Physiology of Hearing

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Characters of the sound waves

1-Frequency: - is the number of waves/second and is expressed in Hertz (Hz). The normal human ear can detect sound frequencies from 20Hz to 20.000Hz

2-Wavelength is the distance between two successive peaks or two successive bottoms

3- Amplitude or intensity of the sound which is measured by specific scale called decibel "dB" **(one decibel = 1/10 Bell)**

$$\text{The intensity of sound in Bels} = \log \frac{\text{intensity of the given sound}}{\text{intensity of the standard sound}}$$

The standard sound is a sound at frequency 1000 Hz and an intensity that is just heard by the average normal human ear (zero bel). Because log 1= zero, a value of zero bel does not mean absence of sound but a sound having an intensity equal to that of the standard.

Masking: It means that the presence of one sound decreases the individual's ability to hear another sound. This phenomenon is attributed to the absolute refractoriness of the previously stimulated auditory nerve fibers.

Functional Structure of the Human Ear

The human ear is divided into **3** parts:- **1- External ear** **2- Middle ear** **3-Inner ear**

THE EXTERNAL EAR It is composed of: 1- ear pinna 2- external auditory meatus

3- tympanic membrane

Functions of external ear:-

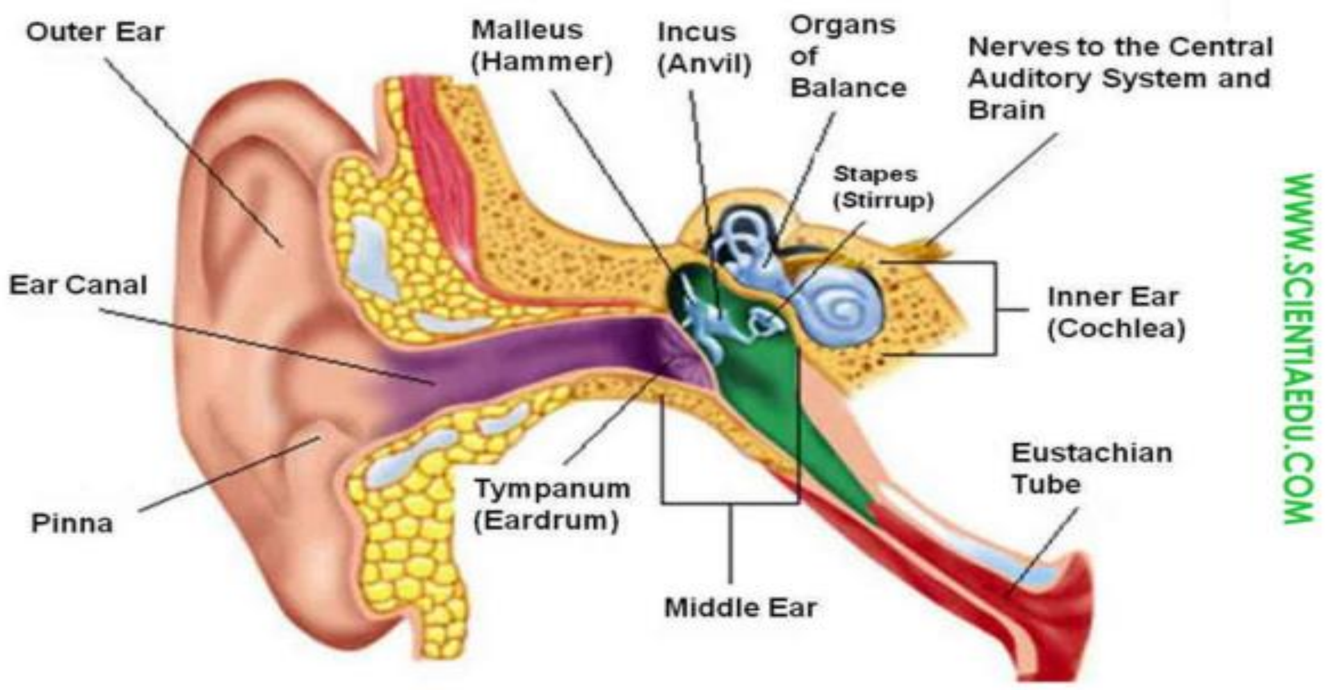
1-Ear pinna collects sound waves acts as a funnel

2-The auditory canal amplify sounds by concentrating pressure on ear drum

3-Hair traps the fine dusty particles from entering the canal while the waxy material has strong antiseptic effect preventing bacteria or fungi from growth due to its acidity

4-External canal keeps air temperature inside it about 37° which is very important to the hearing process

5- The main functions of the tympanic membrane (ear drum) is to transmit sound waves to middle ear and also with the bony ossicles accentuates and concentrates sound pressures on the **oval window**



THE MIDDLE EAR
Functions of the middle ear

1-Faithfull transmition (frequency) of different sound waves from the vibrating tympanic membrane to the inner ear through the **oval window** which is in direct contact with the **perilymph in Scala vestibuli** of the cochlea.

