Neuroanatomy 5: Brainstem

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Pons

Location, relations & external features:

The pons is the middle part of brainstem, situated between the medulla oblongata (below) & midbrain (above), being separated from them by the inferior & superior pontine fissures, respectively. The pons is seen as a bulky mass of nervous tissue bulging anterior to the cerebellum, with a number of cranial nerves emerging from it. The pons is about 2.5 cm long, located in the anterosuperior part posterior cranial fossa. It is related anteriorly to the clivus (dorsal surface of sphenoid body & dorsum sellae), being separated from it by the pontine cistern of the subarachnoid space. The anterior surface of the pons has a shallow vertical "basilar groove", which lodges the basilar artery. On each side, the nerve fibers of the pons converge forming a thick bundle that runs posterolaterally to enter the cerebellum as the middle cerebellar peduncle.

At the anterolateral aspects of the pons, the trigeminal nerves (CN V) (sensory & motor parts) are attached. The abducent nerves (CN VI) emerge from the inferior pontine fissure just above the medullary pyramids. Posterolateral to this, the facial & vestibulocochlear nerves (CN VII, VIII) emerge from the fissure in the pontocerebellar angle, in which the nerves are just anterior to the lateral apertures of the 4th ventricle (foramina of Luschka) & its choroid plexus.

The posterior surface of the pons forms the upper part of the floor of the 4th ventricle, & is totally hidden by the roof of the 4th ventricle. This surface is roughly triangular. It has a median sulcus, & on each side a median eminence (above) & facial colliculus (below) are seen, both limited laterally by the sulcus limitans.

Internal Structure:

The pons is divided into a ventral part & a dorsal part (the pontine tegmentum). Anatomically, the dorsal part is the superior continuation of the medulla oblongata (except the pyramids), & the ventral part surrounds the dorsal part anteriorly & laterally.

Ventral pons: this is the visible part of the pons. It forms a rounded mass anteriorly that tapers into 2 middle cerebellar peduncles laterally. The ventral pons consists of nerve fibers & nuclei, arranged as follows:

- Pontine nuclei: a large number of small aggregations of neurons scattered throughout the ventral pons.
- Longitudinal (descending) fibers: These fibers originate from most of the cerebral cortex regions, aggregate & descend in the cerebral peduncles of the midbrain to enter the pons. According to their destination, longitudinal pontine fibers are divided into:
    - Corticospinal fibers: these fiber pass through the ventral pons without synapsing, to continue in the medulla as the pyramids.
    - Corticonuclear fibers: these fibers usually cross the midline to synapse on the cranial nerve nuclei in the pons & medulla oblongata. The represent the upper motor neurons of the motor pathway of cranial nerves.
    - Corticopontine fibers: these fibers terminate in the pontine nuclei.
- Transverse fibers: these fibers originate from the pontine nuclei, cross the midline to become the contralateral middle cerebellar peduncle & enter the cerebellum. In the cerebellum, these fibers terminate in the cerebellar cortex as the Mossy fibers.

Dorsal pons (pontine tegmentum): lying above the medulla, this part contains the tracts ascending from- & descending to the medulla (except the pyramidal tracts). In addition, this part contains the nuclei of some cranial nerves, & part of the reticular formation. Following is a simplified description:

White Matter:

- Medial lemniscus: this is the continuation of the gracile & cuneate tracts seen in the spinal cord & medulla. The medial lemniscus ascends in the upper medulla next to the midline occupying anteroposterior position in

cross section. In the pons, the lemniscus "rotates" to occupy horizontal position in cross section, lying just posterior to the ventral pons. It continues through the midbrain to the thalamus.

- Trigeminal lemniscus: a small tract originating from the contralateral spinal trigeminal nucleus, & ascends to the thalamus. Trigeminal lemniscus lies very close to the medial lemniscus.
- Lateral spinothalamic tract: ascending from the medulla, this tract lies lateral to the medial lemniscus.
- Lateral lemniscus: a small tract originating from the cochlear (& superior olivary) nuclei, ascends lateral to the lateral spinothalamic tract, to terminate in the inferior colliculus of the midbrain. It is part of the auditory pathway.
- Trapezoid body: a midline horizontal structure just anterior to the medial lemnisci. It is made by the decussating fibers originating from the ventral cochlear nuclei, plus some small trapezoid nuclei.
- Medial longitudinal fasciculus (MLF): a small tract next to the midline just beneath the floor of the 4th ventricle. It connects the vestibular nuclei to the nuclei of the cranial nerves supplying the extraocular muscles (CNs III, IV, VI) & some other CNS regions.
- The inferior cerebellar peduncles bound the lower part of pontine tegmentum posterolaterally.
- The superior cerebellar peduncles bound the upper part of pontine tegmentum posterolaterally.

