Sound Overview:
How do we hear sound? (process of transduction)
Ear traps energy of external pressure waves ➔ pressure is converted into movement of bones, membranes, and fluids ➔ specialized mechanoreceptors convert fluid movement into an electrical signal ➔ this electrical signal is transported by the Vestibulocochlear nerve (VIII) to the brain to be processed by higher centers

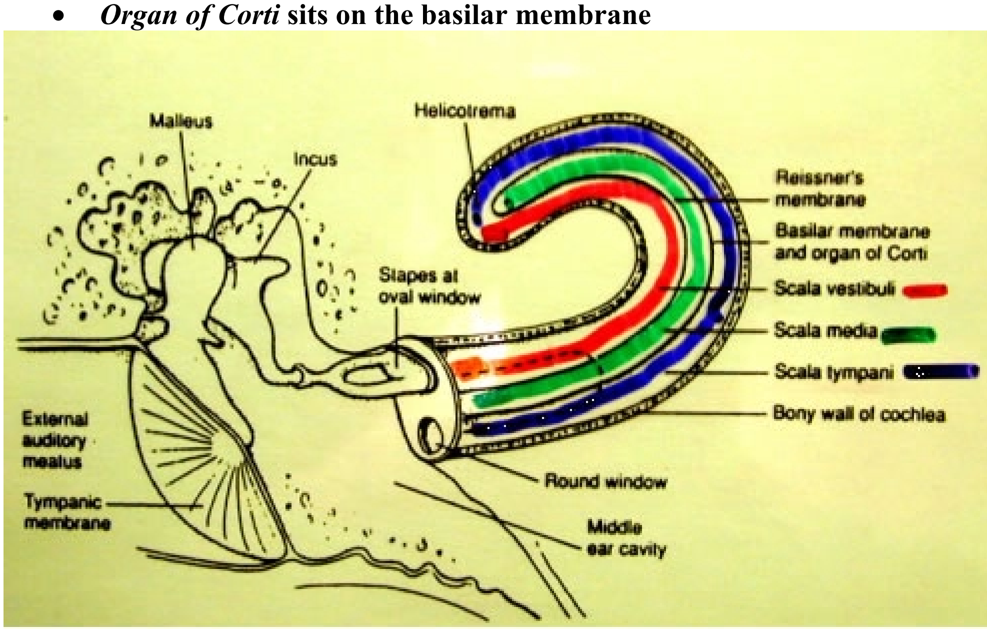
Sound Transduction Anatomy: Sound is the body's way of measuring pressure waves
Frequency (cycles per second) determines pitch – 16Hz – 20,000 Hz is range for normal human ear, with range decreasing with age
Intensity (amplitude of waves) determines loudness – human ear has a range of 120 dB, a jump of 10-fold greater pressure is a jump of 20 decibels (0 dB is barely audible)
Any pressure wave signal can be decomposed into a combination of sine waves of different frequency and amplitude

Outer ear – collection of sound (*pinna* is the funnel, *external acoustic meatus* is the canal)
Middle ear – amplification of sound
Pressure waves hit the tympanic membrane (ear drum) ➔ transmits pressure to malleus (hammer) ➔ incus (anvil) ➔ stapes (stirrup) ➔ oval window ➔ fluid of cochlea (inner ear)

- Structure of the middle ear overcomes air-fluid interface energy loss and deflection by:
    1) AREA – tympanic membrane is 17 X larger than the oval window, so energy is concentrated on oval window
    2) LEVER ACTION – of hammer, anvil, and stirrup increase nrg transfer by 1.7 X

Eustachian tube protects the tympanic membrane from large changes of pressure
Inner ear – transduction and signal analysis of sound
Cochlear anatomy: Oval Window ➔ Scala Vestibuli (perilymph) ➔ Helicotrema ➔ Scala Tympani (perilymph) ➔ Round Window

- Scala Media (endolymph) runs down the middle and is separated from the Scala Vestibuli by the *Reissner's Membrane* and the Scala Tympani by the *Basilar Membrane*
- ***Organ of Corti* sits on the basilar membrane**



- The whole cochlea does 2.75 turns, wrapping around a central part called the *modiolus*

- Inner ear fluids: **Scala vestibula and tympani** are continuous tubes that contain **perilymph** (similar to CSF), and **Scala media contains endolymph** (similar to intracellular fluid, high in K+)
    - Clinical Note: **Disruption in flow of endolymph can result in Meniere's Disease** (increased pressure within membranous labyrinth – **both vestibular and auditory problems**)

Hair Cells: receptors which transduce fluid movement in cochlea ➔ movements of the basal membrane ➔ electrical impulses