2- Amplification of amplitude of sound: This Amplification is mainly attributed to 2 causes: -

First, the arrangement of the bony ossicles in **a lever like system** amplify the pushing force of the stapes over the oval window which magnifies the sound by about 1.3 folds.

Second, the large area of the tympanic membrane in comparison to small area of the oval window. This means that the all force of vibrating waves collected in tympanic membrane is concentrated over the small area of the oval window.

This leads to more 17 times increase in sound intensity. Thus the total increase in pressure force caused by the middle = 17 X 1.3 = **22 times**

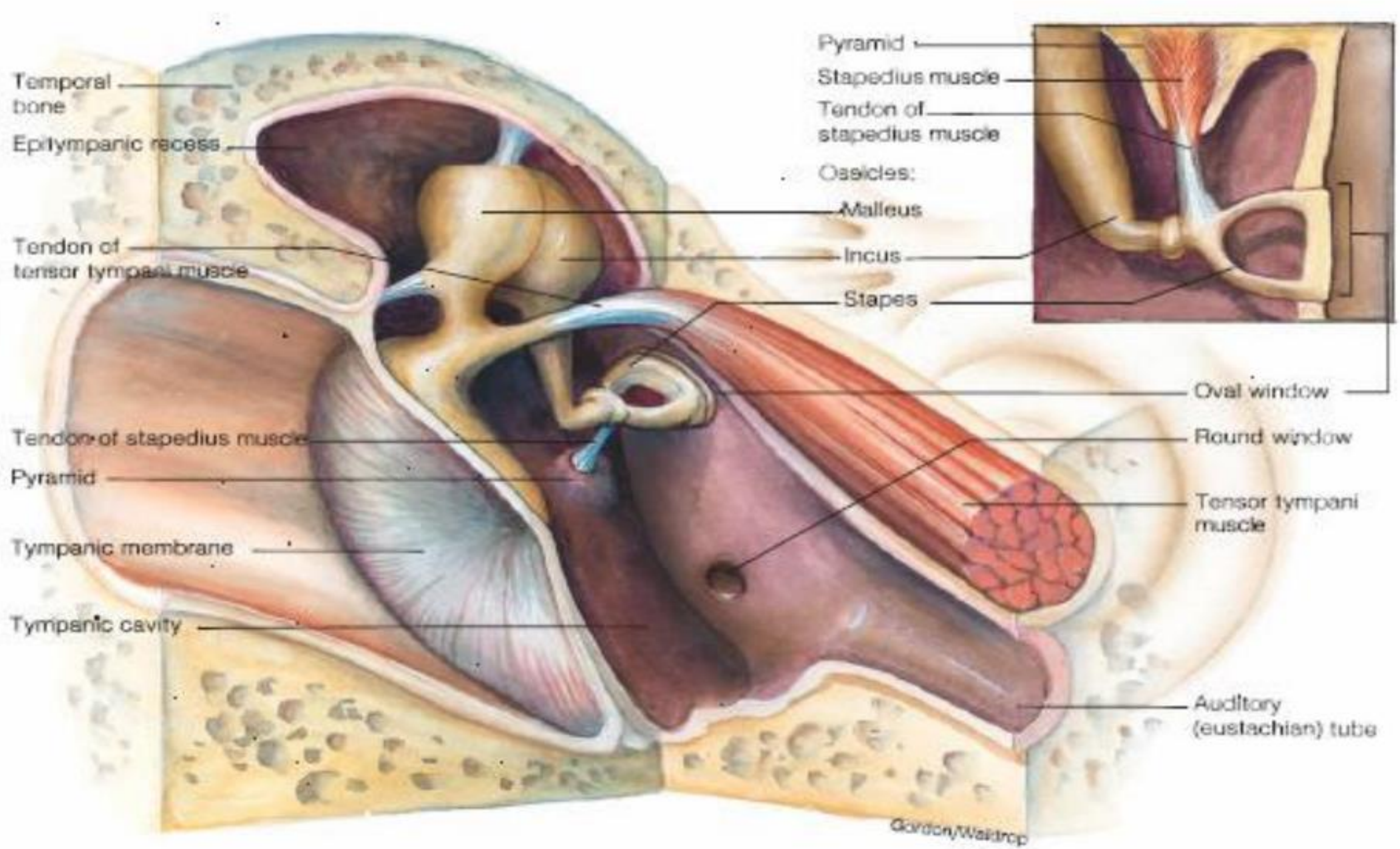
3-The tensor tympani muscle pulls inward the handle of the malleus which in its turn is attached to the tympanic membrane, this keeps the membrane continuously tensed which help optimum vibration and function.

