Physiology 435 team

PHYSIOLOGY OF HEARING

- Describe sound characteristics and explain the **difference between discrimination of loudness & pitch (tone)**
- Describe the steps involved in transmission of sound waves into **neuronal activity in the inner ear.**
- Differentiate between the functions of the **inner and outer hair cells**
- Appreciate that deafness can be caused by defects in either **conduction or neural processing** of sound waves

Done by:

- **Team leader:** Shahad AlEnezi - Omar AlOtaibi .
- **Team members:**
  Norah AlRomaih - Raghad AlMansour - Dania AlHendawi - Munira Alhussaini
  Abdulaziz Alhammad - Wael Aloud - Ammar Almansour - Abdulrahman Alsayyari.

Edited by: Shahad AlEnezi.

Revised by: Norah AlRomaih - Shahad AlEnezi.

Revised by
خولة العماري & هشام الغفيلي

Color index: Important - Further explanation - Doctors Notes - Numbers.

*Please check out this link before viewing the file to know if there are any additions or changes.

**"for better understanding" we advise you to study the "anatomy of the ear" lecture, before studying this lecture.

Introduction:

❖ Our ears not only let us detect sounds, but they also help us maintain balance. Receptors for two sensory modalities (hearing and equilibrium) are housed in the ear. So **the Functions of the ear:**

1. **Hearing (parts involved):**
    a. **External ear.**
    b. **Middle ear.**
    c. **Internal ear** (cochlea).

*The external & middle ear transmit sound waves to the inner ear(Cochlea)

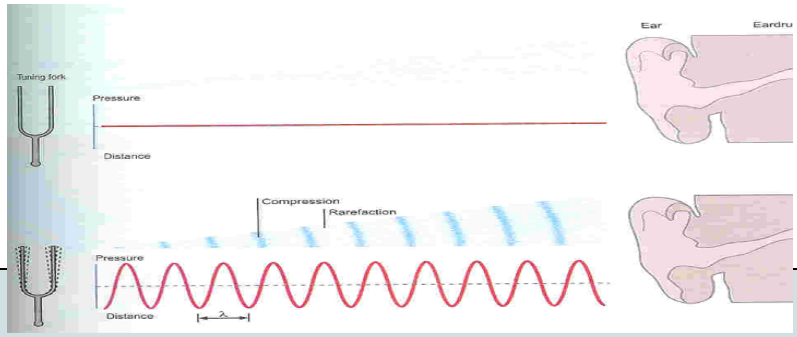
2. **Equilibrium sense (parts involved):**

Internal ear. (semicircular canals, the utricle and the saccule)

Nature of the sound:

- Sound is produced from alternate **compression** and **rarefaction (expansion)** of air molecules by vibrating body. vocal cords also produce rarefaction and compression.
- Sound is a mechanical wave (travelling vibration of air).
- **Sound intensity (loudness) is measured in decibels(dB).**
- Hearing sensitivity is 15-20 dB less in absence of ossicularsystem and tympanic membrane.

A vibrating tuning fork is capable of creating such a longitudinal wave. As the tines of the fork vibrate back and forth, they push on neighboring air particles. The forward motion of a tine pushes air molecules horizontally to the right and the backward retraction of the tine creates a low-pressure area allowing the air particles to move back to the left.



Characteristics of sound:

Any sound considered with reference to its quality, pitch, strength,source, etc

1- **Pitch (Tone)** <u>depends on</u> **number of cycle/sec**. Human ear can detect sound waves with frequency 20-20000 cycle /sec.

★ Note: Any sound less than 20 cycle/sec or more than 20000 cycle/sec the human can not hear it.

