floor of the lower half of the 4th ventricle. At its inferior angle, the ventricle is continuous with the central canal of the medulla (closed part), which is surrounded by a zone of grey matter (the central grey matter).

White Matter:

Medullary white matter includes CNS tracts & intramedullary parts of some cranial nerves. The following tracts exist in the medulla oblongata:

Descending tracts:

- Corticospinal tract: the pyramids of the medulla are the medullary part of the long corticospinal tract. It consists of fibers descending from the motor cerebral cortex to the motor neurons of the spinal cord. At the lower third of the medulla, the majority of these fibers cross the midline (decussate) passing posteromedially to descend in the lateral column of the spinal cord white matter as the "lateral" corticospinal tracts. The remaining uncrossed fibers descend in the same side as the "anterior" corticospinal tracts.
- The Medial longitudinal fasciculus: a small bundle extending in the brainstem close to the midline & the central grey matter. It is seen in the medulla dorsal to the tectospinal tract.
- Tectospinal tract: extending from the midbrain to the spinal cord, this tract is seen on each side of the midline between the medial longitudinal fasciculus & the medial lemniscus.
- Rubrospinal, vestibulospinal, reticulospinal, etc: these tracts descend in the ventrolateral part of the medulla.

Ascending tracts:

- Gracile & cuneate fasciculi: these tracts ascend in the dorsal part of the closed medulla to terminate in their corresponding nuclei (gracile & cuneate nuclei). Efferent fibers of those nuclei run anteromedially to decussate at the middle of the medulla, & ascend in the upper medulla as the "medial lemnisci" on each side of the midline.
- Spinothalamic (anterior & lateral) & spinocerebellar (anterior & posterior) tracts: those tracts ascend in the ventrolateral part of the medulla.

Other tracts:

- Olivocerebellar tract: the efferent fibers of the olivary nuclei of the medulla. They emerge from the concavity of the inferior olivary nucleus, run posteromedially, decussate to enter the cerebellum via the inferior cerebellar peduncle.
- Spinal tract of trigeminal nerve: this band of fibers are the afferent axons of the trigeminal nerve carrying pain & temperature sensation, running along the spinal trigeminal nucleus. In cross-sections, the tract is a C-shape that surrounds its nucleus except ventromedially.
- External arcuate fibers: (1) anterior external arcuate fibers are the efferents of the arcuate nuclei. They run laterally on the pyramids & olives to join the inferior cerebellar peduncle. (2) posterior external arcuate fibers are the efferents of the accessory cuneate nuclei. They run posterolaterally to join the inferior cerebellar peduncle, carrying proprioceptive sensation from the upper limbs to the cerebellum.

Cranial Nerves:

- Fibers of the hypoglossal nerve (XII) project from its nucleus, run ventrolaterally to emerge between the pyramid & olive.
- Fibers of the cranial part of accessory nerve (XI) project from its nucleus, run laterally to emerge from the lateral surface of the medulla.
- Fibers of the vagus (X) & glossopharyngeal (IX) nerves project from their multiple nuclei, converge & run ventrolaterally to emerge posterior to the olive.
- Fibers of the vestibular nerve (VIII) enter the medulla at the groove between the middle & inferior cerebellar peduncles to join the vestibular nuclei. Fibers of the trochlear nerve (VIII) hook around the inferior cerebellar peduncle to run medially & join the cochlear nuclei in the uppermost part of posterior medulla.

Grey Matter:

I- Cranial Nerves Nuclei:

Cranial nerves nuclei are aggregations of nerve cell bodies in the brain connected to the cranial nerves. Cranial nerve fibers either emerge from the nucleus (motor fibers) or terminate & synapse in the nucleus (sensory fibers). The location of cranial nerves nuclei in the brainstem is not random, they are arranged in a specific organization. Accordingly, motor nuclei lie more medially & sensory nuclei more laterally, separated by the plane of sulcus limitans. Furthermore, motor & sensory nuclei are subdivided into function-specific groups, as follows (from medial to lateral):

