

Basal Ganglia

Objective

- To understand the complex anatomy and connections of the components of the basal ganglia that control movement.
- To develop insight into basal ganglia diseases, such as Parkinson's disease and Huntington's disease, by understand basal ganglia connections
NTA Ch. 11
Key Figs: 11-1; 11-2; 11-3; 11-4; 11-6
Clinical Case
#9 Huntington's disease; CC9-1

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

List of media

E-1 Simplified circuit diagram

This slide illustrates a simplified circuit through the basal ganglia. It is based on our understanding of the parts of the basal ganglia that are important in movement control. Follow the direct and indirect paths. Consider this circuitry in a broad context by reviewing the specific cortical, striatal, pallidal, and thalamic regions that are important in the: 1) limb motor function, 2) oculomotor control, 3) cognitive (and other integrative brain) functions, and 4) emotions.

Note, this slide is a "work in progress" and you should follow several guidelines in using the animations. First, navigate by clicking on the labels not the images. Second, note that clicking on more than one structure can produce an amgiguous set of labeled images (e.g., clicking on both direct and indirect paths leaves you unable to distinguish either). Here is an effective plan: 1) click on cerebral cortex, brain stem, striatum, GPe, subthalamic nucleus, GPi/SNpc, and thalamus. 2) Click on inhibitory; click on excitatory; after noting organization, then unclick both inhibitory and excitatory. 3) Click on direct path and note its organization; unclick. 4) Click on indirect path, note its organization, and then unclick.

E-2 Functional basal ganglia loops

This slide illustrates the distinctive regions of the cortex that are connected through the basal ganglia to the frontal lobe. Consider the specific cortical, striatal, pallidal, and thalamic regions that are important in: 1) limb motor function, 2) oculomotor control, 3) cognitive (and other integrative brain) functions, and 4) emotions.

X-120 Horizontal section through the diencephalon and telencephalon

The major components of the basal ganglion can be visualized in this horizontal section. Identify the caudate nucleus, putamen and the internal and external segments of the globus pallidus. Notice that the caudate nucleus and putamen are separated by the anterior limb of the internal capsule and that the posterior limb separates the thalamus from the globus pallidus. You should be able to name the various structures encountered in a path from the lateral margin of the section to the thalamic adhesion.

M-2 Horizontal – internal capsule and thalamus

On the brain stem model, determine the approximate imaging plane. On this scan the white matter of the cerebral hemisphere appears darker than gray matter and CSF appears white. Identify the head of the caudate nucleus and the putamen. Which limb of the internal capsule separates these two components of the striatum? Also identify the thalamus, third ventricle, and the anterior and posterior horns of the lateral ventricles.

X-95 Coronal section rostral to the anterior commissure

In this slide, you should note the anterior horns of the lateral ventricles separated by the septum pellucidum. On each side, the head of the caudate nucleus bulges into, and forms the lateral wall of the lateral ventricles. The putamen is situated inferior and lateral to the caudate nucleus and the two are separated by the anterior limb of the internal capsule. Identify the nucleus accumbens ventral and medial to the caudate nucleus and putamen. How does the function of the nucleus accumbens differ from that of the putamen? Thin cellular bridges connecting the caudate and putamen run through the internal capsule. Note also the thin layer of neurons forming the claustrum, which lies between the putamen and insular cortex. The paired darkly stained fiber bundles located below the basal ganglia are the optic nerves.

E-17 Cortical terminations in the striatum

This is a slide of a monkey brain. The prefrontal cortex was injected with tritiated amino acids. These are picked up by the cell bodies at the injection site and transported orthogradely towards their terminals. The terminal labeling is then demonstrated with autoradiography. (The tissue slice is mounted over a photographic emulsion, which is sensitive to particles emitted by the radiolabeled amino acids contained in the axons and terminals.) The exposed silver grains on the

emulsion are then visualized superimposed on the tissue using dark field illumination. Note that the distribution of label is not uniform, with regions of high density and islands of tissue relatively free of terminal labeling. It is also been demonstrated that the striatal distributions of certain neurochemicals are not homogenous. We as yet do not know the functional significance of the patchy distributions of cortical terminal fields and neurochemicals. (Slide courtesy of Dr. Pat Goldman-Rakic, Yale University School of Medicine)

X-90 Coronal section at the level of the rostral anterior commissure

You should be able to identify the corpus callosum, lateral ventricle, internal capsule, septum pellucidum, anterior commissure, and optic chiasm, as well as the head of the caudate and putamen. As in the previous slide, you can see the claustrum and the insular cortex. Observe that at this level the putamen is separated from the external segment of the globus pallidus by the lateral medullary lamina. The ventral pallidum is also located at this level. How would you distinguish the function of the ventral pallidum from that of the external segment of the globus pallidus? The curved band of gray matter just dorsal to the middle third of the anterior commissure (and running between the septum pellucidum and the head of the caudate) contains the septal nuclei. Inferior to the anterior commissure and superior to the optic chiasm lies the preoptic area. Additional structures to be noted are the amygdaloid nuclear complex which belong to the limbic system and will be discussed in a later laboratory.

X-85 Coronal section at the caudal anterior commissure

This slide contains many of the same features as X090. The differences that should be noted are listed. (1) The anterior commissure, is now located in the center, as an ovoid structure, and placed laterally, at the inferior margin of the putamen. This occurs because the anterior commissure is shaped like a pair of handle bars with the ends bent posteriorly. (2) The internal segment of the globus pallidus is beginning to appear; in the previous slide the internal segment of the globus pallidus was not visible because it does not extend as far rostrally as the external segment. Remember that the putamen and globus pallidus combined are shaped like a cone with the apex aimed medially (termed lenticular nucleus.) (3) The columns of the fornix appear just above the portion of the anterior commissure located in the midline. To facilitate your understanding of the C-shaped structures, try to follow their course again in the posters or in the atlas.

