THE COCHLEA AND AUDITORY PATHWAY

Objectives:

1. Trace the trajectory of a sound wave of a high note from the tympanic membrane to the production of a nerve impulse.
2. Contrast conduction deafness and neural deafness.
3. Describe where in the nervous system a lesion would have to be for a person to have deafness in the ipsilateral ear.
4. Explain why lesions of the auditory pathway are harder to localize and of less clinical value than those of the DCML system.
5. Two people have strokes in part of the distribution of the middle cerebral artery. One does not understand what family members are saying and the other understands but cannot answer. How can a lesion of the same artery produce such different results?
6. Describe the structures that could be affected and the clinical findings associated with an acoustic neuroma (benign Schwann cell tumor) on the VIII nerve in the cerebellopontine angle. Would it be different if it were in the internal auditory meatus? How?

I. General Anatomy of the Ear
   A. Position in the skull.
   B. Middle ear.
      1. Tympanic membrane.
      2. Ossicles=mechanical multipliers of tympanic membrane motion.
         a. Malleus
         b. Incus
         c. Stapes--attachment to oval window of inner ear.
   3. Middle ear muscles dampen sound, improve discrimination.
      a. Tensor tympani--attachment on malleus--acts to decrease sensitivity of the ear to loud sounds. (CNV)
      b. Stapedius--attachment to stapes--acts to decrease sensitivity. (CN VII)
   C. Inner Ear
      1. The bony labyrinth.
         a. Contains the watery perilymph high in sodium, which is in contact with the subarachnoid space. The membranous labyrinth is suspended in the perilymph inside the bony labyrinth.
         b. Oval window (which is closed by the stapes) leads into the vestibule, the middle part of the bony labyrinth.
         c. Anteriorly, the vestibule merges with the bony cochlea, which has the form of a 2-1/2-turn spiral cone.
d. Posteriorly, the vestibule merges with the bony semicircular canals.

2. The membranous labyrinth. Location of the sensory receptors
   a. Contains the viscous fluid endolymph, which is high in potassium.
   
   b. The bony vestibule itself contains two membranous vestibular sensory organs.
      (1) Saccule
      (2) Utricle
   
   c. Three bony semicircular canals emanate from the vestibule at right angles to each other; these contain the membranous semicircular ducts, which communicate with the utriculus and are filled with endolymph.
      
      c. The bony cochlea contains the cochlear canal in which sits the membranous cochlear duct filled with endolymph.
1. The perilymphatic space above the cochlear duct is the scala vestibuli, which opens onto the vestibule.
FIGURE 3  (A) Cross section through the cochlea. The cross section shows how there are approximately three turns in the human cochlea and that it spirals around a central core (modiolus) that contains the auditory nerve. (B) Cross section through one cochlear turn to illustrate important cell groups (organ of Corti), spiral ligament, stria vascularis, and spiral ganglion) and the main fluid compartments (scala vestibuli, scala media [shaded orange], and scala tympani). Within the organ of Corti, sensory cells (inner and outer hair cells) are shaded dark blue and are situated between the basilar and tectorial membranes, which move when sound stimulates the cilia. When these membranes cause motion of the stereocilia of the hair cells, the receptor current, a potassium ($K^+$) current, flows into the hair cells from the endolymph.

The high $K^+$ concentration and high electrical potential of the endolymph are created by the stria vascularis, and these factors increase the driving force for the receptor current. Supporting cells in the organ of Corti are shaded light blue; these cells form a network that is coupled by gap junctions and may recycle $K^+$ back to the stria vascularis. Also shown is the spiral ganglion, which contains cell bodies of the auditory nerve fibers.
3. The cochlear duct is separated from the scala vestibuli by the vestibular membrane. The scala vestibuli merges with the scala tympani at the helicotrema, which is at the apical tip of the cochlea. Thus the pressure wave is continuous and goes "up" the scala vestibuli from the oval window and down the scala tympani to the round window.

4. The **Organ of Corti**.

   1. Position in cochlear duct.
   2. Sits on basilar membrane.
      a. Its width varies along the cochlear duct. Influences discrimination. Membrane shorter at base (high tones) and wider at the apex (low tones).
      
      b. The spiral ligament=lateral attachment of basilar membrane.
      
      c. The stria vascularis forms the lateral surface of the cochlear duct and produces the endolymph high in K+.
3. Histology of Organ of Corti
   A. Supporting cells hold the sensory hair cells in position below the tectorial membrane.
   B. Inner and outer hair cells. Inner are more important and necessary for hearing.