1. **General somatic efferent group (GSE)**: motor fibers to somatic skeletal muscles. This is represented by the nuclei of the oculomotor, trochlear, abducent, & hypoglossal nerves (III, IV, VI, XII).
2. **Special visceral (branchial) efferent group (SVE)**: motor fibers to branchial muscles. "Branchial" muscles are skeletal muscles originating from the branchial (pharyngeal) arches (that's why those muscles are considered "visceral" from embryological point of view, hence, the term SVE was used). This group is represented by the motor nucleus of trigeminal nerve (V), motor nucleus of fascial nerve (VII), nucleus ambiguous of the glossopharyngeal (IX) & vagus (X) nerves, & the nucleus of accessory nerve (XI).
3. **General visceral efferent group (GVE)**: motor fibers to the glands. This group is represented by the following preganglionic parasympathetic nuclei: accessory nucleus (of Edinger-Westphal) of oculomotor nerve (III), superior salivatory nucleus (of fascial nerve- VII), inferior salivatory nucleus (of glossopharyngeal nerve- IX), & posterior (dorsal) nucleus of the vagus (X) nerve.

4. **General Visceral afferent group (GVA)**: nuclei receiving the general sensation (pain, temperature, etc) from the viscera. This group is represented by part of the nucleus solitarius.
5. **Special visceral afferent group (SVA)**: nuclei receiving the special sensation (taste & smell) from the viscera. This group is represented by the nucleus solitarius (connected with the fascial, glossopharyngeal, & vagus nerves- VII, IX, X). For smell sensation, its nuclei are outside the brainstem.
6. **General somatic afferent group (GSA)**: nuclei receiving general sensation (touch, pain, temperature, etc) from the body wall. Trigeminal sensory nuclei are the example.
7. **Special somatic afferent group (SSA)**: nuclei receiving the special sensation (vision, hearing & balance sensation) from the body wall. Examples are the optic nerves (outside the brainstem) & the vestibulocochlear nuclei.

The medulla oblongata contains, partially or totally, the following cranial nerves nuclei:

Motor Nuclei

- Hypoglossal nucleus (GSE): This nucleus is located in the upper medulla, just beneath the floor of the 4th ventricle next to the midline (forming the hypoglossal triangle).
- Nucleus ambiguus (SVE): This is the motor nucleus supplying the branchial muscles of the pharynx, larynx, & upper esophagus. It is located in the dorsal part of the medulla, inside the reticular formation. Nucleus ambiguus gives rise fibers distributed in the glossopharyngeal (IX), vagus (X), & cranial part of accessory (XI) nerves, as follows:
    - Superior part of the nucleus → fibers to the glossopharyngeal nerve (IX) → stylopharyngeus muscle.
    - Middle part of the nucleus (largest) → fibers to the vagus nerve (X) → constrictor muscles of the pharynx, intrinsic muscles of the larynx.
    - Inferior part of the nucleus → fibers of the cranial part of accessory nerve (XI) → unite with the vagus nerve → muscles of the soft palate, pharynx, & larynx.

  Note: the spinal root (part) of accessory nerve originates from the anterior grey horn of the cervical spinal cord (C1 – C5), unites shortly with the cranial part, the separates from it outside the skull to supply the sternocleidomastoid & trapezius muscles, which are not "branchial" muscles (so, this part is not SVE).

Note: the above 2 nuclei receive "corticonuclear fibers" from (both sides) of the cerebral motor cortex descending in the pyramidal tracts.

- Dorsal vagal nucleus (GVE): This nucleus supplies the preganglionic parasympathetic fibers of the vagus nerve. It is located beneath the floor of the 4th ventricle lateral to the hypoglossal nucleus (forming the vagal trigon).
- Inferior salivatory nucleus (GVE): This nucleus supplies the preganglionic parasympathetic fibers of the glossopharyngeal nerve. It is located beneath the floor of the 4th ventricle, superior to the dorsal vagal nucleus.

Note: the above 2 nuclei receive descending fibers from the hypothalamus via the "descending autonomic tract".