Gray Matter:

Cranial nerves nuclei:

- Vestibulocochlear complex: a large group of the nuclei of the vestibulocochlear nerve (CN VIII), situated in the dorsal regions of the lower pons & upper medulla.
  a. Vestibular nuclei: 4 large nuclei (superior, inferior, medial, & lateral) situated beneath the floor of the 4th ventricle, occupying most of the lateral part of the floor (the vestibular area). These nuclei receive the vestibular nerve fibers (originating from the vestibular ganglia in the inner ear), & project to other CNS regions, including: the cerebellum (via the inferior cerebellar peduncle), thalamus, nuclei of CNs III, IV, & VI (via the MLF), & the spinal cord (via vestibulospinal tract).
  b. Cochlear nuclei: 2 small nuclei, ventral & dorsal, situated ventral & dorsal to the inferior cerebellar peduncle respectively. The dorsal cochlear nucleus lies also lateral to the vestibular nuclei. They receive the fibers of the cochlear nerve (originating from the spiral ganglion in the inner ear), & project to other CNS nuclei, including: trapezoid & superior olivary nuclei, nucleus of lateral lemniscus, inferior colliculus of the midbrain, & medial geniculate body of thalamus.
- Facial nuclei: the main (motor) nucleus of the facial nerve is situated in the lower part of the pontine tegmentum. It is a special visceral (branchial) efferent (SVE) nucleus that supplies the muscles of facial expression. The superior salivatory nucleus is just below the motor nucleus. It is a general visceral efferent (GVE) nucleus that gives the preganglionic parasympathetic fibers of the facial nerve. The other components of the facial nerve project to other nuclei, as follows:
  a. Special visceral afferent (SVA): taste sensation: to the nucleus solitarius in the upper medulla.
  b. General visceral afferent (GVA): general sensation from viscera: to the nucleus solitarius in the upper medulla.
  c. General somatic afferent (GSA): general sensation from the external ear: to the trigeminal sensory nuclei
  Note: the motor fibers of the facial nerve emerge from its nucleus, pass posteromedially, wind around the nucleus of abducent nerve (CN VI), then the run anterolaterally to exit the brainstem as the facial nerve. Abducent nucleus plus the facial nerve hooking around it form the facial colliculus in the floor of the 4th ventricle.
- Abducent nucleus: a small motor nucleus (general somatic efferent- GSE) situated next to the midline beneath the floor of the 4th ventricle, in a level slightly superior to the facial nucleus. Its fibers pass anteriorly to emerge between the pons & the pyramids of medulla as the abducent nerve.
- Trigeminal nuclei: 4 large nuclei, situated in a plain lateral to the facial nuclei. They are:
  a. Motor nucleus (SVE): an oval nucleus in the upper part of the pontine tegmentum, that gives the motor root of trigeminal nerve supplying the muscles of mastication.

b. Principal (main) sensory nucleus (GSA): lying just lateral to the motor nucleus, this large spherical nucleus receives trigeminal nerve fibers (originating in the semilunar ganglion of trigeminal nerve) that carry touch & pressure sensation.
c. Spinal nucleus (GSA): a column of cells starting just below the principal nucleus, extending through the medulla to the upper cervical spinal cord. This nucleus receives trigeminal nerve fibers (originating in the semilunar ganglion of trigeminal nerve) that carry pain & temperature sensation.
d. Mesencephalic nucleus (GSA): a column of cells starting just above the principal nucleus, extending through the whole midbrain. This nucleus is made of pseudounipolar neurons with their peripheral processes distributed with the trigeminal nerve fibers. They convey proprioceptive sensation.
Note: efferent fibers from the principal & spinal nuclei & central processes of the mesencephalic nucleus aggregate to form the "trigeminal lemniscus". This tract ascends lateral to the medial lemniscus to reach the thalamus, from which 3rd (or 2nd) order neurons pass to the sensory cortex in the cerebrum.