مثل طيارة الكونكورد لما تقلع، راح نحس بالارض تهتز لكن ماراح نسمع اي صوت لأن ترددها اعلى من ٢٠٠٠٠

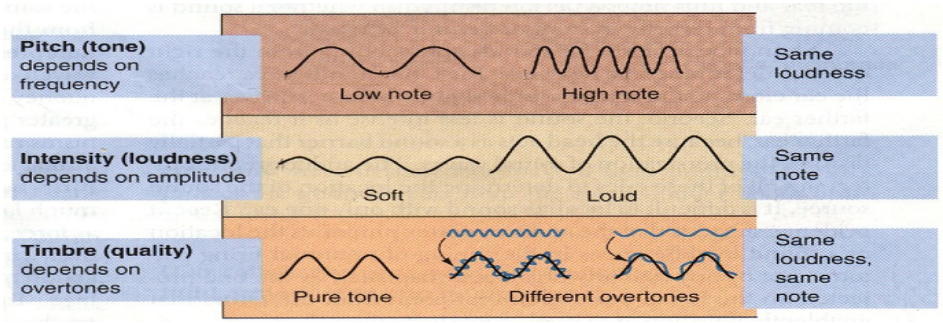
2- **Intensity** (Loudness) <u>depends on</u> **amplitude**[1].low amplitude = soft, high amplitude= high.

3- **Quality** <u>depends on</u> the **overtone** or **interference**.

المقصود بجودة الصوت: هل الصوت صافي أم متداخل؟

تتضح هذه الخاصية لمن "نزكم".. بيكون فيه secretions على الأحبال الصوتية..

فلمن نتكلم وتتحرك بتعطينا أكثر من تردد وبتخلي الصوت مو واضح.. ولو نلاحظ اننا نعالج هالمشكلة باننا "نتنحنح" علشان يضبط الصوت ويرجع طبيعي.. بهالحركة بعدنا الـ interference اللي سوت sectretions



1-External ear:

❖ Components:

1- Pinna. (provide clues about location of the sound)

2- External auditory canal (External auditory meatus)**.**

3-Tympanic membrane "ear drum"(funnel[2] shaped, Pointing inward), the tympanic membrane is not straight, but it is pointed inward for **maximum efficiency of transferring the sound**.

For the eardrum to move freely, the resting air pressure on both side must be equal.

❖ Functions:

[1] The **amplitude** of a periodic variable is a measure of its change over a single period (such as time or spatial period). السعة

[2] قمع.

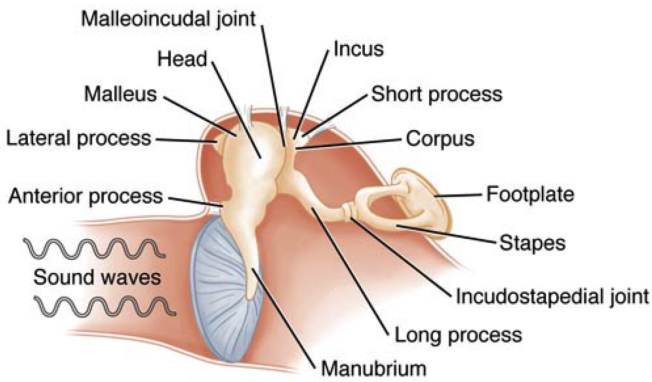
1. **Act as funnel to collect sound (Gathers and focuses sound energy on tympanic membrane (ear drum))** (with the middle ear to transmit it to the inner ear)
2. **Sound localisation**(front,back,high,low)**.** *function of pinna*
3. **Protection** . Earwax is produced by special glands in the skin on the outer part of the ear canal. It protects the skin of the human ear canal, assists in cleaning and lubrication, and also provides some protection from bacteria, fungi, insects and water.

the ear hair also filtrate the entering air from dust

2-Middle ear:

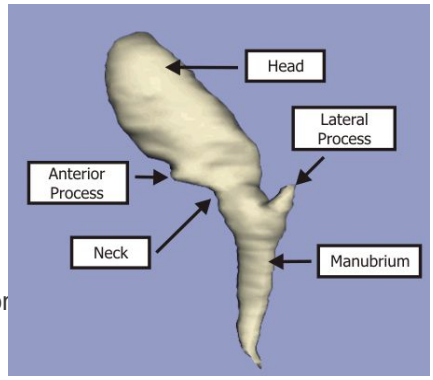
❖ What is "Middle ear"?

