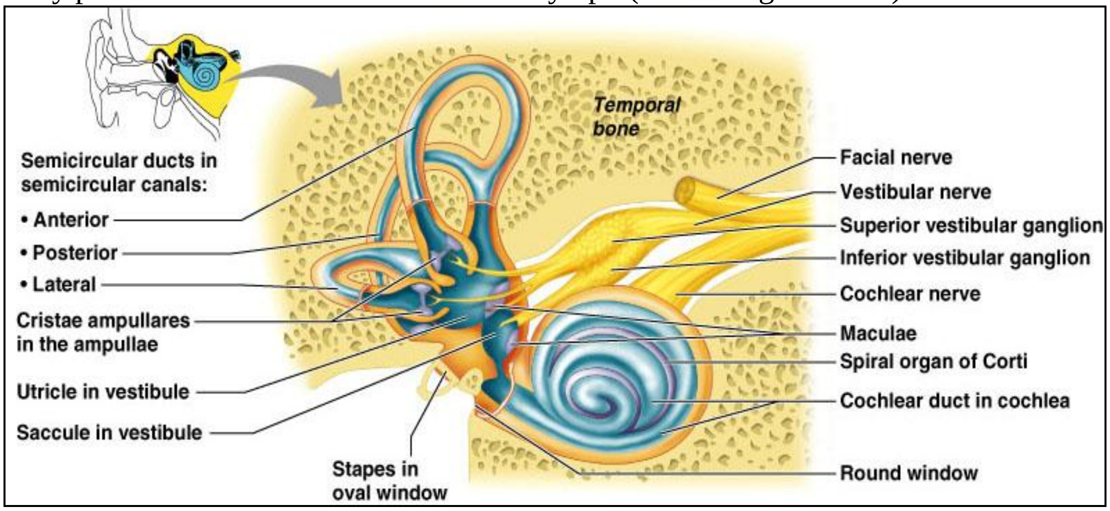
Unit VIII – Problem 9 – Physiology: Hearing

- **We can hear a limited range of frequency between 20 Hz – 20,000 Hz (human hearing acuity is between 1000 Hz – 4000 Hz).**
- **The ear is divided into 3 parts. Those are:**
  - External ear.
  - Middle ear.
  - Internal ear.
- **There is a difference between reptile ear and a mammal ear:**
  - **In reptiles**: there is only one bone in the middle ear cavity which is connected to the stapes.
  - **In mammals**: this bone was pushed further inside the middle ear cavity and converted to 3 bones (auditory ossicles: malleus, incus and stapes). These 3 small bones help us in hearing higher frequencies.
- **Pressure is produced in the air when it is conducting sound waves to the ear**. This air pressure must be very high so it can generate vibrations in the fluid which is present in inner ear → therefore, sound it conducted and heard. For this purpose, the pressure produced by sound waves is augmented through:
  - **The tympanic membrane**: which is X17 time bigger in its surface area than the oval window.
  - **Auditory ossicles** also augment sound waves (but not as much as the tympanic membrane does). They are magnifying sound waves only X1.3 times more.
- **There are 2 muscles in the middle ear:**
  - **Tensor tympani**: which is connected to the tympanic membrane and innervated by mandibular branch of the trigeminal nerve.
  - **Stapedius**: which is connected to the oval window and innervated by the facial nerve.

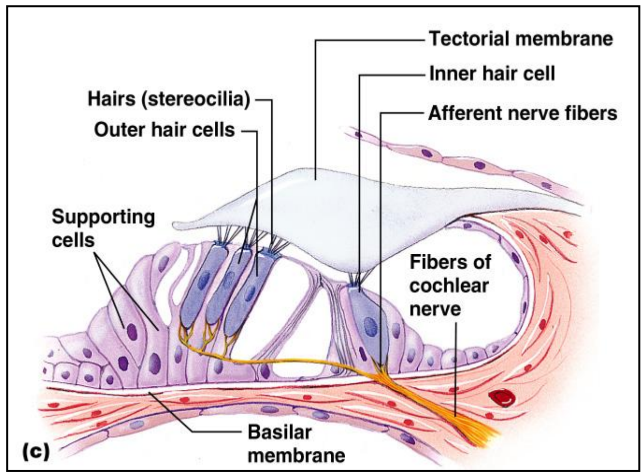
    Notes:
    - ✓ *When both of these muscles contract* → auditory ossicles will stick to each other and the tympanic membrane will become tense → thus, sound transmission is decreased (this is especially occurring with self-produced sound which is high and can affect hearing → this explains why we don't recognize our actual voices when hearing them in recordings!).
    - ✓ *In Bell's palsy (7^{th} CN)* → there is paralysis of stapedius muscle → there is no reduction in transmission of sound → therefore, patient will have hyperacusis.
- **Each sound wave is characterized by:**
  - **Frequency**: which is representing the number of waves per second (measured in Hz) and is equal to "pitch".
    - ✓ The frequency produced is different in babies, males and females due to the difference in their vocal cords. Therefore, we can say that frequency is representing the origin of the sound.
  - **Amplitude**: which is representing how much pressure is applied by the sound waves on the tympanic membrane (measured in dB) and is equal to "loudness".
    - ✓ dB = $\frac{\log(10) x \text{ sound intensity}}{\text{intensity of standard sound}}$
    - ✓ "zero" dB means that the sound intensity is equal to the intensity of the standard sound (it doesn't mean that there is no sound!).
- **The inner ear has:**
  - **A bony part**: which is composed of channels in the temporal bone filled with perilymph (containing more Na^+). These channels are present in 3 regions:
    - ✓ Vestibule.
    - ✓ Semicircular canals.
    - ✓ Cochlea.