4-Protection of the delicate structure of the inner ear from high sound by the acoustic or **tympanic reflex**

This reflex occurs in response to **high pitched loud sounds** and causes both muscles to contract reflexly.

Contraction of **tensor tympani** pulls on tympanic membrane makes it more tense thus preventing vigorous vibration to occur.

Contraction of **the stapedius** prevents inward displacement of the stapes inside oval window, thus abolishing effect of high sounds to damage cochlear structure.


Temporal bone
Epitympanic recess
Tendon of tensor tympani muscle
Tendon of stapedius muscle
Pyramid
Tympanic membrane
Tympanic cavity
Pyramid
Stapedius muscle
Tendon of stapedius muscle
Ossicles:
Malleus
Incus
Stapes
Oval window
Round window
Tensor tympani muscle
Auditory (eustachian) tube
Gordon/Waldrop

5-The middle ear equalizes the pressure across the two sides of the tympanic membrane thus facilitates its mobility which is essential for the hearing process.

This is **mediated by the Eustachian tube** which connects the cavity of the **middle ear** to the **nasopharynx** making both sides of the tympanic membrane are exposed equally to the atmospheric pressure.

The **Eustachian tube is normally collapsed** but is **opens during swallowing, yawing or chewing** which cause renewal of the air in the middle ear

6-Impedance matching function of the middle ear which means the ability of the middle ear to overcome inertia of perilymph by converting movement of low density air waves to high density aqueous medium of the inner ear. This is done through marked potentiation of sound waves **(22 times)**

7-The middle ear contains the round window (secondary tympanic membrane) which is a flexible membrane connected to the Scala tympani of the inner ear.

This membrane moves with the movements of the basilar membrane to absorb waves created in the perilymph of the Scala vestibuli secondary to the movement of basilar membrane.

Fixation of this membrane leads to hearing loss

THE INNER EAR (Cochlea)

