

Limbic System

Objective

- To learn the complex 3-dimensional anatomy of some of the C-shaped deep brain structures
- To become familiar with the brain systems for emotions and learning and memory, with an emphasis on the amygdala and hippocampal formation
NTA Ch 15, pgs. 447-462
Key Figs. 15-1 through 15-6
Table 15-1
Clinical Case
#13 Temporal lobe epilepsy; CC13-1

Self evaluation

- Be able to identify all structures listed in key terms and describe briefly their principal functions
- Use neuroanatomy on the web to test your understanding

I-1 General anatomical organization of the limbic system

The medial surfaces of the telencephalon and diencephalon are illustrated in the top panel. Below is a “cut-away” view of diencephalic and telencephalic nuclei and tracts. Use these two illustrations to familiarize yourself with the key structures of the limbic system. On the medial brain surface, identify the limbic association areas: the cingulate and parahippocampal gyri and the cortex of the temporal pole. The orbital gyri are not visible on this slide. What are some functions of the parahippocampal gyrus and temporal pole? The amygdala and rostral hippocampal formation are under the region of the uncus. Space occupying lesions above the cerebellar tentorium may cause the uncus on the side of the lesion to become displaced medially thereby squeezing the midbrain and the third nerves. This is termed uncal herniation. The more caudal portions of the hippocampal formation are located beneath the parahippocampal gyrus. The septal nuclei (see outline of approximate boundaries in the lower brain view) are located on the lateral surface of the septum pellucidum. They are continuous with the “septal region”, which is located on the medial brain surface. The fornix, the output pathway of the hippocampal formation, is also located on this brain view, although not numbered. In the cut-away view, locate the amygdala and its output pathways, the stria terminalis and ventral amygdalofugal pathway. What are the three major nuclear groups of the amygdala? The hippocampal formation and its major path, the fornix (unnumbered structure beneath the stria terminalis) are also visible. It will be helpful to come back to this view when you consider Papez circuit later in the lab. For now, consider the circuit briefly (cingulate gyrus – parahippocampal gyrus –

hippocampal formation – forni-mammillary bodies – mammillothalamic tract – anterior thalamic nuclei – cingulate gyrus).

SA01 Medial brain view

Note the cingulate gyrus, which is one of the limbic association areas

SA03 Inferior brain view

Note the following limbic association areas: parahippocampal gyrus, temporal pole, uncus, and inferior frontal cortex

hipposeptal Hippocampal-septal system (movie)

Key:

Fornix=gray

Hippocampal formation=lavender

Septal nuclei=yellow

Anterior commissure=white

Limbic association cortex=green

limbicparts Limbic system

innominata Nucleus basalis (movie)

Key:

Substantia innominata=aqua

Nucleus basalis=purple (in substantia innominata)

Septal nuclei=yellow

Anterior commissure=gray

Fornix=white

Hypothalamus=brown

X-95 The septal nuclei and other structures of the basal forebrain

The septal nuclei are relatively small groups of cells that lie close to the midline lateral and ventral to the septum pellucidum. At their rostral extent they form the ventromedial wall of the anterior horn of the lateral ventricle. They stretch caudally for more than a centimeter, where they lie dorsal and lateral to the columns of the fornix. One portion of the septal nuclei has more acetylcholinesterase. This portion is neurochemically similar to the nucleus of the diagonal band of Broca, which lies just ventral to the septal nuclei. Locate the region of the septal nuclei.

X-90 The septal nuclei and other structures of the basal forebrain

Identify the septal nuclei (See text for X095)

X-85 The septal nuclei and other structures of the basal forebrain

Identify the septal nuclei (See text for X095)

I-3 Basal forebrain cholinergic neurons

The Nissl-stained hemisection of normal human brain on the left shows the large, densely stained cells of the basal forebrain. At this rostrocaudal level, these AChE containing cells form the nucleus basalis (of Meynert). Their distribution is shown in the projection map in the upper right, while the cell cluster itself is shown at greater magnification in the lower right. Note the presence of neurons lying on the border of, or embedded within, the anterior commissure and internal capsule. This diffuse layer of cells ventral to the globus pallidus is continuous with similar cells extending as far anterior as the medial septal nucleus. What is the projection target of the cholinergic cells shown here? What is the projection target of the septal neurons of this type?