- **A membranous part**: which is a series of membranous sacs and ducts within the bony part of the inner ear filled with endolymph (containing more K^+).



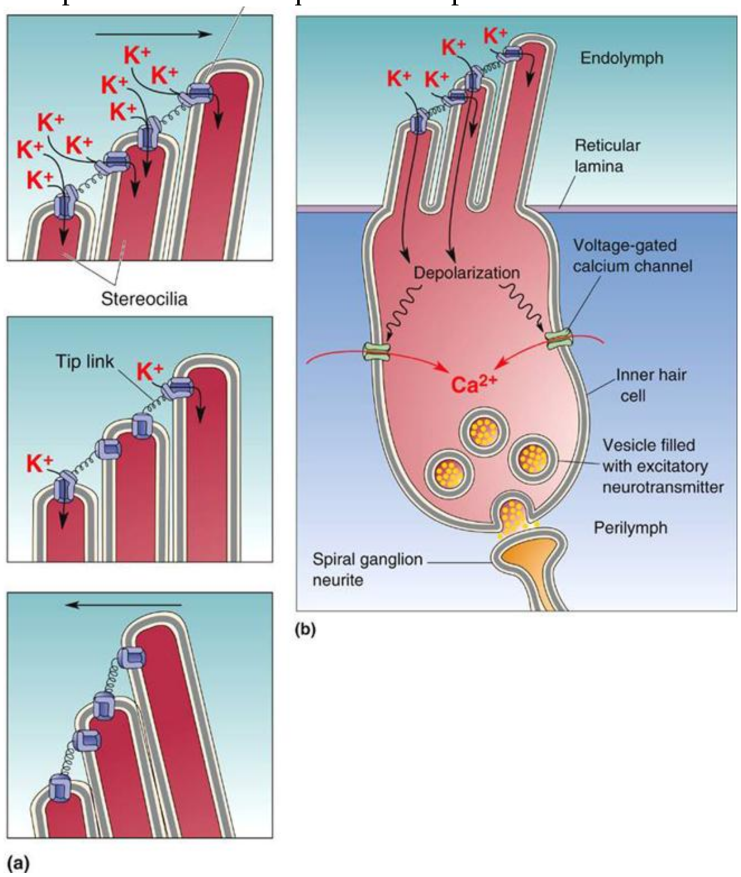
- **The tube of the cochlea is divided into 3 cavities by 2 membranes (basilar membrane and Reissner's membrane). These cavities are:**
  - **Scala vestibule.**
  - **Scala media.**
  - **Scala tympani**

    Note: both scala vestibule and scala tympani contain perilymph while scala media contains endolymph.

