Neuropsychiatry Block

جامعة الملك سعود
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Mechanism of Hearing

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References

The Sense of Hearing

Chapter 53

(Guyton & Hall)

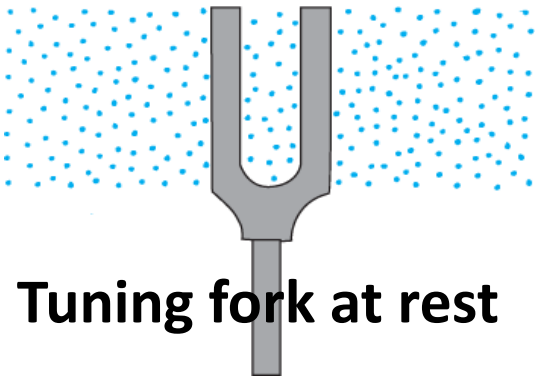
Objectives

By the end of this lecture students are expected to:

- 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

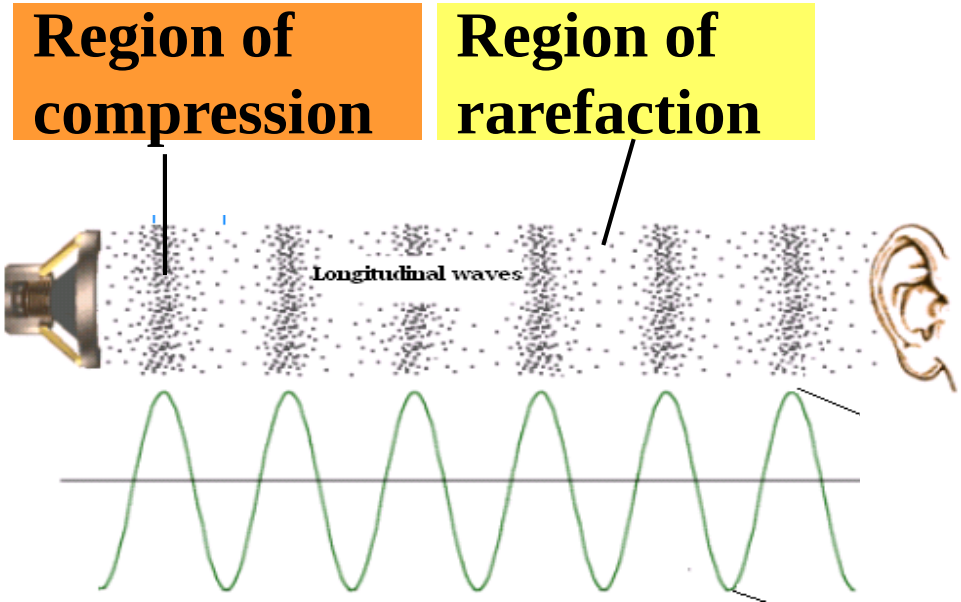
Characteristics of Sound Waves

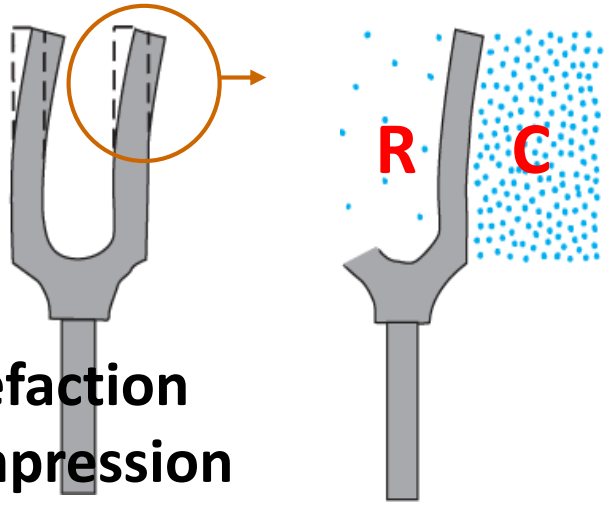
- Sound is a **mechanical wave** (travelling vibration of air)
- Sound waves are alternating regions of **compression** and **rarefaction** (expansion) of air molecules
- **Sound intensity (loudness) is measured in decibels (dB)**



