

Auditory and Vestibular Systems

Objective

- To learn the functional organization of the auditory and vestibular systems
- To understand how one can use changes in auditory function following injury to localize the site of a lesion
- To begin to learn the vestibular pathways, as a prelude to studying motor pathways controlling balance in a later lab.

Ch 7

Key Figs: 7-1; 7-2; 7-4; 7-5

Clinical Case

#2 Hearing loss and dizziness; CC4-1

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

F-5 Vestibular efferent connections

The first order neurons of the vestibular system are bipolar cells whose cell bodies are located in the vestibular ganglion in the internal ear (NTA Fig. 7-3). The distal processes of these cells contact the receptor hair cells located within the ampulae of the semicircular canals and the utricle and saccule. The central processes of the bipolar cells constitute the vestibular portion of the vestibulocochlear (VIIIth cranial) nerve. Most of these primary vestibular afferents enter the ipsilateral brain stem inferior to the inferior cerebellar peduncle to terminate in the vestibular nuclear complex, which is located in the medulla and caudal pons. The vestibular nuclear complex (NTA Figs, 7-2, 7-3), which lies in the floor of the fourth ventricle, contains four nuclei: 1) the superior vestibular nucleus; 2) the inferior vestibular nucleus; 3) the lateral vestibular nucleus; and 4) the medial vestibular nucleus. Vestibular nuclei give rise to secondary fibers that project to the cerebellum, certain motor cranial nerve nuclei, the reticular formation, all spinal levels, and the thalamus. Many of these secondary neurons send their axons into the medial

longitudinal fasciculus, a brain stem pathway located just beneath the floor of the ventricular system close to the midline. The vestibular nuclei project to the extraocular motor nuclei via the rostral part of the medial longitudinal fasciculus. The medial longitudinal fasciculus caudal to the vestibular nuclei carry axons that terminate in the upper spinal cord (termed the medial vestibulospinal tract or descending medial longitudinal fasciculus or the medial vestibulospinal tract – see Descending Motor Systems Lab). These fibers originate primarily in the medial vestibular nuclei.

The axons of certain second order neurons in the vestibular nuclei ascend to the thalamus. This is a bilateral projection. The thalamic nucleus that receives a vestibular projection is a portion of the ventral posterior nucleus. A Canadian neurosurgeon, Ronald Tasker, elicited sensations of vertigo and movement in a patient by electrically stimulating this thalamic region. From the ventral posterior nucleus, vestibular information projects to two regions of the parietal lobe (NTA Fig. 7-10). One region is located in the posterior parietal cortex immediately caudal to the primary somatosensory cortex (termed vestibular cortex). This cortical area, which also contains neurons that encode joint angle and limb position, may serve an important role in the perception of the orientation of the body in space.

We will learn in a later lab that the lateral vestibular nucleus projects fibers to the ipsilateral spinal cord via the lateral vestibulospinal tract. The other three vestibular nuclei give rise to two bilateral tracts which ascend and descend the neuraxis near the midline: the medial vestibulospinal tract descends into the spinal cord, and the ascending fiber tract, the medial longitudinal fasciculus (MLF). This pathway may help stabilize retinal images during head and eye movements.

B-11 The auditory pathway

The peripheral apparatus of the auditory system (NTA, Fig. 7-3) conducts pressure (i.e., sound) waves from the environment to the flexible basilar membrane. Mechanical displacement of the basilar membrane activates auditory receptor cells, called hair cells, by deflection of the microvilli (or hairs) that are on their cell membranes (NTA, Fig. 7-3). Hair cells are innervated by neurons whose cell bodies are located in the spiral ganglion. The central processes of these cells constitute the cochlear (auditory) division of the vestibulocochlear (VIIIth cranial) nerve. There is a relationship between the frequency of maximal sensitivity of an auditory nerve fiber and its site of origin in the cochlea. Because of both the mechanical properties of the basilar membrane and electrophysiological properties of hair cells, fibers from the base of the cochlea respond selectively to high-frequency stimuli, and fibers from the apex respond to low-frequency stimuli. This differential sensitivity is the basis of the tonotopic organization of the receptive sheet, an organization that is present at virtually every level of the auditory system.