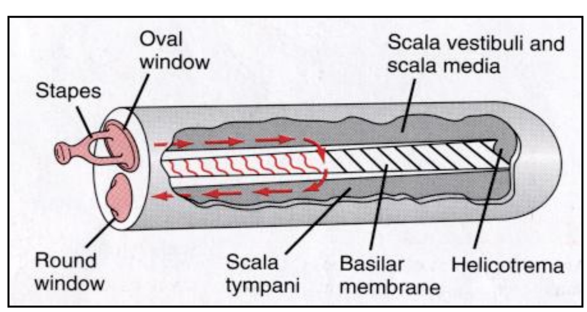


- **The endolymph contains a lot of potassium ions** which are needed to cause depolarization of inner hair cells (one of the rare areas in the CNS in which depolarization is caused by influx of potassium ions).
- **Hair cells are divided into outer and inner hair cells** (16,000 hair cells from which 3,500 are inner hair cells). The tectorial membrane is present above (at the superior aspect) these cells. Stereocilia of outer hair cells are piercing the tectorial membrane but stereocilia of inner hair cells do not.
  - **Notice that hearing is produced by inner hair cells**. Outer hair cells only aid in sharpness of sound by bringing the tectorial membrane very close to inner hair cells and thus the process of hearing occurs more easily.
  - **Arrangement of hair cells**: a single row of inner hair cells and 3 rows of outer hair cells.
  - **There are supporting cells under inner and outer hair cells. These supporting cells are:**
    - ✓ Phalangeal cells.
    - ✓ Pillar cells.
- **Notice that when there is any defect in hearing process** → this will render you unable to hear and understand the word which is spoken (you cannot correct it). In contrast, a defect in vision can be corrected (example: when you are reading a text → and the fovea doesn't catch a word → you can go back to that word and focus the fovea on it so you can read it).
- **Hair cells have a response to minute stimuli (they respond to a movement of 1 atom!)** so the stimulus will cause movement of hair cells and release of neurotransmitters by them → generating an action potential which must be rapidly conducted within 10 msec → so another stimulus (another sound wave) can come and repeat the process.

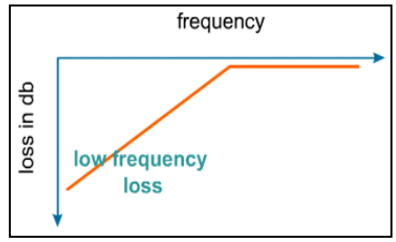
- **In the process of hearing → response is produced by ion-changes** (there is no secondary message system which is consuming more time). Depolarization and repolarization produced by ion changes is a passive mechanism in which energy is not needed/consumed (very effective mechanism).
- **The number of inner hair cells (which are responsible for hearing) is only 3500** (as mentioned previously). These cells are very specialized with good anatomical modifications.
- **Stereocilia of inner hair cells are attached to each other by mechanical (spring) gates** → when there is movement and they are pulled toward the longer stereocilia → this results in opening of K^+ channels leading to influx of potassium ions → then, there will be immediate closure of K^+ channels (even if stereocilia are still bending) → and this aims in preparing inner hair cells for the next stimuli.
- **Inside hair cells, there are voltage-gated calcium channels which facilitate influx of Ca^{++}** (when depolarization occurs) that is needed for the release of excitatory neurotransmitter from storage vesicles.
- **Stereocilia of hair cells are projected in endolymph** (which is present in scala media and contains a lot of potassium ions required for depolarization of these cells).



- **When outer hair cells contract** → the tectorial membrane is brought down → resulting in increased sharpness of sound.
- **Most of the sensory afferent fibers of cochlear nerve (8th CN) are projecting from inner hair cells (Why?)** → because they are the ones which are responsible for hearing.
- **When a person is talking, how do you know who is he?** → according to the frequency of sound generated by this specific person:
  - **Sound with low frequency** causes bending at the apex of basilar membrane (where it is very thin).
  - **Sound with high frequency** causes bending of basilar membrane at the base (where it is thick).



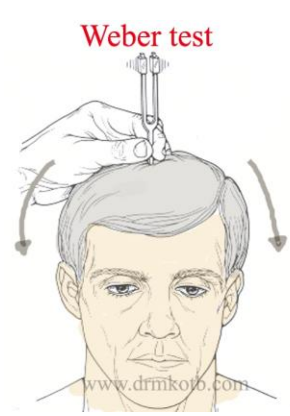
- **Cochlear implant** → a special wire is implanted in the inner ear and connected to external headphones which will detect sound waves and convert them into electrical stimuli which can be transmitted by the auditory/ cochlear nerve to the cortex.
  - **Notice that this technique is not useful if the auditory nerve is damaged.**
- **When someone is shouting** → the sound waves will become bigger → and thus exerting a bigger displacement of the basilar membrane → resulting in stimulation of multiple areas of the basilar membrane (notice that each area is responsible for a specific frequency) → so the other person will be unable to differentiate the voice of the person who is screaming (no specific frequency is stimulated).