1. Stereocilia of sensory hairs touch the tectorial membrane.

2. Afferent (95%) and efferent (5%) synaptic endings on outer hair cells form on base of cells. 95% of axons in auditory nerve innervate inner hair cells.

3. Outer hair cells appear to be contractile and change the stiffness of the basilar membrane in response to electrical currents.
II. Auditory Pathway

A. Organizing principles.

1. **Tonotopic organization**: there is a topographic map of the cochlea at each level of the ascending auditory pathway. This results in an orderly representation of sound frequencies (tones) at each level.
2. Because of the many crossing pathways, there is **bilateral representation** of the cochlea at most levels of the auditory system.
B Sequence of relays and processing of information

1. **Spiral ganglion neurons** innervate the inner and outer cochlear hair cells.
2. Medullopontine Junction: Cochlear Nuclei

A. All cochlear nerve fibers (axons of spiral ganglion neurons) make synapses on neurons in the ipsilateral cochlear nucleus.

B. Each entering axon forms an ascending and a descending branch as it enters the brain. Thus, two separate representations of the cochlea are formed in the cochlear nucleus.

1. The ascending branch forms synapses on neurons in the
dorsal cochlear nucleus.

2. The descending branch forms synapses in the ventral cochlear nucleus.

C. Different types of neuron in the two-cochlear nuclei send their axons through two major pathways to higher auditory centers.

1. The dorsal cochlear nucleus next to the inferior cerebellar peduncle, crosses the midline, and ascends in a tract called the lateral lemniscus. The axons carry information about the frequency spectrum of sound stimuli.

2. The ventral cochlear nucleus, also next to the inferior cerebellar peduncle and then join the lateral lemniscus

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3. Mesencephalon: \textbf{Inferior Colliculus}

A. Lateral lemniscal axons end in the ipsilateral inferior colliculus. Map of auditory space.

B. The inferior colliculus is involved in \textit{auditory reflexes} and sound localization.

C. Neurons in the colliculus project to the \textit{medial geniculate} body of the \textit{thalamus} through the brachium of the inferior colliculus.
4. Thalamus: Medial Geniculate Body

A. Medial geniculate neurons receive ascending auditory input from the brachium of the inferior colliculus.

B. Project to the ipsilateral transverse temporal gyrus of the cerebral cortex via the auditory radiations in the internal capsule. This is primary auditory cortex.
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III. Auditory Cortex

A. The primary auditory cortical region is located on the dorsal surface of the temporal lobe deep within the lateral fissure. Two prominent transverse temporal gyri (Heschl's gyri) receive the thalamocortical projections from the medial geniculate body.

B. Surrounding this primary auditory cortex are secondary auditory association areas in the temporal lobe.

C. As elsewhere, there are extensive projections from primary and secondary auditory cortical areas to various association areas of neocortex.

IV. Association Areas - The Posterior Superior Temporal Lobe and Language Function

A. The posterior superior temporal lobe (area 22) Unlike the primary auditory cortex, it is not activated by simple auditory stimuli (e.g., tones or clicks) but during language comprehension tasks that involve auditory or phonetic processing and short-term memory of words. We call this Wernicke’s area

B. Aphasia: an impairment in language or communication

1. Comprehension
2. Production, verbalization, fluency
3. Writing
4. Reading
5. Signing
C. Two major types of Aphasia result from strokes in dominant hemisphere.

1. **Receptive or sensory aphasia** typically involves damage of the posterior part of the **left superior temporal gyrus**. This is also called **Wernicke's aphasia or Wernicke's area**. Other terms are fluent aphasia since they produce words but they often use the wrong words or unrelated words. Sometimes described as “word salad”. Grammar is intact. Don’t understand what they are saying, what you say or what they hear or read.

2. **Expressive aphasia** is **non-fluent**. The patient understands but has difficulty speaking. Typical of frontal **motor cortex lesions** particularly in the **inferior frontal gyrus or Broca's area**. Very frustrating and often only expletives come out.

3. **Conduction Aphasia** involves the arcuate connections between the two areas. Can usually comprehend.

4. **Global aphasia** affects all areas such as a massive middle cerebral artery occlusion.)
D. The planum temporale, which is the portion of the dorsal surface of the temporal lobe just posterior to the transverse gyrus (primary auditory cortex),

1. Is normally about one-third larger in the language-dominant hemisphere (the left hemisphere in 97% of people)?
2. Unlike the primary auditory cortex, is not activated by simple auditory stimuli (e.g., tones or clicks) but is activated during language comprehension tasks that involve auditory or phonetic processing of words