G-4 Basal forebrain cholinergic neurons

Magnocellular neurons are the ones prominently stained (See text for I003)

X-85 The amygdala

The amygdala is composed of numerous nuclear groups that can be divided into the basolateral, central, and corticomедial nuclei. Identify their approximate locations. The amygdala gives rise to two major pathways, the stria terminalis and the ventral amygdalofugal pathway. The stria terminalis is a C-shaped structure which exits from the caudal end of the amygdala and curves around the lateral ventricle in close proximity to the caudate nucleus, terminating in the hypothalamus. The bed nucleus of the stria terminalis, runs along with the stria terminalis and is largest rostrally. It receives input from all nuclei of the amygdala. The bed nucleus of the stria terminalis has widespread connections to the rest of the limbic system and therefore provides an important route by which the amygdala can affect structures beyond the connections of the stria terminalis itself.

The ventral amygdalofugal pathway courses medially from the amygdala to the basal nucleus of Meynert and the dorsal medial nucleus of the thalamus. It is a diffuse, myelinated bundle lying ventral to the globus pallidus (medial pole) which can be seen in Slide X085.

X-110 Parasagittal section through the temporal lobe showing the hippocampal and amygdala

Before reviewing this slide, identify the plane of section. The amygdala is located in the anterior part of the temporal lobe, just rostral to the hippocampal formation. Just dorsal to the amygdala lies the anterior commissure which is caught here at its lateral-most extent. For review, identify the putamen and locate the tail of the caudate nucleus. Note the position of a lenticulo-striate artery in the putamen.

I-7 Development and structure of the hippocampal formation

A transverse section (I006) through the medial temporal lobe shows that the distinct regions of the hippocampal formation and parahippocampal gyrus roughly take the form of the letter "S" (see NTA Fig. 15-14). The entorhinal cortex, a restricted portion of the parahippocampal gyrus, forms the lower arc of the "S". The entorhinal cortex has six layers like neocortex on the lateral surface. The subiculum forms the superior surface of the parahippocampal gyrus and is partially infolded into the temporal lobe. The subiculum, upon which the hippocampus and dentate gyrus appear to rest (subiculum means a support), is a region of cortex transitional between six-layered neocortex and three-layered archicortex of the hippocampus. The uppermost curve of the "S" is the hippocampus proper (Ammon's Horn), lateral and dorsal to the subiculum. The hippocampal fissure separates the parahippocampal gyrus and subiculum from the hippocampus proper. The hippocampus takes a final bend to form a flat sheet of gray matter directly above the subiculum known as the dentate gyrus, which is also three-layered archicortex. What are the layers of the various components of the hippocampal formation? Using I007, trace how the hippocampal formation acquires its S-shaped cross-sectional configuration during development.

I-9 Cellular organization of the hippocampus

To test your familiarity with the cellular organization of the hippocampal area, examine slide I009. This is a Nissl-stained section through a human hippocampus. Locate the collateral sulcus, entorhinal cortex, parahippocampal gyrus, and subiculum. Which horn of what ventricle lies just lateral to the hippocampus? Locate the alveus and the fimbria. The CA designations apply to different regions of the Ammon's horn (hippocampus proper). Identify the three layers of the dentate gyrus and hippocampus proper. The pyramidal cell layer of the hippocampus is replaced by what cell layer in the dentate gyrus? What is the orientation of the apical dendrites of the pyramidal cells relative to laminar structure of the hippocampus? Note that the pyramidal cell bodies form a discrete band close to the hilus of the dentate gyrus, but are more spread out elsewhere. These differences in cytoarchitecture are correlated with the fact that different parts of hippocampus have different sets of connections. For review, identify the lateral geniculate and the tail of the caudate nucleus.