Sensory Nuclei

- Nucleus solitarius (SVA): this sensory nucleus is concerned with taste sensation. It is located in the dorsal part of medulla, lateral to the sulcus limitans. It receives afferent fibers carrying taste sensation from:
    - The fascial nerve (upper part of the nucleus),
    - Glossopharyngeal nerve (middle part of the nucleus),
    - Vagus nerve (lower part of the nucleus).

  Then, this nucleus projects its axons to the thalamus. This nucleus also receives afferent fibers (via the glossopharyngeal nerve) from the carotid sinus baroreceptors.

- Spinal nucleus of trigeminal nerve (GSA): this large sensory nucleus extends from the pons, throughout the whole medulla, to the upper cervical spinal cord. In the medulla, it is situated posterolaterally, dorsal to the exit of cranial nerve roots (IX, X, & XI). Along its length, this nucleus is surrounded dorsolaterally by a the spinal tract of trigeminal nerve, that represents the trigeminal afferent fibers entering the nucleus. The spinal trigeminal nucleus receives sensation of pain & temperature from the 3 divisions of the trigeminal nerve. Also, it receives general somatic afferent (GSA) fibers from the fascial, glossopharyngeal, & vagus nerves carrying sensation from the external ear & other areas.
- Vestibular & cochlear nuclear complex (SSA): those are the nuclei of the vestibulocochlear nerve (VIII). They are a group of nuclei situated beneath the lateral regions of the floor of the 4th ventricle, in the upper pert of

medulla & lower part of pons. Vestibular group lie more medially, they receive afferents carrying balance sensation from the vestibular neurons in the vestibular ganglion of the vestibular nerve, then they project their efferents mainly to the ipsilateral cerebellar hemisphere via the inferior cerebellar peduncle. Cochlear group lie laterally, they receive afferents carrying hearing sensation from spiral ganglion of the cochlear nerve, then they project their efferents to the contralateral midbrain & thalamus.

II- Specific Nuclei:

1. Nucleus gracilis & nucleus cuneatus: those nuclei are situated in the dorsal part of the medulla, inferior to the 4th ventricle. The gracile nucleus lies medially, it receives the gracile fasciculus (carrying proprioception, vibration, muscle tone, fine touch, & other sensation from the lower part of the body). The cuneate nucleus lies superolateral to the gracile nucleus, it receives the cuneate fasciculus (carrying same sensation from the upper part of the body). Efferents from both nuclei cross the midline & ascend as the contralateral medial lemniscus to the thalamus. The small accessory cuneate nucleus lies superolateral to each cuneate nucleus, it receives afferents from the upper limbs & send efferent fibers to the ipsilateral cerebellar hemisphere via the posterior external arcuate fibers that enter the inferior cerebellar peduncle.
2. Olivary nuclei: 3 nuclei in the upper ventrolateral part of medulla. They include the large inferior olivary nucleus, & the small medial & dorsal accessory olivary nuclei. The inferior olivary nucleus resembles a corrugated sac, with its opening (hilum) facing medially. The other 2 nuclei are small curved laminae of grey matter situated medial & dorsal to the inferior nucleus. Olivary nuclei receive afferents from the spinal cord, cerebral motor cortex, & the midbrain (red nucleus & central grey matter). Efferent fibers project via the hilum of the inferior nucleus, run medially, cross the midline dorsal to the pyramids, to enter the contralateral cerebellar hemisphere via the inferior cerebellar peduncles (the olivocerebellar tract, the major component of the inferior cerebellar peduncle).
3. Arcuate nuclei: small scattered nuclei situated on the ventral aspect of the pyramids. They receive descending afferent fibers from cerebral cortex, & project efferent fibers to the ipsilateral & contralateral cerebellar hemispheres via the anterior external arcuate fibers & the stria medullaris (both enter the inferior cerebellar peduncle). Arcuate nuclei are considered inferiorly-displaced pontine nuclei.
4. Other regions of grey matter in the medulla include (1) the central grey zone: a region of grey matter around the medullary central canal & in the floor of the 4th ventricle, & (2) the ventral horns: in the lower 1/3rd of medulla, the spinal cord ventral grey horns continue to exist, appearing as grey masses lateral to the pyramidal decussation. They give rise to the upper rootlets of C1 spinal nerve.