- An air filled cavity that is located between tympanic membrane and the inner ear.
- It opens via **Eustachian tube** "Pharyngotympanic tube\ Auditory tube" **into nasopharynx** "Anterior relation".Air pressure is highest nearer the ground. So as a plane descends, the air pressure becomes higher. This pushes the eardrum inwards which can be painful. To relieve this, the pressure inside the middle ear has to rise quickly too. Air needs to travel up the Eustachian tube into the middle ear to equalise the pressure



❖ Content:

1. **Air.**
2. **Ossicles:**
   - **Malleus[3].**
   - **Incus.**
   - **Stapes.** (with its foot sitting on the oval window of the inner ear.)
   - Manubrium of the **malleus[4]** attached to the back of the tympanic membrane and its short process attached to the **incus**.
   - The **incus** then articulates with the head of the **stapes**, and its foot plate attached to the oval window.
   - Ossicles Amplify vibrations of tympanic membrane to oval window



[3] Malleus means hammer. It was named for its resemblance to the hammer.
[4] the handle of the malleus; the portion that extends downward, inward, and backward fror
embedded throughout its length in the tympanic membrane.

- This is needed for movement of sound waves in the fluid of the inner ear

3. **Muscles:**
   - **Tensor tympani.**
   - **Stapedius.**

❖ Functions of the middle ear:

1- Protection effect against constant loud noise- Muscles:

- These Muscles contract **reflexly** in response to loud sound (over **70dB**[5]**)**, thereby reducing the transmission of sound to the inner ear. This is called "the acoustic reflex or tympanic reflex".
  - **How?**
    - Contraction of the **tensor tympani** pulls the manubrium & makes the tympanic membrane tensed, Thus **decreasing** the vibration.
    - Contraction of the **stapedius** pull the foot plate outward, so that vibration are reduced. the connection will be interrupted

★ Explanation:

When a high-intensity sound stimulus is presented, the stapedius and tensor tympani muscles of the ossicles contract. The stapedius stiffens the ossicular chain by pulling the stapes of the middle ear away from the oval window of the cochlea and the tensor tympani muscle stiffens the ossicular chain by loading the tympanic membrane when it pulls the malleus in toward the middle ear. The reflex decreases the transmission of vibrational energy to the cochlea, where it is converted into electrical impulses to be processed by the brain.

- **They provide:**

  protection from constant loud noise, but **not** sudden noise, latency [6]of 40-80 msec.

2- Middle ear magnifying [7]effect:

1. **The force** from a large surface area (**Tympanic membrane**) are concentrated to a small (**oval window**).

   the ratio is 17/1

حجم tympanic membrane اكبر من oval window ب١٧ مرة، عشان كذا لما توصل الموجات الصوتية للاوفال بتكون متركزة بشكل كبير عليها . فتكون العلاقة بين المساحة والقوة عكسية.

2. **Lever action of ossicles** = the lever action of ossicles **increase** the force of movement 1.3 times.

السبب الثاني الي يساعد في انتقال الحركة وارتفاعها هو اختلاف احجام العظام الثلاث. فلما تنتقل من العظمة الكبيرة الى الصغيرة بتكون الحركة اعلى

▲ **the total increase** 17 X 1.3 = 22 times.

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[5] decibel (ديسيبل)

[6] Latency is the delay from input into a system to desired outcome. تحتاج من 40 إلى 80 ميلي سكند حتى تظهر

[7] Make (something) appear larger than it is.