I-11 Three-dimensional organization of the hippocampal formation and fornix

The fornix, a C-shaped structure, is the major efferent pathway of the hippocampal formation. The fornix contains axons derived from pyramidal cells in the subiculum, and to a lesser extent, the axons of pyramidal cells of the hippocampus. Pyramidal cell axons course towards the ventricular surface of the hippocampal formation. This surface is termed the alveus. These fibers converge on the medial surface of the hippocampus to form a flattened band, the fimbria, lying medial to the hippocampus and the dentate gyrus. The fimbria forms the beginning of the fornix. The fornix consists of four components: in addition to the (1) fimbria,

(2) crus, (3) body, and (4) column. Fibers ascend from the fimbria and curve rostrally to form the crus and body of the fornix, lying immediately ventral to the corpus callosum, and then descend toward the anterior commissure as the columns. As the columns of the fornix approach the anterior commissure, each column splits into a major postcommissural and minor precommissural division. The postcommissural fornix arises mainly from the subiculum and terminates predominantly in the mammillary body on the same side. The precommissural fornix is destined for the septal area, and come from the hippocampus proper.

X-80 Mammillary bodies - coronal section

Note the fornix terminating in the lateral portion of mammillary bodies and the mammillothalamic (and mammillotegmental) tract originating from their medial aspects. The mammillary bodies are composed of a number of nuclear groups, the largest being the medial group which occupies more than 75% of the structure. The medial mammillary nucleus is the principal termination of the fornix. It also gives rise to a well-myelinated fiber bundle, the mammillothalamic tract, which ascends dorsally to the anterior thalamic nucleus. The mammillary nuclei are the only hypothalamic nuclei that do not receive or project fibers into the MFB. They are also the only hypothalamic nuclei that do not appear to be involved in some aspect of visceral-endocrine control. Lesions of the mammillary bodies result in behavioral, emotional, and memory dysfunctions.

X-75 Coronal section through the mammillothalamic tract.

In this slide, a portion of the mammillothalamic tract can be observed ascending through the thalamus and forming a capsule around the ventral portion of the anterior nucleus. To what cortical gyrus do neurons of the anterior nucleus project? The mammillothalamic thalamic tract forms part of the internal medullary laminae. The body of the fornix is located beneath the corpus callosum. Identify the hippocampal formation. It forms the floor of the inferior horn of the lateral ventricle. Also identify the stria medularis through which the septal nuclei project to the habenula.

X-70 Coronal section through the diencephalon and cerebral hemispheres

Identify the hippocampal formation. It forms the floor of the inferior horn of the lateral ventricle. Also identify the stria medularis through which the septal nuclei project to the habenula.

X-100 Sagittal section - close to the median plane

In an earlier slide, you reviewed Papez's circuit. A key component of the circuit is the mammillary body. In slide X100, which is a section cut in the sagittal plane close to the midline, a mammillary body can be seen receiving input from the postcommissural fornix and giving rise to its major efferent projection, the mammillothalamic tract. What thalamic nucleus receives this ascending

hypothalamic projection? Another limbic system tract, the stria medullaris, is visible on this sagittal section. The stria medullaris contains axons of the medial septal nuclei, which terminate in the habenula.

In addition, you should take the opportunity to review other important structures. Three easy structures to identify are: 1) the corpus callosum (Do you remember its four component parts?), 2) the basal portion of the pons and the pontine nuclei, and 3) the pyramidal tract. How about three harder identifications: 1) the red nucleus, 2) the decussation of the superior cerebellar peduncle, and 3) the medial longitudinal fasciculus. Name two brain stem nuclei that are connected by the MLF.

X-110 Parasagittal section through the temporal lobe showing the hippocampal and amygdala

The hippocampal formation is located caudal to the amygdala. Note the pes hippocampus, the most anterior, folded back section of the hippocampus. The pes is surrounded by the alveus which merges into the fimbria of the fornix at the posterior dorsal edge of the hippocampal formation. Identify the subiculum and dentate gyrus.

Key Structures and Terms

Entorhinal cortex
Cingulate gyrus
Orbital-frontal cortex
Temporal pole
Hippocampal formation
Hippocampus
Subiculum
Dentate gyrus
Pyramidal cells of the hippocampus
Granule cells of the dentate gyrus
Fornix
Thalamus
Medial dorsal nucleus
Anterior nuclei
Internal medullary laminae
Ventral striatum
Amygdala
Corticomedial nuclear group
Basolateral nuclear group
Central nucleus
Ventral amygdalofugal pathway
Stria terminalis
Nucleus basalis of Meynert
Septal nuclei
Uncus