Reticular Formation of the Medulla:

Numerous islets of grey matter are scattered centrally in the ventrolateral medulla, an area intersected by nerve fibers that run in all directions. This is the reticular formation, which exists throughout the medulla and extends up into the pons and midbrain, & down into the upper cervical spinal cord.

Notes:

- The terms "Cardiac center", "cardiovascular center", & "respiratory center" in the medulla oblongata refer to the sensory nuclei receiving sensation from those systems (specifically, the nucleus solitarius via the glossopharyngeal & vagus nerves), plus the nuclei sending efferent fibers to those systems (specifically, the preganglionic parasympathetic nucleus of the vagus nerve: the dorsal vagal nucleus), together with their connections with the sympathetic spinal nucleus.
- Reflexes mediated by the medulla oblongata: see the below table:

Reflex	Stimulus	Afferent Pathway	Efferent Pathway	Result
Swallowing	Foods & drinks touching the pharyngeal mucosa	CN IX (to the nucleus solitarius)	CN X (from nucleus ambiguous)	Closure of nasopharynx (soft palate muscles) & larynx (epiglottis) & pharyngeal muscle contraction → swallowing
Gag reflex	Irritation of pharyngeal mucosa	CN IX (to the nucleus solitarius)	CN X (from nucleus ambiguous) ± the sympathetic splanchnic nerves to the stomach	Forceful contraction of the pharynx & relaxation of the gastroesophageal sphincter, may result in retching & vomiting.

Carotid message reflex	Messaging the carotid sinus	CN IX (from carotid sinus baroreceptors, to the nucleus solitarius)	CN X (parasympathetic fibers from dorsal vagal nucleus to the heart)	Bradycardia
Coughing	Irritation of the laryngeal & tracheal mucosa	CN X (to the trigeminal sensory nuclei in the brainstem)	CNs IX, X, XI; phrenic nerve, & intercostal nerves	Forceful contraction of the pharyngeal muscles, plus the diaphragm, intercostal, & abdominal wall muscles → coughing
Sneezing	Irritation of the nasal mucosa	CN V2 (to the trigeminal sensory nuclei in the brainstem)	CNs IX, X, XI; phrenic nerve, & intercostal nerves	Deep inspiration, then forceful contraction of the pharyngeal muscles (with closure of oropharyngeal isthmus by palatoglossus), plus the diaphragm, intercostal, & abdominal wall muscles → sneezing

Clinical Considerations:

- ***Arnold-Chiari Phenomenon***

The Arnold-Chiari malformation is a congenital anomaly in which there is a herniation of the tonsils of the cerebellum and the medulla oblongata through the foramen magnum into the vertebral canal. This results in the blockage of the exits in the roof of the fourth ventricle to the cerebrospinal fluid, causing internal hydrocephalus. It is commonly associated with craniovertebral anomalies or various forms of spina bifida. Signs and symptoms related to pressure on the cerebellum and medulla oblongata and involvement of the last four cranial nerves are associated with this condition.

- ***Raised Pressure in the Posterior Cranial Fossa and Its Effect on the Medulla Oblongata***

The medulla oblongata is situated in the posterior cranial fossa, above the foramen magnum. In patients with tumors of the posterior cranial fossa, the intracranial pressure is raised, and the brain tends to be pushed toward the area of least resistance; so there is a downward herniation of the medulla and cerebellar tonsils through the foramen magnum. This will produce the symptoms of headache, neck stiffness, and paralysis of the glossopharyngeal, vagus, accessory, and hypoglossal nerves due to traction. In these circumstances, it is extremely dangerous to perform a lumbar puncture because the sudden withdrawal of cerebrospinal fluid may precipitate further herniation of the brain through the foramen magnum and a sudden failure of vital functions, resulting from pressure and ischemia of the cranial nerve nuclei present in the medulla oblongata.

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