The auditory nerve enters the brain stem immediately caudal to the vestibular division, terminating upon neurons of the dorsal and ventral cochlear nuclei, which

are located dorsal and ventrolateral to the inferior cerebellar peduncle. (The ventral cochlear nucleus contains separate anterior and posterior divisions. You will not, however, be held responsible for this information in the neuroanatomy lab.) As a group, the secondary auditory fibers, originating in the cochlear nuclei, are mostly crossed and ultimately terminate in the inferior colliculus (NTA Fig. 7-1). The decussation of the auditory fibers from the ventral cochlear nucleus occurs in the trapezoid body. Neurons of the ventral cochlear nucleus synapse in the superior olivary nuclear complex, which is located in the pons (see NTA Fig. 7-5 for salient features of the organization of the superior olivary complex). These neurons project their axons in the lateral lemniscus and terminate in the inferior colliculus.

While some neurons of the dorsal cochlear nucleus synapse in the superior olivary complex, the axons of most of its neurons cross the midline dorsal to the trapezoid body and ascend directly to the inferior colliculus. This latter group decussates in the dorsal and intermediate acoustic striae (which do not form discrete commissures like the trapezoid body). Whereas the ascending projection from the superior olivary complex is clearly important in sound localization, the function of the direct projection to the inferior colliculus is less well understood. It has been suggested that this pathway is important in auditory pattern recognition.

Most neurons of the inferior colliculus give rise to axons that form the brachium of the inferior colliculus and terminate in the medial geniculate nucleus of the thalamus (NTA Fig. 7-7, 7-8). The medial geniculate nucleus transmits information in a tonotopic fashion to the posterior portion of the superior temporal gyrus. This area contains Heschl's gyri, which form the primary auditory cortex (Brodmann's area 41).

latlemniscus Lateral lemniscus (movie)

Key:

Trapezoid fibers, lateral lemniscus, brachium of inferior colliculus=yellow

Thalamus=brown

Cochlear nuclei, superior olivary complex, inferior colliculus=aqua

X-20 Mid-medulla just rostral to the obex

Identify the vestibular nuclei (at this level, the medial and inferior nuclei are present) and the medial longitudinal fasciculus (MLF). Where do most of the axons in the MLF at this level terminate?

The posterior inferior cerebellar artery (PICA) supplies blood to the dorsolateral medulla. Occlusion of PICA infarcts this medullary region because there is little collateral circulation from other arteries; the condition is termed Wallenberg's (or lateral medullary) syndrome. What somatic sensory and vestibular signs would you expect to observe in a patient with an infarction of the dorsolateral medulla?

X-25 Rostral medulla

Identify the dorsal and ventral cochlear nuclei and the vestibular nuclei. Through what decussation do most of the axons from the ventral cochlear nucleus cross the midline? Is this pathway entirely crossed? Where do the axons of dorsal cochlear neurons synapse?

X-30 Pons at the level of the facial colliculus

Identify the vestibular nuclei. The lateral vestibular nucleus is located at this level. It gives rise to the lateral vestibulospinal tract (a pathway for controlling primarily axial muscles) and an ascending projection to the thalamus. Identify the following fiber tracts: MLF, trapezoid body, medial lemniscus, middle cerebellar peduncle, central tegmental tract, and corticospinal and corticobulbar tracts. Identify the superior olivary nucleus. Fibers of the trapezoid body pass through the medial lemniscus. The medial lemniscus is an important landmark for understanding brain stem organization. Identify the spatial relationship between the trapezoid body and the medial lemniscus. What are the nuclear origins of the axons in the trapezoid body?

X-35 Rostral pons at level of the sensory and motor trigeminal nuclei.