The cochlea is a coiled tube which in human is **35mm long**

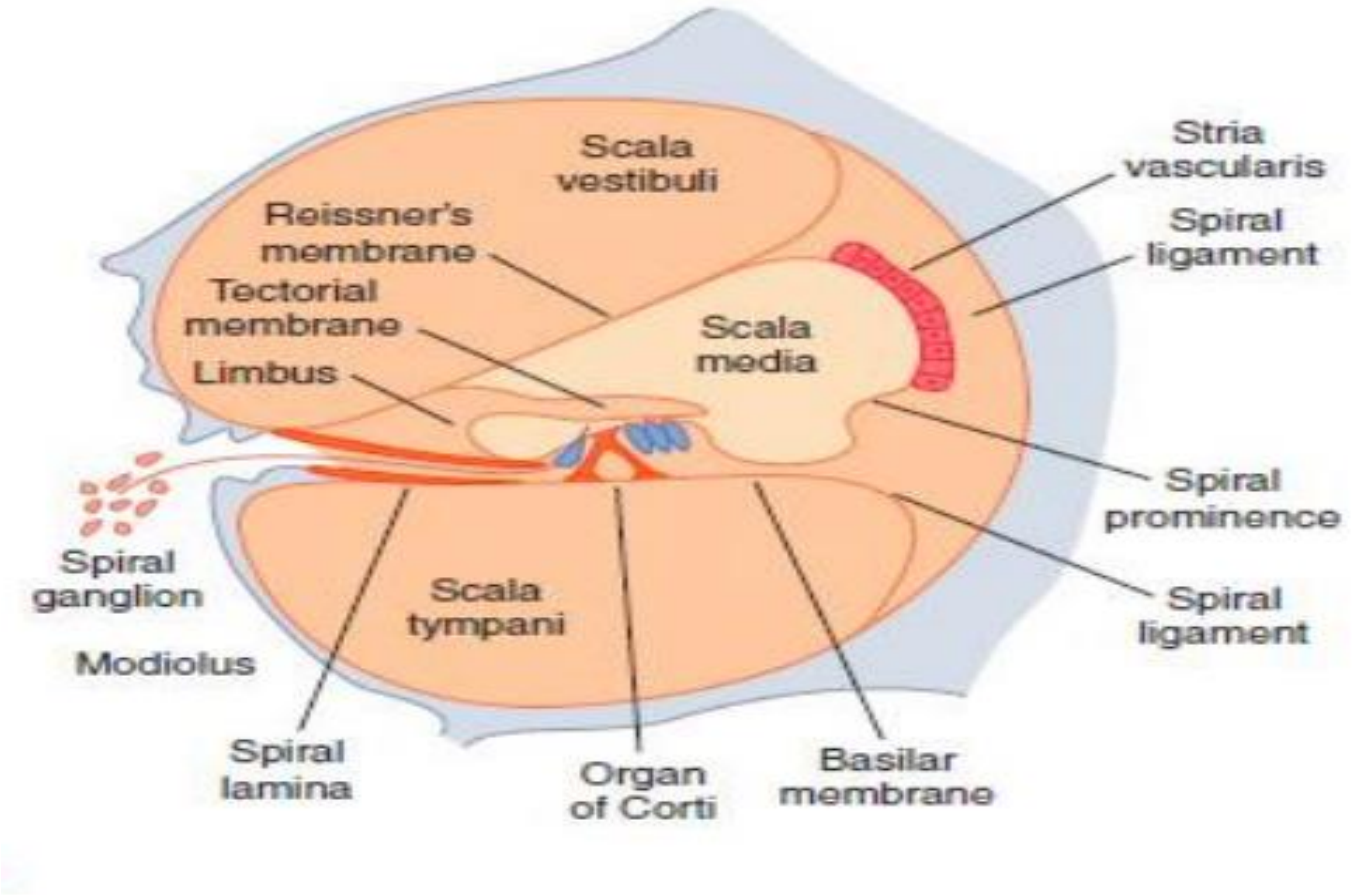
The **basilar membrane** and **Reissner's membrane** divide it into **3** chambers (scalae).

The **upper Scala vestibuli** and the **lower Scala tympani** contain perilymph (which resembles in structure the extracellular fluid i.e. rich in Na^+ and poor in K^+) and communicate with each other at the apex of the cochlea.

The **Scala vestibuli** ends at the **oval window**, which is closed by the foot plate of the stapes.

The **Scala tympani** ends at the **round window**, a foramen on the medial wall of the middle ear that is closed by the flexible secondary tympanic membrane.

The **Scala media**, the middle cochlear chamber, does not communicate with the other 2 scalae. It contains endolymph (which resembles in structure the intracellular fluid, it is rich in K^+ (135mEq/L) and poor in Na^+ (15mEq/L)


Scala
vestibuli
Reissner's
membrane
Tectorial
membrane
Limbus
Scala
media
Stria
vascularis
Spiral
ligament
Spiral
prominence
Spiral
ligament
Spiral
ganglion
Modiolus
Scala
tympani
Spiral
lamina
Organ
of Corti
Basilar
membrane

Organ of Corti

The organ of Corti is located on the **basilar membrane**

It contains the **hair cells** which are the **auditory receptors**

This organ extends from the apex to the base of the cochlea.

The hair cells are arranged in **4 rows: 3 outer hair cells** lateral to the tunnel formed by the rods of Corti, and **one row inner hair cells** medial to the tunnel.