Specific nuclei:

- Nuclei of trapezoid body: a group of small nuclei situated around the midline within the decussation of fibers coming from the ventral cochlear nuclei. They are part of the auditory pathway.
- Nuclei of lateral lemniscus: small nuclei situated within the lateral lemniscus, they also are part of the auditory pathway.

Reticular Formation:

Pontine reticular formation is continuous with reticular formation in the medulla & midbrain. It is more extensive compared to that of the medulla. It occupies the central region of the pontine tegmentum on both sides of the midline.

Reflexes mediated in the pons:

Reflex	Stimulus	Afferent Pathway	Efferent Pathway	Result
Corneal reflex	Touching the cornea	CN V (to the trigeminal sensory nucleus)	CN VII (from motor facial nucleus)	Forceful contraction of orbicularis oculi muscle → closure of the eye
Jaw-jerk	Stretching the masseter & temporalis muscles	CN V (to the trigeminal mesencephalic nucleus)	CN V (from trigeminal motor nucleus)	Upward movement of the mandible

Midbrain

The midbrain (mesencephalon) is the upper part of brainstem. It connects the diencephalon (above) with the pons & cerebellum (below). It is situated in the concavity of the tentorium cerebelli, at the transition between the posterior & middle cranial fossae.

The midbrain is roughly-cylindrical in shape, with its upper part wider than the lower part from side to side. The midbrain, like other parts of brainstem, is a large collection of tracts (white matter) in which gray matter nuclei are embedded.

External Features:

Ventrolaterally, the midbrain has 2 broad bundles of nerve fibers that descend from the diencephalon & converge inferiorly, these are the "crura cerebri" (singular: crus cerebri, or cerebral crus). A triangular fossa forms between crura cerebri, the "interpeduncular fossa", the floor of which has many small foramina for blood vessels entry & called the "posterior perforated area". The 2 oculomotor nerves (CNs III) emerge from this area just medial to the cerebral crura. The interpeduncular fossa is bounded rostrally by the 2 spherical "mamillary bodies" (parts of the hypothalamus). Dorsal to the crus cerebri, the lateral surface of the midbrain is formed by the medial lemniscus, then the lateral lemniscus that ends at the inferior colliculus on the dorsal aspect of midbrain.

Dorsally, the midbrain has 4 elevations, 2 superior colliculi, & 2 inferior colliculi. On each side, the superior cerebellar peduncle enters the midbrain inferior to the inferior colliculus & medial to the lateral lemniscus. Just below the inferior colliculi, the 2 small trochlear nerves (CNs IV) emerge near the midline & run around the lateral surface of the midbrain to the middle cranial fossa. Note the following:

- The upper end of the midbrain is surrounded by a horizontal bundle of fibers, the "optic tract". It extends from the optic chiasma (near the mamillary bodies) to the lateral geniculate body at the posterior part of the thalamus.
- The lateral geniculate body is a thalamic nucleus related to the visual pathway. It is connected to the superior colliculus of midbrain by a nerve fiber bundle, the "brachium of superior colliculus".
- The medial geniculate body is a thalamic nucleus related to the auditory pathway, lying medial to the lateral geniculate body. It is connected to the inferior colliculus of midbrain by a nerve fiber bundle, the "brachium of inferior colliculus".
- At the midline posteriorly, the pineal gland (part of the diencephalon) is situated just superior to the superior colliculi of the midbrain.

Internal Structure:

Divisions of the midbrain: in a cross section, the midbrain has the following features & divisions:

- Cerebral aqueduct: a small CSF-filled canal that runs along the midbrain, connecting the 3rd ventricle (the cavity of the diencephalon) to the 4th ventricle (the cavity of the hindbrain). The cerebral aqueduct is not in the center of midbrain, it is much closer to the posterior surface.
- A horizontal line passing through the cerebral aqueduct divides the midbrain into a "tectum" dorsally & a "cerebral peduncle" ventrally.
- On each side, the cerebral peduncle is subdivided into 3 parts: crus cerebri, substantia nigra, & tegmentum.
- Crus cerebri: the broad bundle of descending fibers, occupying the anterolateral aspects of the midbrain.
- Substantia nigra: a flattened mass of gray matter separating crus cerebri from the rest of the midbrain.
- Tegmentum: the rest of the cerebral peduncle, back to the level of cerebral aqueduct.