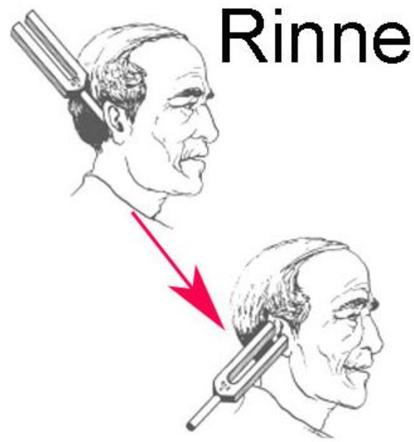
- **In audiogram** → if there is a point on the lower portion of the line → this indicates that the person is suffering from hearing loss.
- **Every part of the basilar membrane is connected along the pathway through one neuron. The firing rate of the neurons decide the intensity of the sound**.
- **Sensory neural hearing loss is a result of a lesion in the following structures:**
  - Cochlea.
  - Cochlear nerve.
  - Or cochlear nucleus.

    Note: after these structures, any lesion will not result in sensory neural hearing loss because of bilateral supply and interconnections.
- **The mandatory stops of the auditory pathway are:**
  - "**C**ome **I**n **M**y **B**ird":
    - ✓ Cochlear nucleus.
    - ✓ Inferior colliculus.
    - ✓ Medial geniculate body.
    - ✓ Brodmann's area 41 (auditory cortex).
- **Superior olivary nucleus is the structure which is functioning in sound localization**. It is the first station in auditory pathway which is receiving biauricular information (from both ears). Notice that superior olivary nucleus is connected to inferior olivary nucleus which is responsible for orientation toward the sound.
- **Evoked potentials**: different frequencies are heard by the person/baby and then we check if these information are reaching the auditory cortex or not → therefore, knowing if the person/baby can hear or not.
  - **Evoked potentials are mainly used to detect the presence of a brainstem tumor or multiple sclerosis**.
- **Deafness: it is divided into 2 types:**
  - **Conductive deafness**: in which there is a cause preventing augmentation or transmission of sound in external and middle parts of the ear (the causes include: earwax, perforated eardrum, otitis media and otosclerosis of the ossicles).
  - **Sensory neural deafness**: when there is a lesion from the cochlea all the way up along the auditory pathway.

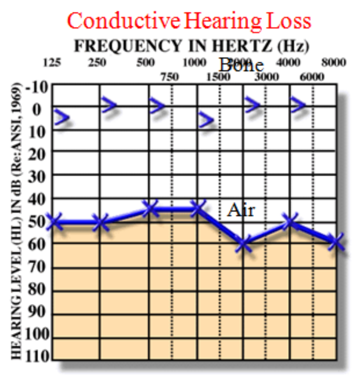
    Note: tinnitus is ringing/clicking sound in the ears in the absence of auditory stimuli.
- **Weber's test (see the image):**
  - **If the person is normal**: he will hear sound from both sides.
  - **If the patient has conductive hearing loss in one ear**: he will hear more sound from this affected ear.
  - **If the patient has sensory neural hearing loss in one ear**: sound will be heard more from the opposite (normal) ear.

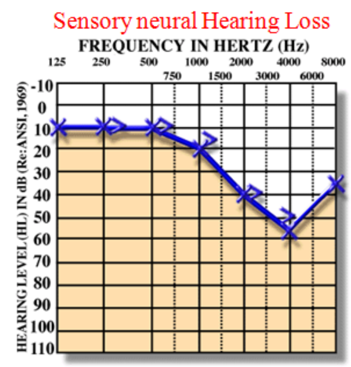


- **Rinne test**: using the vibrating tuning fork → you place it first on the person's mastoid and ask the person to raise his finger as soon as he stops hearing the sound → then immediately you place the tuning fork near the air:
    - **If the person is normal**: air conduction must be longer than bone conduction.



- **Plotting results on audiogram:**
    - **If you notice the presence of gaps in audiometry** → this indicates that the patient has conductive hearing loss. There will be loss of almost all frequencies because they are not reaching the cochlea.
    - **If there are no gaps in audiometry** → this indicates the presence of sensory neural hearing loss.





- **Menieres disease**: resulting from increase in the fluid of endolymph which leads to:
    - **Tinnitus of high frequency sounds.**
    - **Hearing loss of low frequency sounds.**
- **Sound localization:**
    - **High frequency sound is detected by intensity difference** → then going to lateral part of superior olivary nucleus.
    - **Low frequency sound is detected by timing difference** → then going to medial part of superior olivary nucleus.
- **The primary auditory cortex** is divided into strips, each is representing an area with specific frequency in the basilar membrane. In addition, each strip is receiving information from 1 receptive field.
- **Secondary auditory cortex is differentiating between phonemes.**
    - **Phonemes which are not heard from birth will be deleted and this explains why people with different languages cannot pronounce specific letters.**