Identify the MLF. What is the axonal composition of the MLF at this level (i.e., nuclear origins, terminations)? How is the composition different at this level compared with the caudal medulla? Identify the superior olivary complex. What is the approximate location of the lateral lemniscus? What are the functional and anatomical differences of the lateral and medial lemnisci?

X-37 Pons-Midbrain juncture

Identify the lateral lemniscus. Within the lateral lemniscus at this level is the nucleus of the lateral lemniscus: this is an auditory relay nucleus where some, but not all, ascending auditory fibers synapse.

X-40 Midbrain at level of the inferior colliculus

The inferior colliculus is an obligatory relay for audition. Identify the lateral lemniscus as it enters the inferior colliculus. From here information passes to the medial geniculate nucleus via the brachium of the inferior colliculus. What is the source of axons in the brachium of the superior colliculus?

X-45 Midbrain at level of the superior colliculus

Review the location of the medial geniculate nucleus, a diencephalic nucleus, on the brain stem model to better understand the plan of section in this slide. Observe the medial geniculate nucleus in relation to the superior colliculus. Contrast the functions and connections of the superior and inferior colliculi.

X-50 Midbrain at level of the midbrain-diencephalon juncture

First identify the plane of section of this slide. Identify the medial geniculate nucleus. What accounts for the difference in locations of the medial geniculate on this and the previous slide? Hint, take a look at the brain stem model. To what cortical area does this nucleus project. Follow the optic tract into the lateral geniculate nucleus.

X-65 Medial geniculate nucleus

Identify the medial geniculate nucleus. Reconstruct in you mind's eye the spatial relationships of the medial and lateral geniculate nuclei on this and the previous slide. Follow the auditory path to Heschl's gyri.

auditoryrad Auditory radiations

Key:

Primary auditory cortex (transv. temp. gyri; Heschl's gyri)=lavender/blue

Thalamus=purple

Projections from MGN to auditory cortex=yellow

X-70

Vestibular input terminates in the portion of the ventral posterior nucleus located ventral to the ventral posterior medial and lateral nuclei. The medial lemniscus also courses through this region, and as a consequence, is darkly stained in myelinated sections. Projection neurons in all regions of the ventral posterior nucleus send their axons into the posterior limb of the internal capsule to terminate in cerebral cortex. Contrast the locations of the somatic sensory and vestibular cortical projection.

B-15 Auditory cortex

The primary auditory cortex (A-I) is located in the two Heschl's gyri. The secondary auditory cortex (A II) is an area of temporal lobe cortex that also participates in perception of sound.

The secondary and higher-order auditory areas surround the primary auditory cortex. Wernicke's area, a higher-order auditory cortical area important in the reception of speech, is located caudal to the primary auditory cortex. The motor speech area, Broca's area, is located in the frontal lobe. Unlike most areas of the brain, Wernicke's and Broca's areas are not bilaterally symmetrical. In the majority of individuals, they are present in the dominant hemisphere only, which typically is the left hemisphere. The gross anatomy of the homotopic cortex contralateral to Wernicke's area is smaller (NTA Figure 7-10). Wernicke's area projects to Broca's area via a bundle of cortical association fibers, the arcuate fasciculus.

planum Planum temporale (movie)

Note the location of the auditory cortex (transverse temp. gyrus) on the dorsal surface of the posterior temporal lobe (planum temporale)

Key:

Insular cortex=yellow

Clastrum=aqua

Caudate nucleus=green

Rest of brain=brown

Key Structures and Terms:

Vestibular division of CN VIII

Vestibular ganglion

Vestibular nuclei

MLF

Ventral posterior nucleus

Posterior parietal cortex

Auditory System

Auditory division of CN VIII

Basilar membrane

Cochlea

Spiral ganglion

Dorsal and ventral cochlear nuclei

Superior olivary nucleus

Trapezoid body

Lateral lemniscus

Inferior colliculus and brachium

Medial geniculate nucleus

Heschl's gyri

Wernicke's area