Tuning fork at rest

Normal density of air molecules

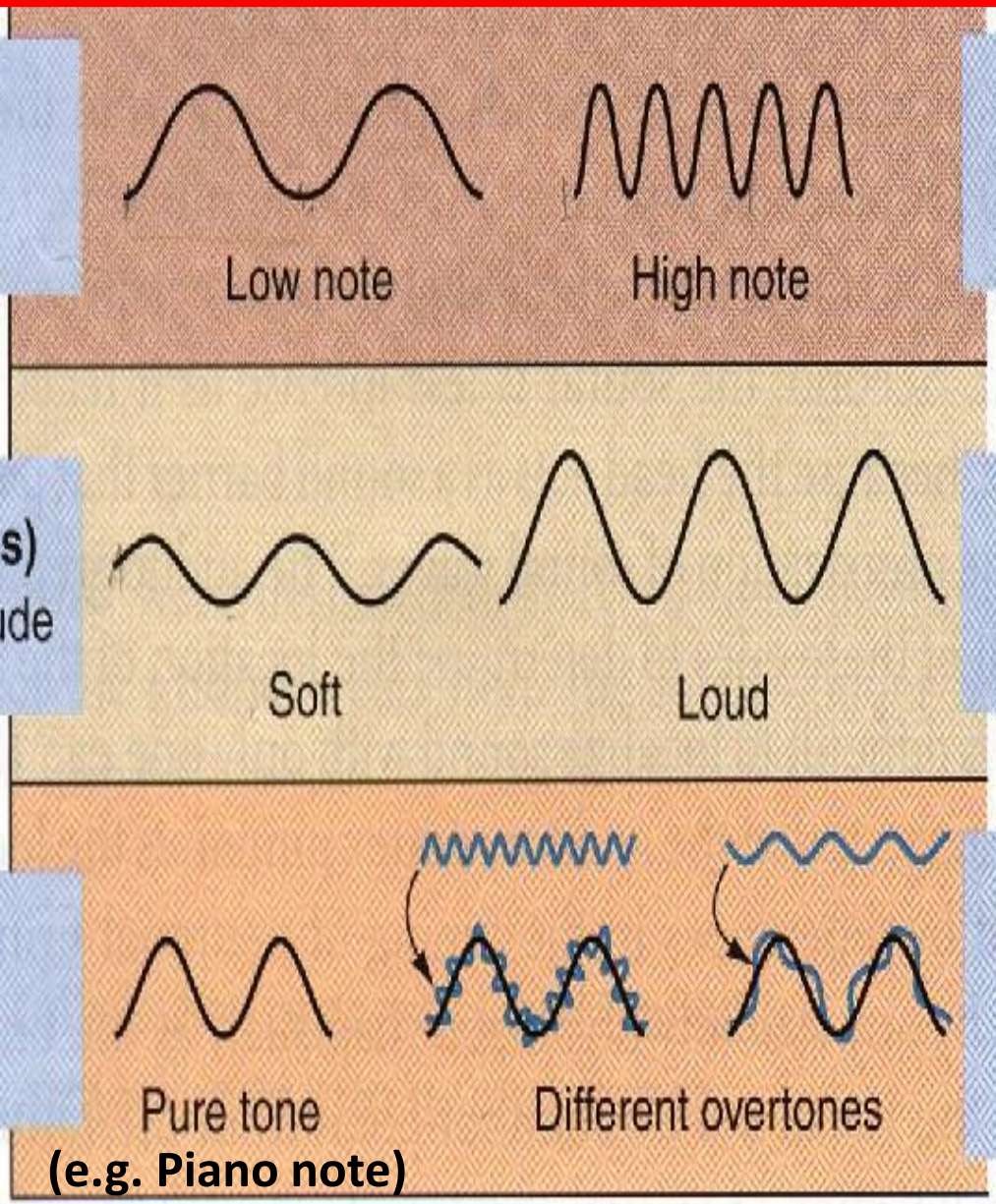




R= rarefaction

C= compression

Sound Characteristics-1



Relative Magnitude of Common Sounds

Sound	Loudness in Decibels (dB)	Comparison to Faintest Audible Sound (Hearing Threshold =0.0002 db)
Rustle of leaves	10 dB	10 times louder
Ticking of Watch	20 dB	100 times louder
Whispering	30 dB	1000 times louder
Normal Conversation	60 dB	1 million times louder
Food Blender, Lawn Mower, Hair Drier	90 dB	1 billion times louder
Ambulance Siren	120 dB	1 trillion louder
Takeoff of Jet Plane	150 dB	1 quadrillion times louder