White Matter:

Crus cerebri:

This thick bundle of fibers is made by descending fibers from cerebral cortex to the lower parts of CNS (midbrain, pons, medulla, & spinal cord). According to their destination, fibers in the crus cerebri include 3 groups: corticospinal (ending in the spinal cord), corticonuclear (ending in the cranial nerve nuclei & other brainstem nuclei), & corticopontine (ending in the pontine nuclei). In the crus cerebri, these fibers are arranged as follows:

- Corticospinal & corticonuclear fibers occupy the middle 2/3rd of the crus,
- Corticopontine fibers: fronto-pontine fibers occupy the medial 1/6th of the crus, temporo-pontine fibers occupy the lateral 1/6th of the crus, while the few parieto-pontine & occipito-pontine fibers lie medial to the temporo-pontine fibers.

While corticospinal (pyramidal) fibers pass through the pons & medulla oblongata to end in the spinal cord, corticonuclear fibers leave the other descending fibers at variable levels in the midbrain, pons, & medulla to cross the midline & end in the (motor) nuclei of cranial nerves, & other specific nuclei in the brainstem (like the olivary nuclei of the medulla). Corticopontine fibers were described previously.

Ascending tracts (medial lemniscus, spinal lemniscus, trigeminal lemniscus, & lateral lemniscus):

Those tracts, together, form a continuous broad curved bundle that occupies the lateral region of the midbrain tegmentum. They are arranged as follows (from anterior to posterior):

- Medial lemniscus: situated dorsal to substantia nigra, it is the continuation of the cuneate & gracile tracts of the spinal cord.

- Spinal lemniscus: the continuation of the spinothalamic tracts.
- Trigeminal lemniscus: fibers of the second order neurons connecting the trigeminal sensory nuclei to the thalamus.
- Lateral lemniscus: the most posterior one, its fibers originate from the trochlear nuclei, to terminate in the inferior colliculus of the midbrain, or continue (through the brachium of inferior colliculus) to the medial geniculate body of the thalamus.

Superior cerebellar peduncles:

The superior cerebellar peduncles are the main efferent pathway of the cerebellum. They enter the posteroinferior aspect of the midbrain (below the inferior colliculi). In the midbrain, the fibers pass superomedially, to decussate at the lower part of the midbrain, at the level of inferior colliculi, where they are seen in cross section occupying the central region of the tegmentum. Fibers of the superior cerebellar peduncle either end in the red nucleus of the midbrain (the cerebellorubral tract) or in the thalamus (cerebellothalamic tract).

Central tegmental tracts:

2 bundles of fibers originating from the red nucleus on its dorsolateral aspect. They descend ipsilaterally to the inferior olivary nucleus of the same side, which relay its efferent fibers to the contralateral cerebellar cortex.

Rubrospinal tracts:

Fibers originating from red nucleus of the midbrain (described below) decussate in the upper part (at the level of superior colliculi) to descend mainly to the spinal cord motor neurons as the small "rubrospinal tract".

Medial longitudinal fasciculus (MLF):

A small bundle of fibers extending throughout the midbrain, reaching up to the thalamus & down to the upper spinal cord. It mainly connects the vestibular nuclei with the nuclei of cranial nerves moving the eye, nuclei of accessary nerve, & the motor neurons of upper cervical spinal cord. It functions to coordinate the movement of the head, neck & eyeballs with the body position determined by the vestibular input.

Gray Matter:

Superior colliculi: 2 flattened-spherical nuclei (right & left) occupying the upper part of midbrain tectum. Gray matter of superior colliculi reaches the surface (not covered by white matter). Those are parts of the visual pathway, concerned mainly with visual reflexes. The superior colliculi receive afferents mainly from the retina, occipital cortex, spinal cord, the inferior colliculus, & the other superior colliculus. Efferent fibers go to the lateral geniculate body & retina (via the brachium of superior colliculus), the other superior colliculus, the cranial nerve nuclei (those supplying the eyeball), & the spinal cord (tectospinal tract).

