Neuroanatomy 10: Limbic System

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The limbic system is the region of the brain believed to be responsible for feeling & expressing emotions & behavior. It forms a circular zone between the hypothalamus and the cerebrum. Therefore, it was called the limbic system (on the edge). Also, the limbic system is known as the circle of Papez (or Papez's Circuit). The functions of the limbic system can be memorized by five "F's":

- Feeding (satiety & hunger)
- Forgetting (memory)
- Fighting (emotional response)
- Family (sexual reproduction and maternal instincts)
- Fornicating (sexual arousal)

Those functions are expressed through the hypothalamus by way of the autonomic nervous system.

The limbic system can be divided into a cortical component (known also as the limbic lobe), and a subcortical component.

I- Limbic lobe:

The limbic lobe refers to a specific group of anatomical structures found in the cerebral cortex on the medial aspect of cerebral hemisphere forming a rim around the corpus callosum. It mainly consists of: the subcallosal, paraterminal, cingulate and parahippocampal gyri. In addition, it also involves the orbital frontal cortex & hippocampus.

Subcallosal gyrus

The subcallosal gyrus is a relatively small gyrus that is found anterior to the lamina terminalis (anterior wall of the hypothalamus) and the anterior commissure. Also, it is inferior to the rostrum (first part) of the corpus callosum. It is believed to be involved in depression.

Cingulate gyrus

The cingulate gyrus is a "C" shaped structure that begins ventral to the rostrum of the corpus callosum, curves rostrally then follows the genu of the corpus callosum to progress posteriorly to blend with the precuneus of the parietal lobe. The cingulate gyrus is separated from the corpus callosum by the callosal sulcus (inferiorly) and from the medial frontal gyrus and paracentral lobule by the cingulate sulcus superiorly. The cingulate sulcus is continuous with the marginal sulcus, which separates the paracentral lobule from the precuneus. Inferior to the splenium of corpus callosum, the cingulate gyrus becomes continuous with the parahippocampal gyrus vis the isthmus. It is believed that the cingulate gyrus is strongly associated with the perception of neuropathic pain and nociception.

Parahippocampal gyrus

The parahippocampal gyrus lies on the inferior surface of the temporal lobe of the cerebrum. It is located medial to the rhinal sulcus (an anterior continuation of the collateral sulcus) and the lateral occipitotemporal gyrus, lateral to the uncus, geniculate bodies and pulvinar of the thalamus, and anterior to the medial occipitotemporal gyrus. The parahippocampal gyrus provides a path of communication between the hippocampus and all cortical association areas through which afferent impulses enter the hippocampus.

Uncus

The uncus is the home of the amygdala. It appears to be an anteromedial extension of the parahippocampal gyrus.

Orbitofrontal cortex

This is the inferior surface of the frontal lobe. The olfactory bulb and tract can be found running along the olfactory sulcus. The olfactory sulcus separates the straight gyrus of the orbitofrontal cortex from the medial orbital gyrus. The orbitofrontal cortex perceives smell, which can also be involved in the formation of memories. This cortex has reciprocal connections with the mediodorsal nucleus of thalamus. It is also connected with the septal & hypothalamic nuclei via the medial forebrain bundle.

Hippocampal Formation

The hippocampal formation is an general term used to describe specific structures. These structures are the hippocampus, dentate gyrus, subiculum, and entorhinal cortex.

Hippocampus: The hippocampus is a C-shaped mass of grey matter, residing in the floor of the inferior horn of the lateral ventricle; that resembles a sea horse (also called cornu ammonis). Anteriorly, the hippocampus is wide and lobulated, forming the "pes hippocampi". The posterior end of hippocampus tapers & curves up to end near the splenium of corpus callosum. It has several afferent & efferent pathways that are mentioned later.

Dentate gyrus: The dentate gyrus is a serrated grey matter structure that is found between the hippocampus and parahippocampal gyrus as it travels along the floor of the temporal horn of the lateral ventricle. It extends anteriorly into the uncus and continues superomedially with the fimbria of the hippocampus (see below) and becomes the indusium griseum (a thin grey matter structure that covers the dorsal surface of the corpus callosum & represents the rudiment of hippocampus).

Subiculum: The subicular complex is a region of the hippocampal complex lying between the hippocampus & the entorhinal cortex. This complex contains pyramidal neurons that project to the entorhinal cortex and other parts of the hippocampal formation.

Entorhinal complex: The entorhinal cortex (Brodmann 28) is made up of the anterior pole of the parahippocampal gyrus and the uncus and is preceded by the gyrus semilunaris. It is a direct recipient of afferents stimulation from the olfactory bulb.

II- <u>Subcortical components:</u>

The subcortical component includes the amygdala, olfactory bulb, septal nuclei, hypothalamus and the anterior and dorsomedial nuclei of the thalamus. The subcortical region works in conjunction with the limbic lobe.

Amygdala

The almond-shaped amygdala (amygdaloid body) is located anterosuperior to the temporal (inferior) horn of the lateral ventricle, deep to the uncus. The apex of the tail of the caudate nucleus fuses with the amygdala in the roof of the temporal horn of the lateral ventricle.

The amygdala can be subdivided into a large ventrolateral component and a smaller dorsomedial division. The ventrolateral group links the dorsomedial division to the entorhinal cortex. The dorsomedial division receives sensory input from the olfactory bulb & sensory association cortices. From the posterior aspect of the amygdala, the stria terminalis emerges and takes a curved pathway. It extends posteriorly, then superiorly in a posterior relation to the thalamus. Finally, it travels anteriorly along the dorsal surface of the thalamus, between the thalamus and the caudate nucleus and rostral to the thalamostriate veins. These fibers allow communication between the amygdala and regions of the hypothalamus & septal nuclei to regulate the fear and anxiety responses. Notes: (1) stimulation of amygdala causes fear & sympathetic overactivity, (2) lesions causes placidity & hypersexual behavior.