3- Transmission of sound through the middle ear:

Sound waves vibrate the tympanic membrane → Tympanic membrane moves the handle of malleus → Incus moves → Stapes move in & out of the oval window → The pressure transmitted through cochlea cause stimulation of hair cells in the organ of corti, which will stimulate the auditory nerve.

Hearing sensitivity is 15 - 20 dB less in absence of ossicular system and tympanic membrane

How Sound is Transferred to the Inner Ear (Duration: 11:35)

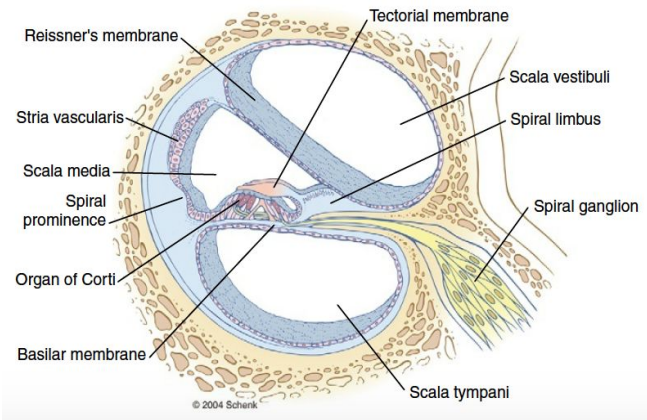
3-Inner ear:

❖ Anatomy:

- Bony labyrinth.

- Membranous labyrinth.

- cochlea. (snail like, coiled fluid-filled tubular system lying deep in the temporal bone.)



❖ Functions:

- **Transduction:** convert sound wave to nerve impulses
- **Transmission:** send auditory signals to the CNS

❖ Cochlea:

- **What is it ?**
- **It is a system of three coiled tubes through its length .**
- Contains the hearing sensory organ (organ of corti)
- The basilar membrane & the Reissner's membrane[8] divide it into three canals:
  - **Vestibular membrane:** separates **scala media** from **scala vestibuli** (very thin).(is removed) and does not obstruct passage of sound vibrations
  - **Basilar membrane:** separates **scala media** from **scala tympani.**

[8] Also called vestibular membrane

- **Tectorial membrane:** attached to the **stereocilia** of hair cells.

-

		1-Scala Vestibuli	2- Scala Media "cochlear duct"	3- Scala Tympani
composition	Na	high	low	high
	K	low	high	low
	Similar to	Similar to the ECF	Similar to the ICF	Similar to the ECF

A way to remember : as you can see in the picture that the three canals look like burger, scala vestibuli and tympani are the bread and (scala media) is the beef inside them (ICF) .

The scala vestibuli and scala media are considered as one chamber, as far as fluid movement is concerned.

★ Note : the difference between inner and middle ear is that the inner ear is fluid filled cavity otherwise the middle ear is air filled cavity .

- **The cochlear canals contain two types of fluid:**
  1. **Perilymph:**
     - Found in scala vestibuli and scala tympani.
     - Has a similar ionic composition as extracellular fluid found elsewhere.
     - The main body of hair cells & support cells are bathed in perilymph
  2. **Endolymph:**
     - Found inside the **cochlear duct** (scala media).
     - Has a unique composition not found elsewhere in the body!!
     - Is very rich in K+(150mM), very poor in Na+(1mM) and almost completely lacking in Ca2+ (20-30 μM).
     - Has a similar ionic composition as intracellular fluid which unique and not found elsewhere in the body.
     - Only stereocilia of the hair cells are bathed in endolymph.
     - The hair cells have a resting membrane potential of -60mV which favours an influx of K+.

❖ **Organ of Corti :** (Guyton 12th edition Page 636)

- **The hearing sense organ is located in scala media, resting on(on top of) the basilar membrane** and it is extended from base to apex .