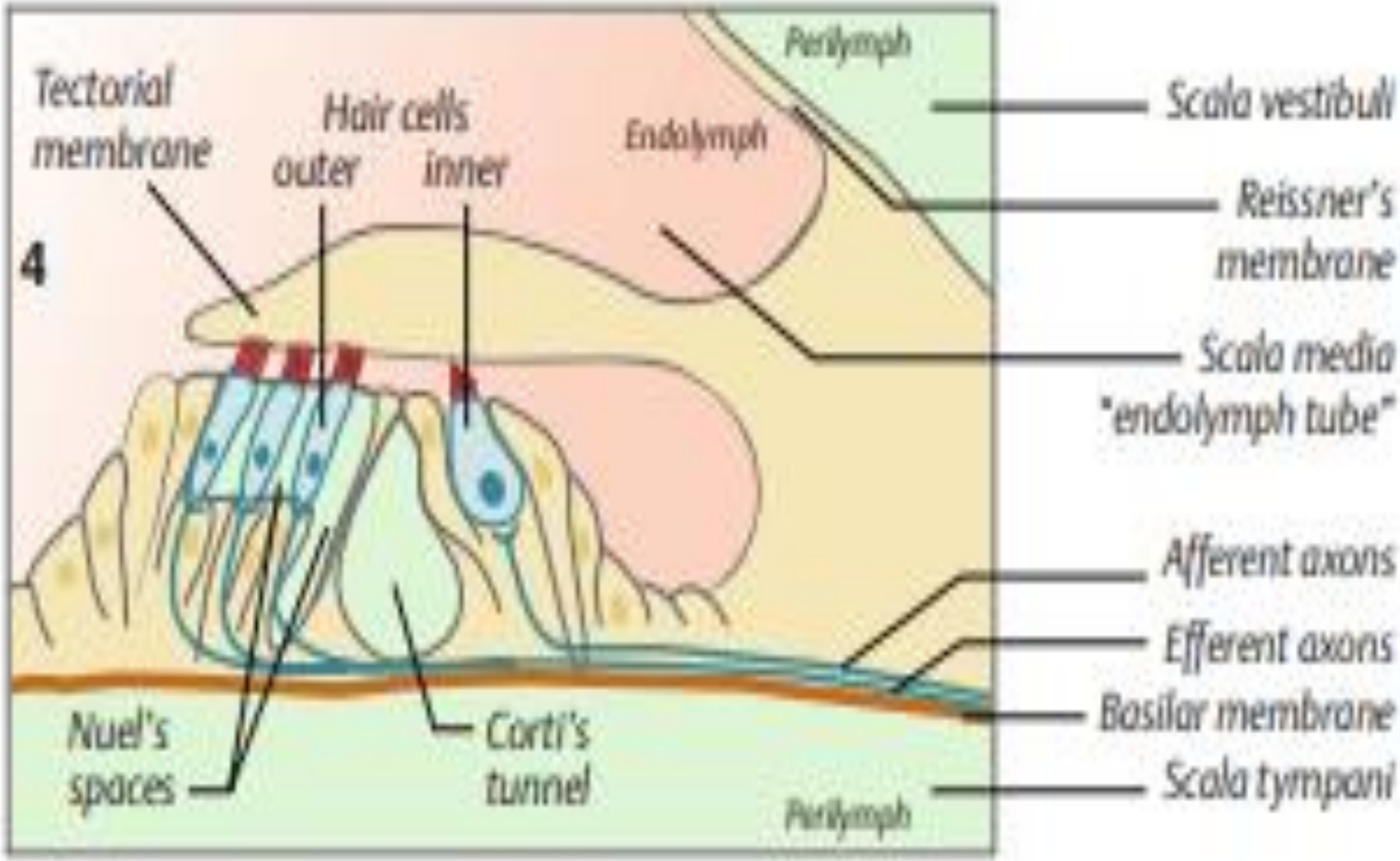
There are **20.000 outer hair cells** and **3500 inner hair cells** in each human cochlea

Covering the rows of hair cells is a thin, viscous, but **elastic tectorial membrane** in which the **tips of the hair cells are embedded**

The **cell bodies of the afferent neurons** are located in the **spiral ganglion**

- ***Types of hair cells in organ of Corti:***

Inner hair cells	Outer hair cells
1 row.	3 rows.
Medial to the tunnel of Corti.	Lateral to the tunnel of Corti.
3500 in each cochlea.	20.000 in each cochlea.
Give 90- 95% of afferent in cochlear nerv	Give 5-10% of afferent in cochlear nerve.
Receive less efferent.	Receive more efferent.
Auditory receptors: generate impulses in cochlear nerve	**Improve hearing** by affecting vibration of basilar membrane


4
Tectorial membrane
Hair cells
outer
inner
Endolymph
Perilymph
Scala vestibuli
Reissner's membrane
Scala media "endolymph tube"
Afferent axons
Efferent axons
Basilar membrane
Scala tympani
Nuel's spaces
Corti's tunnel
Perilymph

In the cochlea, there are tight junctions between the hair cells and the adjacent cells, these prevent endolymph from reaching the bases of the hair cells

However, **the basilar membrane is relatively permeable to perilymph** in the Scala tympanai and consequently the **tunnel of the organ of Corti and the bases of the hair cells are bathed in perilymph**

Therefore, the **bases of the hair cells are bathed in perilymph** while their **processes are bathed in endolymph** and this is very important for generation of receptor potential.