X-80 Coronal section at the level of the mammillary bodies

By now, you should be able to identify the various components of the basal ganglia and related structures mentioned in the preceding slide. Key differences can be seen, however, in the configuration of these structures. Because of their curvature (see Appendix III, Figures 5 and 11) the columns of the fornix can be seen in two locations: dorsal and medial to the Foramen of Monro, and at the superior and lateral margins of the mammillary bodies (at whose lateral margins the fornices

will terminate). (The mammillary bodies also give rise to a bundle of fibers directed towards the thalamus: the mamillo-thalamic tracts.) In this slide, the globus pallidus can be seen to be divided into clear internal and external segments (by what structures?) and the internal segment itself can be seen to be incompletely divided by a collection of fibers at the inferior margin of the internal segment of the globus pallidus. This is the ansa lenticularis which conveys impulses from the internal segment of the globus pallidus to the thalamus. The complex course of this and related fiber tracts is illustrated in the reconstructions shown in the next slides.

E-5 Schematic 3-dimensional reconstruction of the efferent fiber systems leaving the lenticular nucleus (E005 coronal, E006 lateral view)

The three-dimensional geometry of the ansa lenticularis and the lenticular fasciculus are particularly difficult to appreciate. Note in this slice the ansa lenticularis originating from the ventral aspect of the medial globus pallidus and coursing ventrally, toward the midline to hook around the posterior limb of the internal capsule, where it courses dorsally towards the thalamus. The lenticular fasciculus issues from the dorsal aspect of the internal segment of the globus pallidus and follows a more direct course. Small fascicles of fibers pierce directly through the internal capsule rostral to the subthalamic nucleus and collect to form a well-defined bundle just ventral to the zona incerta. The majority of fibers in the ansa lenticularis and lenticular fasciculus enter the thalamic fasciculus, dorsal to the zone incerta.

globus Globus pallidus (movie)

Note, the ventral pallidum is located ventral to the anterior commissure

Key:

Globus pallidus=gray

Anterior commissure=yellow

E-6 Schematic 3-dimensional reconstruction of the efferent fiber systems leaving the lenticular nucleus (E005 coronal, E006 lateral view)

This is a lateral view of the fibers of the striatum. Note the course of the ansa lenticularis.

striatum Striatum (movie)

Key:

Striatum=green

Ventricles=aqua

Nucleus accumbens=yellow

Anterior commissure and globus pallidus=gray

X-75 Coronal section through subthalamic nuclei

Because of its orientation, this section passes through the basal ganglia, thalamus and brain stem. Identify the subthalamic nucleus and review its connections; discuss hemiballism.

X-60 Oblique section through thalamic nuclei and ansa lenticularis

Can you tell why the plane of section illustrated is oblique? Clues can be found in the body of the fornix and the anterior commissure. The ansa lenticularis and lenticular fasciculus are deeply stained and well defined. Immediately dorsal to the lenticular fasciculus is the zona incerta and lying dorsal to zona incerta is the thalamic fasciculus (Forel's field H1). What tracts contribute fibers to the thalamic fasciculus? Note also the columns of the fornix lying within the hypothalamus.

E-12 Nissl-stained sections of the midbrain

Two zones are commonly distinguished in the substantia nigra: a compact zone, rich in large, polygonal, melanin-containing cells, and a reticular part. The pigmented cells of the pars compacta manufacture and deliver dopamine to axon terminals in the striatum.

Additional information:

The substantia nigra is the largest cellular mass in the mesencephalon and lies just dorsal to the basis pedunculi. The substantia nigra contains two biochemically distinct parts: (1) the pars compacta is made up of darkly pigmented, melanin-containing neurons (this is the dopaminergic system discussed earlier); and (2) the pars reticulata contains nonpigmented GABAergic neurons (NTA Fig. 11-4).

X-45 Myelin-stained sections of the midbrain

Identify the general regions of the substantia nigra and ventral tegmental area. In addition to the striatum, where else do midbrain dopaminergic neurons project? From which dopaminergic cell group does this non-striatal projection originate? Parkinsonism is associated with decreased levels of dopamine in the substantia nigra and the striatum. The cells in the reticular part release GABA on their postsynaptic target neurons. Can you name where these target neurons are located?

subnigra Substantia nigra (movie)

Key:

Substantia nigra=pink

Subthalamic nucleus=yellow

Cerebral peduncle=white

Rest of brain=brown

Subthalamus corresponds largely to the zona incerta.

subthalam Subthalamic nucleus Key:
Substantia nigra=pink
Subthalamic nucleus=yellow
Thalamus and hypothalamus=brown

Exercise during laboratory:

- 1) Figure out the relative locations of the caudate nucleus, putamen, and nucleus accumbens.
- 2) Follow the ansa lenticularis from the internal segment of the globus pallidus to the thalamus.

Key Structures and Terms:

Striatum
Caudate
Putamen
Nucleus accumbens

Major function basal ganglia loops

Globus pallidus, External and
Internal segments
Lenticular nucleus
Clastrum
Subthalamic nucleus
Substantia nigra pars compacta
Substantia nigra pars reticulata
Zona incerta
Subthalamic nucleus
Mammillary bodies
Raphe nuclei
Thalamus (CM, VA, VL, MD)

FIBER BUNDLES AND TRACTS:

Ansa lenticularis
Lenticular fasciculus
Thalamic fasciculus

DISORDERED MOTOR FUNCTION

Rigidity
Akinesia
Ballism
Athetosis
Chorea