- This structure **contains** highly specialized auditory receptors called: **inner & outer hair cells** (stereocilia).
- Supporting cells

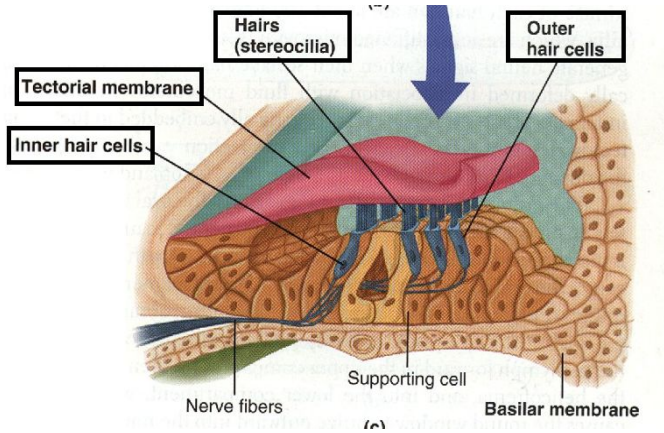
❖ Hair cells:

- Highly specialized auditory receptors located in the organ of corti.
- Hair cells (receptors) act as neurons but are not neurons themselves!
- ~17500 hair cells within each cochlea
- **Arrangement:** arranged in 4 rows
  - **Three** rows of **outer** hair cells, innervated by **C-fiber** afferents (type-2)
  - **One** row of **inner** hair cells, innervated by **A-fiber** afferents (type-1).

❖ About 95% of afferents are type 1 and the other 5% are type 2.

❖ Protruding from surface of each hair cell are up to 100 hairs (stereocilia)

❖ Stereocilia Move collectively as a unit



- **Types:**

1- Outer hair cells:

- Stereocilia is **attached** to the reticular lamina \ tectorial membrane.

-Functions of the outer hair cells :

- Large number, but stimulate only small fraction of nerve fibres in the cochlear nerve .
- Do not signal the brain about incoming sounds
- They amplify motion of the basilar membrane
- Can rapidly alter their **length** in response to changes in **membrane potential** resulting from sound vibrations (shorten on depolarization and lengthen on hyperpolarization).
- Amplify motion of the basilar membrane
- If damaged, significant loss of hearing.
- they control the **sensitivity** of inner hair cells to particular sound frequency.

قلنا أن OHCs يتحكمون بالترددات اللي داخلة اذا بتحس فيها IHCs او لا. كيف؟ عن طريق التحكم بقوة شد basilar membrane. اذا كان BM مشدود راح تكون IHC مرتفعة بالتالي بتحس بالموجات الجاية وتحولها لكهرباء. أما اذا كان BM مرخي بتكون IHC بمستوى منخفض ولا راح تتأثر بالموجات الصوتية او بيقل احساسها بهذه الموجات

2- Inner hair cells (mechanoreceptors):

- Stereocilia is **not attached** to tectorial membrane.

-Functions of the inner hair cells :

- Vibration of the basilar membrane causes stereocilia to move toward the tallest hair → this causes stretch of tip links → which causes opening of mechanically gated K^+ channels → influx of K^+ results in membrane depolarization.
- Striocellia[9] not embedded in tectorial membrane, but bent by **fluid movement** under the tectorial membrane (between the tectorial membrane and underlying hair cells.) .
- They are **primary receptors for sound "hearing"**, transducing fluid movement in **cochlea** into action potential in the auditory nerve

★ Hair cells (receptors) act as neurons but are not neurons themselves!

Receptors & Endocochlear potentials .(Guyton 12th edition Page 637)

1. Sound transmission into the inner ear causes upper & lower movements of the reticular membrane (tectorial membrane).
2. Bending of stereocilia of hair cells (alternatively opening & closing cation channels at its tip of stereocilia)
3. (inward current) depolarization, (outward current) hyperpolarization the net results is **depolarization** → depolarization causes influx of **Ca^{2+}**.
4. Return of cilia to original position → closure of **K^+** ion channels → **hyperpolarization**
5. Generation of **receptor potential** (not action potential) when their hairs are deformed by fluid movement.
6. Release of **neurotransmitter (glutamate)** which synapse with afferent **spiral ganglion neurons** via a chemical synapse.
7. These 1st order (type 1) neurons are bipolar.The collection of their cell bodies form the spiral ganglion.