Inferior colliculi: 2 flattened-spherical nuclei (right & left) occupying the lower part of midbrain tectum. Gray matter of superior colliculi does not reach the surface (covered by white matter of the lateral lemniscus). Inferior colliculi are parts of the auditory pathway, concerned mainly with auditory reflexes. The inferior colliculi receive afferents mainly from the cochlear nuclei (via the lateral lemniscus), & some fibers from the auditory cortex in the temporal lobe (via the brachium of inferior colliculus). Efferent fibers go to the medial geniculate body (via the brachium of inferior colliculus, with some fibers going directly to the auditory cortex), the other inferior colliculus, the superior colliculus, & the spinal cord (tectospinal tract). The last 2 tracts may mediate the reflex of moving the eyes & head towards the source of sound.

Substantia nigra: a flattened layer of gray matter extending throughout the midbrain, from the subthalamic region to the pons, separating the crus cerebri from the tegmentum on each side. It is part of the motor system, being connected mainly to a group of motor nuclei in the cerebrum called the "basal ganglia (nuclei)". Substantia nigra is also connected to other parts of the CNS, including the cerebral cortex, thalamus, subthalamus, reticular formation, etc. With advanced age, some people suffer from degeneration of the dopaminergic neurons of substantia nigra, & this may result in Parkinson's disease.

Red nucleus: an oval pinkish nucleus occupying the center of the upper tegmentum on each side, dorsomedial to substantia nigra. Rostrally, it extends to the subthalamic region. The main afferent fibers reach the red nucleus from the cerebral motor & sensory cortex (corticorubral tract), the deep cerebellar nuclei (cerebellorubral tract), & other regions (basal ganglia, substantia nigra, thalamus, etc). The main efferent pathways of the red nucleus are the central tegmental tract (uncrossed, from red nucleus to the inferior olivary nucleus of the medulla, which connects it to the contralateral cerebellar cortex), the rubrospinal tract (crossed, to the motor neurons of the upper spinal cord), & other tracts (to the thalamus, substantia nigra, etc).

Occulomotor nuclei (CN III): these lie in the upper midbrain tegmentum, in the ventral part of the periaqueductal gray matter. They include: (1) the motor nucleus (GSE), supplying the extraocular muscles of the eye, (2) the accessory nucleus (Edinger-Westphal nucleus) (GVE), supplying the ciliary ganglion with preganglionic parasympathetic fibers. The accessory nucleus lies dorsal to the motor nucleus. Fibers of the oculomotor nerve pass ventrally from the nuclei, penetrating the red nucleus, substantia nigra, & medial part of crus cerebri to exit at the interpeduncular fossa.

Trochlear nucleus (CN IV): this smaller nucleus occupies the same position of the oculomotor nucleus but in the lower part of tegmentum. It is a motor nucleus (GSE) that supplies the superior oblique muscle of the eye. From the nucleus, trochlear nerve fibers turn dorsally around the periaqueductal gray matter to exit from the posterior surface just inferior to the inferior colliculi.

Mesencephalic nucleus of trigeminal nerve (CN V): extending from the pons, this (GSA) nucleus is a column of neurons situated in the lateral region of the periaqueductal gray matter of the midbrain. It reaches to the level of the superior colliculi. Axons (central processes) of its neurons join the trigeminal lemniscus to the thalamus.

Periaqueductal (central) gray matter: a zone of gray matter surrounding the cerebral aqueduct. It has the nuclei of the oculomotor & trochlear nerves, & mesencephalic nucleus of trigeminal nerve as parts of it. In addition, it has many connections with other parts of the brain.

Reticular Formation of the Midbrain: the reticular formation of the midbrain is continuous with that that of the pons. It is located in the tegmentum, surrounding the red nuclei & the decussation of the superior cerebellar peduncles.

Reflexes mediated by the Midbrain:

Reflexes involving the nuclei of the midbrain are visual & auditory reflexes. These involve other (higher) centers in the brain, so it is better to discuss them later, when we describe the visual & auditory pathways in details.

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