Possible Mechanism of Hearing

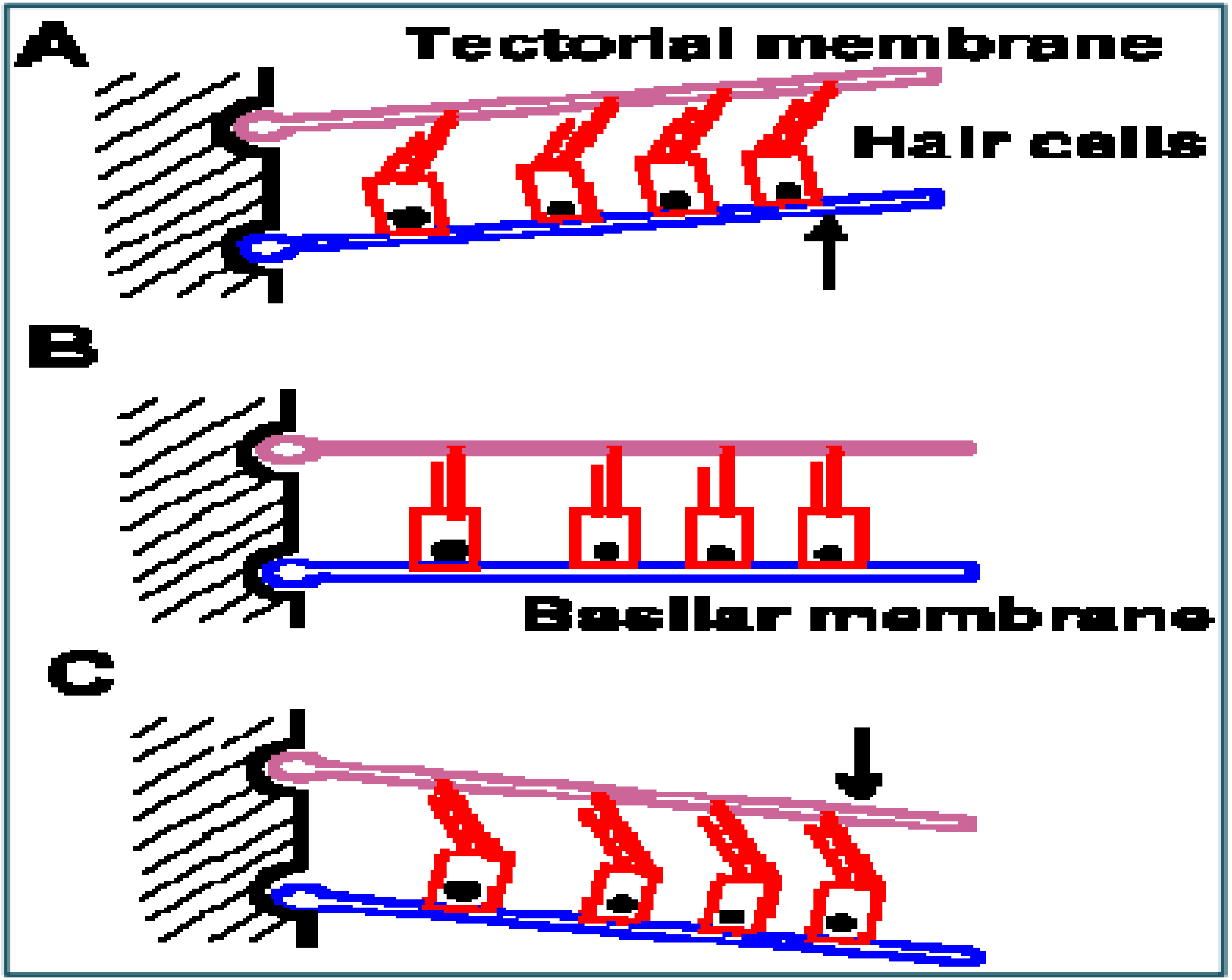
- The sound waves are collected to some extent by the ear pinna which also determines the direction of the sound.
- Then these waves travel the external auditory tube to be concentrated on the tympanic membrane which responds to these sound vibrations and with the help of the three bonny ossicles, these vibrations are magnified and produces forward and backward movements in the oval window.
- The movements of the oval window lead to movements in the perilymph of the Scala vestibuli with subsequent upward and downward movements of the thin Reissener's (vestibular) membrane.
- The vibrations of this membrane are transmitted to the endolymph of the Scala media and causes vibration of the basilar membrane which moves the hair cells up and down and from side to side.