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[9] the inner ear, **stereocilia** are the mechanosensing organelles of hair cells, which respond to fluid motion in numerous types of animals for various functions, including hearing and balance.

8. Central axons of the spiral ganglion will form the auditory nerve (VIII) which will synapse on the **cochlear nucleus** in **the medulla**.
9. Production of action potentials...

Transduction of Sound: Overview

1. Sound waves cause **vibration of tympanic membrane**
2. Ossicles **amplify** sound wave from tympanic membrane to **oval window**
3. **Vibrations of stapes** against oval window produce pressure waves in **perilymph** (fluid of cochlea)
4. Waves travel to **apex of cochlea through vestibular canal and back toward base through tympanic canal**
5. Energy in waves causes **basilar membrane to vibrate**
6. This vibration **stimulates hair cells**
7. Fluid waves dissipate when they strike round window (Reset)

The Auditory Cortex is Mapped According to Tone

- Primary and secondary auditory cortex is **tonotopically organized**
- Each region of the basilar membrane is linked to specific region of primary cortex
- Specific cortical neurons are activated only by particular tones
- Secondary auditory cortex - Wernicke's area (Detection of language sounds)
- **Auditory agnosia :** can hear but can't recognize sounds

Pitch & loudness discrimination

Pitch discrimination

- Depends on the location "WHERE " of the basilar membrane that vibrate .
- Its called tonotopic mapping of frequency in the basilar membrane .
- **Base : narrower & stiffer**

Vibrate at higher frequencies .

- **Abex : wider & more flexible**

Vibrate at lower frequencies **.**

- Different **region** of the basilar membrane vibrate maximally at different **frequencies .**

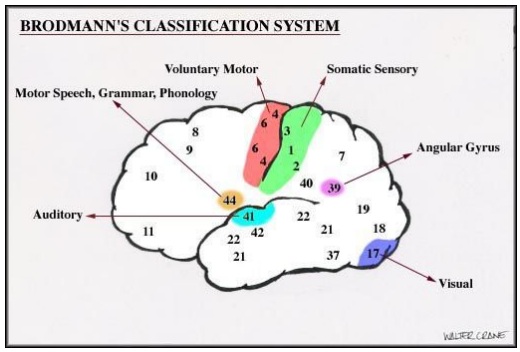
Maximal firing of afferent fibers depends on location along basilar membrane

Loudness discrimination

- Depends on " HOW MUCH ' that place vibrates .
- **Loud sounds** cause the eardrum to vibrate more vigorously , but at the same frequency of a softer sound .
- The great vibration of tympanic membrane ,the great basilar membrane movement **.**
- This cause greater bending of hair cells , which is interprets in CNS as a loud sound **.**

The Central Auditory pathway

- This pathway begins in the **organ of corti.**
- End in the **primary auditory cortex** (area **41& 42**[10], superior temporal gyrus in the temporal lobe of the brain)
- Fibres end in the auditory area, where it is heard, then **interpretation**[11] occurs in the auditory association areas (**wernicke's area**).
- There is a **bilateral** cortical connection of auditory area



[10] They are the primary auditory area

[11] comprehension - understanding - analysing the sounds!

- Thus damage to one side **only** slightly reduces hearing . (doesn't cause complete deafness)

Sound localization: (Guyton 12th edition Page 641)

Determination of the direction from which a sound emanates in the horizontal plane depends on:

1. **Differences in the time arrival of the sound wave at the ears** (time-lag).

الصوت القريب يصل إلى الأذن أسرع من الصوت البعيد.

2. **Differences in the loudness.** (the sound is louder on the side closest to the source.)