- At free end, hair cells have **sensory hairs (*stereocilia*)** which extend into perilymph and are attached to the *tectorial membrane*
- At their basal end, hair cells have **afferent nerve connections**, and are attached to the basilar membrane
- **Bending of stereocilia controls release of glutamate** onto afferent nerve endings of CN VIII ➔ electrical conduction
- Area of basilar membrane close to oval window **(base) vibrates best at high frequency** – short and stiff
- Area close to helicotrema **(apex) – vibrates best low frequency**, wide and floppy
- Pressure causes whole basilar membrane to vibrate and forms a traveling wave (like a snapping rope)
- **Inner hair cells – primary sound transduction:** ~3,500 per cochlea, 90% of cochlear fibers come from here, 10 fibers/hair cell, each fiber only enervates one hair cell, most fibers respond best to one frequency
- **Outer hair cells – selective frequency response, otoacoustic emissions (sounds emanating from ear**): ~15,000 per cochlea, 10% of cochlear fibers, each fiber enervates several hair cells

<u>The Sound Transduction Neuronal Pathway: (just know the basics)</u>

Vestibulocochlear Nerve: consists of axons of primary sensory neurons

1) Vibrations of hair cells ➔ nerve sensory endings
2) Sensory endings ➔ nerve cell bodies (in *spiral ganglion* of cochlea)
3) Spiral ganglion axons travel in CN VIII ➔ *internal acoustic meatus* ➔ *cochlear nuclei* (brain stem at the ponto-medullary junction) ➔
    - Signals are sent to both dorsal and ventral cochlear nuclei
    - Tonotopically organized (medial – high frequency, lateral – low frequency)
4) Cochlear nuclei ➔ *superior olivary nucleus* AND ➔ lateral lemniscus ➔ *inferior colliculus*
    - Some cells from the cochlear nuclei project to the ipsilateral superior olivary nucleus
    - Other cells project through trapezoid body to the contralateral superior olivary nucleus
    - Also, superior olivary nucleus ➔ ipsilateral lateral lemniscus ➔ ipsilateral inferior colliculus
5) Thus, the inferior colliculus receives input from **both the cochlear nuclei and the ipsilateral superior olivary nuclei**
6) **Also, each superior olivary nucleus receives input from both ears**
    - Sound localization occurs here – **medial** portion compares **time of arrival** of signal; **lateral** portion compares **sound intensities**
7) Inferior colliculus ➔ *brachium* ➔ *medial geniculate nucleus of the thalamus*

8) Medial geniculate ➔ internal capsule ➔ ipsilateral *superior temporal gyrus (primary auditory cortex)*
   - Medial processes Music (Hearing), Lateral process Light (Visual)
   - Sound localization: Sounds in Left Space – Right brain processes and vice versa (however, only a large lesion will impede sound localization)

So, in summary: hair cells ➔ spiral ganglion of cochlea (cell bodies) ➔ cochlear nuclei ➔ superior olivary nucleus AND inferior colliculus ➔ medial geniculate of thalamus ➔ superior temporal gyrus (primary auditory cortex)
Please read pts 4 -6 for more certain unique parts of the pathway between cochlear nuclei ➔ medial geniculate

<u>Hearing Loss:</u>
Conductive – mechanical problems (pressure waves are not conducted to hair receptors)
- E.g. external ear obstructions (wax), middle ear obstructions (otitis), otosclerosis (progressive hearing loss)
- Symptoms: deafness, tinnitus (ringing or crackling sound), speech is soft, negative Rinne's test

Sensorineural – transduction and nerve problems (PNS cannot conduct signal to CNS)
- E.g. degeneration of hair cells (presbycusis -- high frequency hearing goes first), lesion of cochlear nerve (acoustic neuroma – Schwannoma)
- Symptoms: deafness, tinnitus, dizziness, speech is loud, positive Rinne's test

Central – CNS damage
- E.g. lesion at primary cortex, Wernicke's area, or seizure in temporal lobe

<u>Hearing Tests:</u>
Weber's Test – if tuning fork sound is diminished in bad ear (sensorineural problem), if sound is louder in bad ear (conduction problem)
- Gallman's humming example (stick finger in ear and hear it sound louder)

Audiometric Tests
1) **Stapedial Reflex** (acoustic reflex) – loud noise in healthy ear elicits contraction of stapedius muscle (tests if CN VII which enervates stapedius is functioning)
2) **Otoacoustic Emissions** (OAE) – healthy ear hair cells contract to pressure waves and generate a sound (sound coming FROM ear!) – tests if auditory pathway is intact up to outer hair cells
   - Used to differentiate between sensory and neural source of hearing loss, as well as to detect malingering
3) **Brainstem Auditory Evoked Responses –** a click sound is used to evoke potentials which are recorded by electrodes on the head
   - Used to locate source of hearing loss, screen infants for deafness, and monitor brain stem health during surgery