The stereocilia of the hair cells are attached to the tectorial membrane and both the tectorial and basilar membranes are attached to the **limbus**, thus both membranes slide on each other causing what is called **"shearing movement"**

These shearing movements make the stereocilia on the hair cells to bend back and forth.

It was found that when the **organ of Corti moves up**, the **stereocilia bend away from the limbus** (modiolus) **causing the K+ channels to be opened** with subsequent **K+ influx into hair cells** causing their **depolarization**.

On the other hand when the **organ of Corti moves down**, the **stereocilia bend towards the limbus** and the **K+ channels are closed** causing their **hyperpolarization**.


A
Tectorial membrane
Hair cells
B
Basilar membrane
C

- Depolarization of the hair cells appears to allow **Ca 2+ ions to enter the hair cells** with subsequent **release of synaptic transmitter** which stimulates the auditory nerve fibers that are scattered around the inner hair cells mainly (afferent fibers)

Endo cochlear potential

- The endolymph is positive (+80 mV.) relative to the perilymph (0 mV.).
- There is a potential difference between the endolymph and the perilymph about 80 mV. and this is called the ***endo cochlear potential***.
- The hair cells which have their processes projecting into the endolymph have a negative intracellular potential = -70 mV. , Thus they have about I50 mV. potential difference between inside these cells and the endolymph.
- The tunnel of Corti which contains fibers of the auditory nerve contains perilymph. If it was filled with endolymph the nerve impulses in the nerve would be not transmitted because the endolymph has nearly the same ionic composition of their axoplasm.

Discrimination of Sound

Sound must be discriminated according to 4 items:-

1- Frequency or "pitch". 2- Intensity or "loudness" 3- Regular or noise 4- Sound localization

1-Frequency discrimination of sound theories that explain discrimination of sound frequencies are:-

A- Place or Helmholtz theory

- It was put in consideration after studying the detailed examination of the basilar membrane structure.
- This membrane consists of nearly 20.000 transverse parallel fibers which differ in thickness and tension. The fibers are short and highly stretched near the base of the cochlea but becomes gradually longer and more lax as they become nearer to the apex of the cochlea i.e. the basilar membrane is wider near the apex.

- It was found that high frequencies sound cause vibration of those fibers that lie near the base of the cochlea (short, tense fibers) while low frequency sound waves cause resonance or vibration of lax long fibers near the apex of the cochlea. Such different vibrations in the basilar membrane will excite different groups of hair cells which would excite the auditory cortex at different localities. According to these different localities the brain can differentiate between high and low pitched sounds.
- This theory was proved by histological examination of the basilar membrane as well as destruction of that membrane at certain sites makes the animals "deaf "to certain frequencies. Also prolonged exposure to high frequency sounds cause damage of the basilar membrane at certain localities.

B-Traveling wave theory of Von Bekesy

- It assumes that the sound vibrations when reach the foot plate of the stapes that move the oval window produce a pattern like traveling waves in the perilymph of the Scala vestibuli that run from the base towards the apex of the cochlea.
- Sound of high frequency waves produce maximum height near the base of the cochlea, while sounds of low frequencies produce maximum height near the apex of the cochlea.
- Because the basilar membrane is not under tension, it is readily depressed into the Scala tympani by the peaks of waves in the Scala vestibuli. Therefore, sound waves produce distortion of the basilar membrane and the site at which this distortion is maximal is determined by the frequency of the wave.
- Thus according to the pitch of the sound the basilar membrane is moved maximally at certain site, stimulating specific hair cells that also reach certain localities in auditory cortex which can determine these frequencies.