Masking effect:

لما تدخل موجات صوتية بتردد معين راح تفعّل مستقبلات مخصصة لهذا التردد. وبنفس الوقت لو دخلت موجات صوتية ثانية من مصدر اخر بنفس التردد ماراح نسمعها، لأن الموجات الاولى مازالت في مرحلة refractory. بنسمع الموجات الصوتية الثانية اذا كانت بتردد اعلى او اقل.

- Presence of background noise affect the ability to hear another sound, due to some receptors are in **refractory period**.
- Masking is more clear if two sound are having the **same** frequencies.
- Noise pollution is an environmental hazard.
- Exposure to sound intensity above **80dB** may damage outer hair cells.

هذي الملاحظة حرصت عليها الدكتورة خلال المحاضرة وطلبت مننا نكتبها!

Each part of cochlea is sensitive to certain sound frequency. that means when sound waves enter to cochlea, it won't stimulate the whole organ of coli in it. it will just stimulate a certain part that is responsible for a certain frequency

★ **High frequencies** sound waves will stimulate hair cells at the **base**.

★ **Low frequencies** sound waves will stimulate hair cells at the **apex**!

Conduction of a sound wave:

Air conduction:	Bone conduction:

- Normal situation of hearing, sound travel in air causes vibration of **Tympanic m.**, transmitted by ossicles to the oval window. - It is the main conduction pathway of hearing in humans.	Sound cause vibration of **skull bones** directly transmitting the sound vibration to the cochlea (eg when placing tuning fork on the head or mastoid process).

Deafness: (Guyton 12th edition Page 642)

Conductive deafness	Sensorineural (nerve) deafness
Impairment of sound transmission through external or middle ear due to: **- Blocked auditory canal** (Wax,fluid) **- Repeated infection.**(Otitis media middle ear infection /inflammation) **- Perforated drum**(Rupture or perforation of tympanic membrane). **- Destruction of ossicles.**(e.g. by fibrosis or calcification) **- Osteosclerosis** (pathological fixation of stapes on the oval window).	Due to congenital or damage to cochlea or auditory nerve pathway, <u>due to:</u> **- Toxins** (antibiotics, **gentamicin**). **- Inflammation.** **- Vascular.** **- Tumour.** **Neural presbycusis:** degenerative age related process occurs as hair cells wear out with use (loss of ~ 40% of hair cells by age 65) hearing loss happen anywhere in the auditory pathway , due to : 1-loss of hair cells 2- damage to 8th CN
- All sound frequencies are equally affected. - Bone conduction is **better than** air conduction.	**Both** air and bone conduction are affected.

Cochlear implants have become available (do not restore normal hearing!)

Test of hearing

1. **Audiometer.**
   - Air phone connected to electronic device emitting tones of low & high frequencies .
   - **Right** ear goes with **red** color

- **Left** ear goes with **blue** color

2. **Weber test.**
    - Lateralization to better ear
    - A vibrating tuning fork is placed in the middle of the head.
    - The Patient answers where the sound coming from R ear or L ear or both.
    - Result : normal hearing will indicate sound in both ears.
    - Either its **Conductive loss**: sound travels towards the **poor ear. (lateralization to bad ear)**
    - **Or nerve loss** : sound travels towards **good ear.**
3. **Rinne's test.**
    - The base of the tuning fork placed on mastoid process until the sound is not heard.
    - Then the prongs of the fork held in air near the ear.
    - Normal subject continue to <u>hear near ear</u> (**positive test**).

      "Air conduction is better than bone conduction "

    - If not reveres the test (if heard <u>near the mastoid process</u>, **negative test**).

      " Bone conduction is better than air conduction

Rinne test (duration: 1:35)

★ References:

- 435 girls and boys slides and notes.
- Guyton and hall medical physiology - 12 edition.
- Ganong's review of medical physiology - 25th edition.