Hypothalamus

The hypothalamus is involved in specific functions, like emotional response, endocrine regulation, sexual development, thermoregulation, regulation of satiety and hunger, and is also involved in osmoregulation. It feeds information into the limbic system, and serves as its final output. The hippocampo-hypothalamic fibers connect the hippocampus with the mammillary bodies of the hypothalamus via the fornix. This pathway serves as the major output of the limbic system. There are also amygdalohypothalamic fibers that emerge from the amygdaloid complex, travels via the stria terminalis and enters the hypothalamus. There are several nuclei that make up the hypothalamus. The preoptic, dorsomedial, lateral, and ventromedial nuclei are examples of hypothalamic nuclei that are closely related to the limbic system. The preoptic nucleus regulates the secretion of gonadotropin releasing hormone (GnRH), which is important for sexual development. The lateral nucleus modulates the feeding impulse (lesions associated with this nucleus has been associated with anorexia nervosa), while the dorsomedial and ventromedial nuclei are involved in the regulation of satiety, fear and sexual activity.

Mammillary bodies

The mammillary bodies are a pair of rounded structures found inferior to the floor of the third ventricle. They are posterior to the pituitary gland and the tuber cinereum (floor of the hypothalamus) and anterior to the posterior perforated substance and interpeduncular fossa. The mammillary bodies receive the major part of the fornix as its main afferent pathway, & gives the mammillothalamic tract as its main efferent pathway.

Thalamus

The **anterior nucleus** of the thalamus receives input from (1) the mammillary body via the mammillothalamic tract, & (2) the hippocampus via the fornix. It projects to the cingulate gyrus & it is a major part of Papez circuit.

The **mediodorsal nucleus** of the thalamus has reciprocal connections with the orbitofrontal & prefrontal cortices & the hypothalamus. It receives input from the amygdala & has a role in affective behavior & memory.

Other Components of the Limbic System:

Alveus

The alveus is a thin layer of white matter covering the hippocampus, (making its main output pathway), deep to the ependymal layer. The nerve fibers of the alveus emerge from the hippocampus, unite on the medial surface to form the fimbria of the hippocampus. The fimbria passes superomedially and become the crura of the fornix as the hippocampus terminates and the fornix begins ventrally to the splenium of the corpus callosum. It should be noted at this point where the crura of the fornix ascend posterior to the thalamus, they communicate with each other via the commissure of the fornix. The decussating fibers permit communication between the hippocampi of each side.

Habenular nucleus

The Habenular nucleus lies deep to the Habenular commissure that resides in the suprapineal space (above the pineal gland and recess). This nucleus communicates with the rest of the limbic system via the stria medullaris thalami (along the midline of the roof of the third ventricle).

Septal area

An area around the septum pellucidum that contains multiple nuclei known together as septal nuclei. These nuclei are part of the limbic system, they have reciprocal connections with the hippocampus via the fornix & with the hypothalamus via the medial forebrain bundle. The septal nuclei project to the habenular nucleus via stria medullaris thalami.

Afferent Connections of the Hippocampus:

- Fibers arising in the cingulate gyrus pass to the hippocampus.
- Fibers arising from the septal nuclei (nuclei lying within the midline close to the anterior commissure) pass posterior in the fornix to the hippocampus.
- Fibers arising from one hippocampus pass across the midline to the opposite hippocampus in the commissure of the fornix.
- Fibers from the indusium griseum pass posteriorly in the longitudinal striae to the hippocampus.
- Fibers from the entorhinal area or olfactory-associated cortex pass to the hippocampus.
- Fibers arising from the dentate and parahippocampal gyri travel to the hippocampus.

Efferent Connections of the Hippocampus

The alveus and fimbria are the efferent pathway of the hippocampus. The fimbria is a band of fibers (formed by aggregation of alveus fibers) that runs along the upper side of dentate gyrus, & continues as the crus of the fornix. The two crura converge to form the body of the fornix. The body of the fornix splits into the right & left columns of the fornix, which curve downward and forward in front of the interventricular foramina. The majority of the fibers of the column pass posterior to the anterior commissure, & the minority pass anterior to it.

Fibers passing posterior to the anterior commissure go to:

- The medial nucleus of the mammillary body,
- The anterior nuclei of the thalamus,
- The tegmentum of the midbrain.

Fibers passing anterior to the anterior commissure go to:

- The septal nuclei,
- The lateral preoptic area,
- The anterior part of the hypothalamus.

Some fibers join the stria medullaris thalami to reach the habenular nuclei.

Circle of Papez

In 1937, James Papez described the interconnection between the cerebral cortex and the hypothalamus in order for emotional behavior to be consciously perceived. This proposal was then termed the circle of Papez. This circuit involves communications between the entorhinal area, cingulate gyrus, mammillary nucleus, hippocampal formation and anterior thalamic nucleus.

The entorhinal cortex sends information to the hippocampal formation. By way of the fornix and fimbria, the hippocampal formation can then transmit information to the mammillary bodies. Subsequently, the mammillary bodies communicate with the anterior thalamic nucleus through the mammillothalamic tract. The internal capsule then takes information from the thalamus to the cingulate gyrus, which then returns impulses to the entorhinal area via the cingulum. The afferent and efferent information travelling to and from the limbic system originate in cortical, reticular and diencephalic regions of the brain.

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