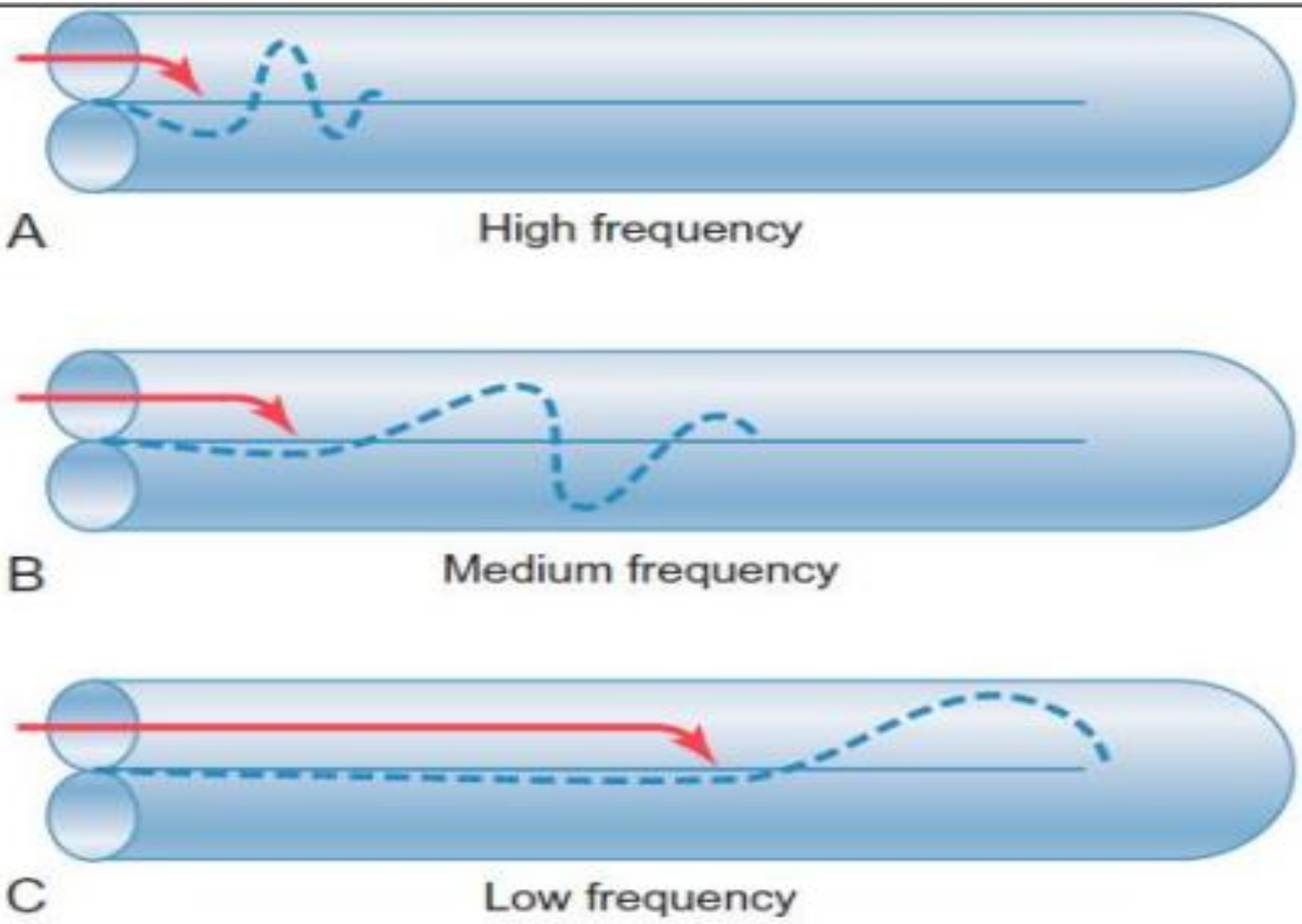


Figure 53-5. "Traveling waves" along the basilar membrane for high-, medium-, and low-frequency sounds.

2-Discrimination of the intensity (loudness)

The stronger the intensity .of the sound, the larger the portion of the basilar membrane that is vibrated and the more the number of action potentials that travel the auditory nerve fibers. These are interpreted by the auditory cortex as an increased intensity of sound

3- Determination of sound locality (source of the sound)

Near sounds usually are heard stronger than far sounds.

Also the direction is determined by the time differences in the sound waves striking the two ears.

4-Determination of sound patterns

It is the ability to recognize combination and sequence of tones and to differentiate regular sound from noisy sound. This is appearing to be a cortical function. Ear can discriminate two separate sounds if the interval time between them is more than 1/10 second.

Auditory pathway

1st. order neuron: - Found in the spiral ganglia (bipolar cells)near modulus in the cochlea

2nd. order neuron: - Ventral & dorsal cochlear nuclei at the junction of pons with medulla

Most of 2nd order neurons cross to the opposite side passing through the trapezoid body to relay in the superior olivary nucleus.

3rd. order neuron: - Superior Olivary nucleus , 3rd order neurons ascend in the lateral lemniscus then reach the inferior colliculi of the mid brain

4th. order neuron: - Inferior colliculi of the mid brain then 4th order neurons ascend to relay in the Medial geniculate body of the thalamus (MGB) .

5th. order neuron: - Medial geniculate body of the thalamus (MGB) Axons of the 5th order neurons arise from MGB and run as the auditory radiation pass in the retro-lenticular part of the internal capsule to relay finally in the auditory cortex in the temporal lobe.

THANKS