Anatomy of the Ear-1

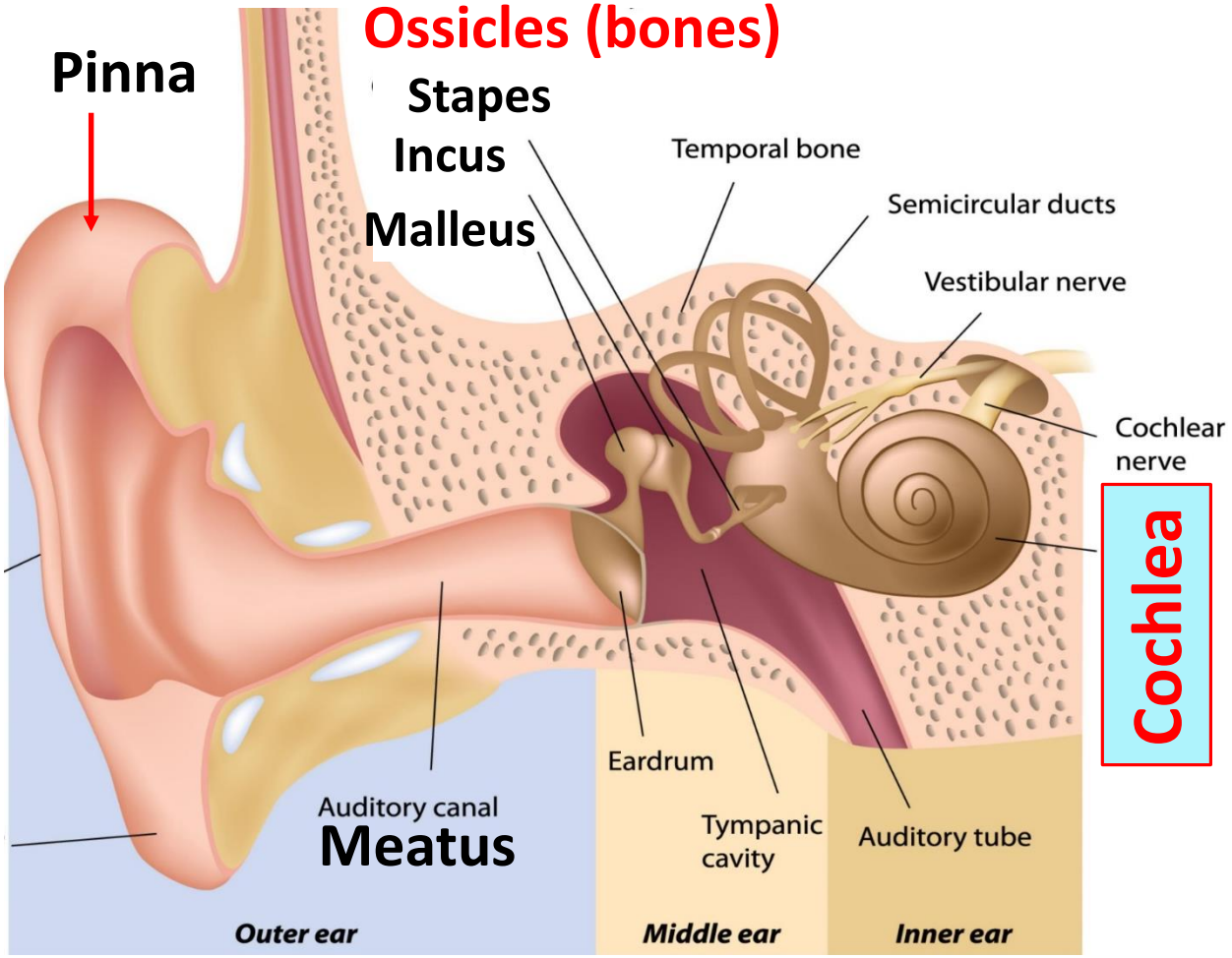
The ear consists of:

- **External ear:**
  - Pinna
  - Meatus
  - Eardrum
- **Middle ear**
- **Inner ear**

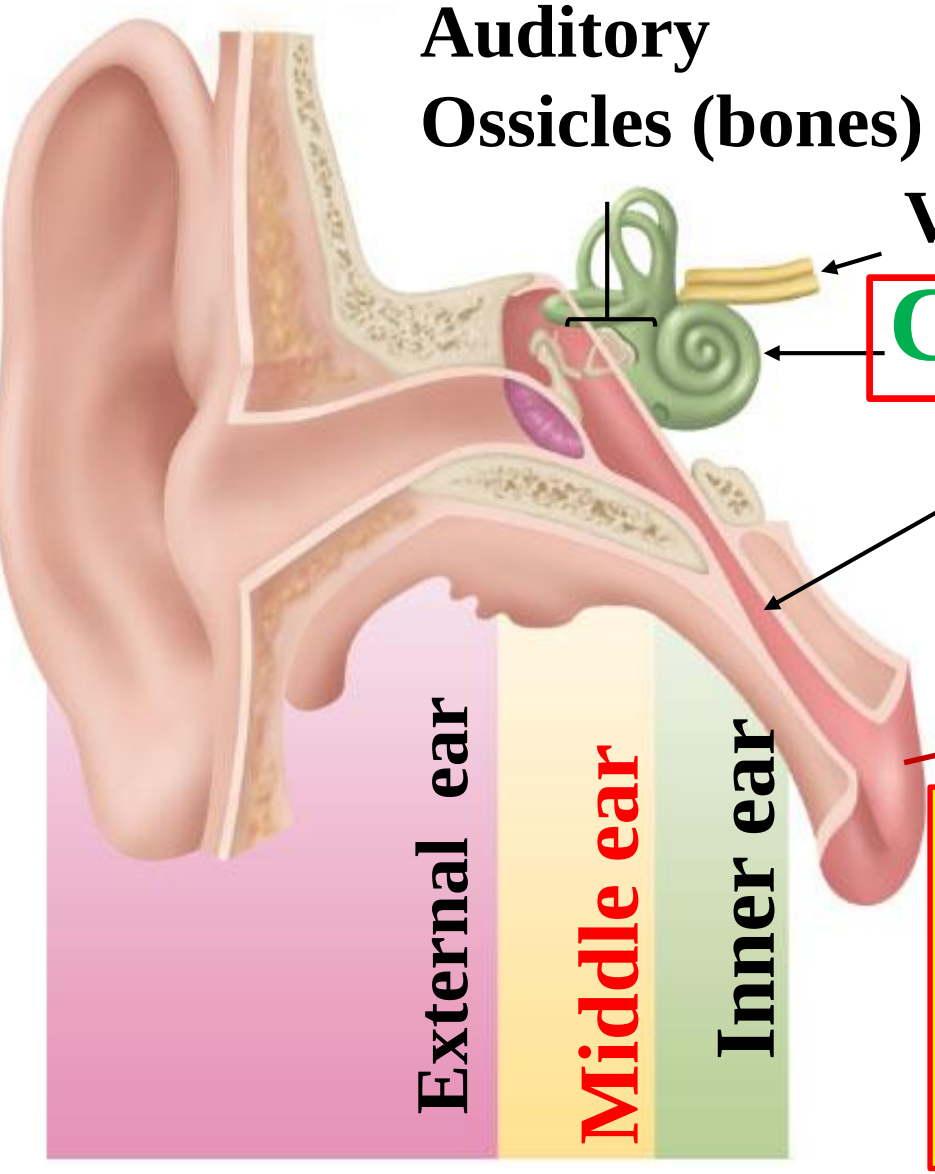
Functions of Ear:

- **Hearing**
- Equilibrium

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



Anatomy of the Ear-2



Auditory Ossicles (bones)

Vestibulocochlear nerve

Cochlea

Eustachian tube

To pharynx (back of throat)

For the eardrum to move freely, the resting air pressure on both sides of eardrum must be equal

Anatomy of the Ear-3

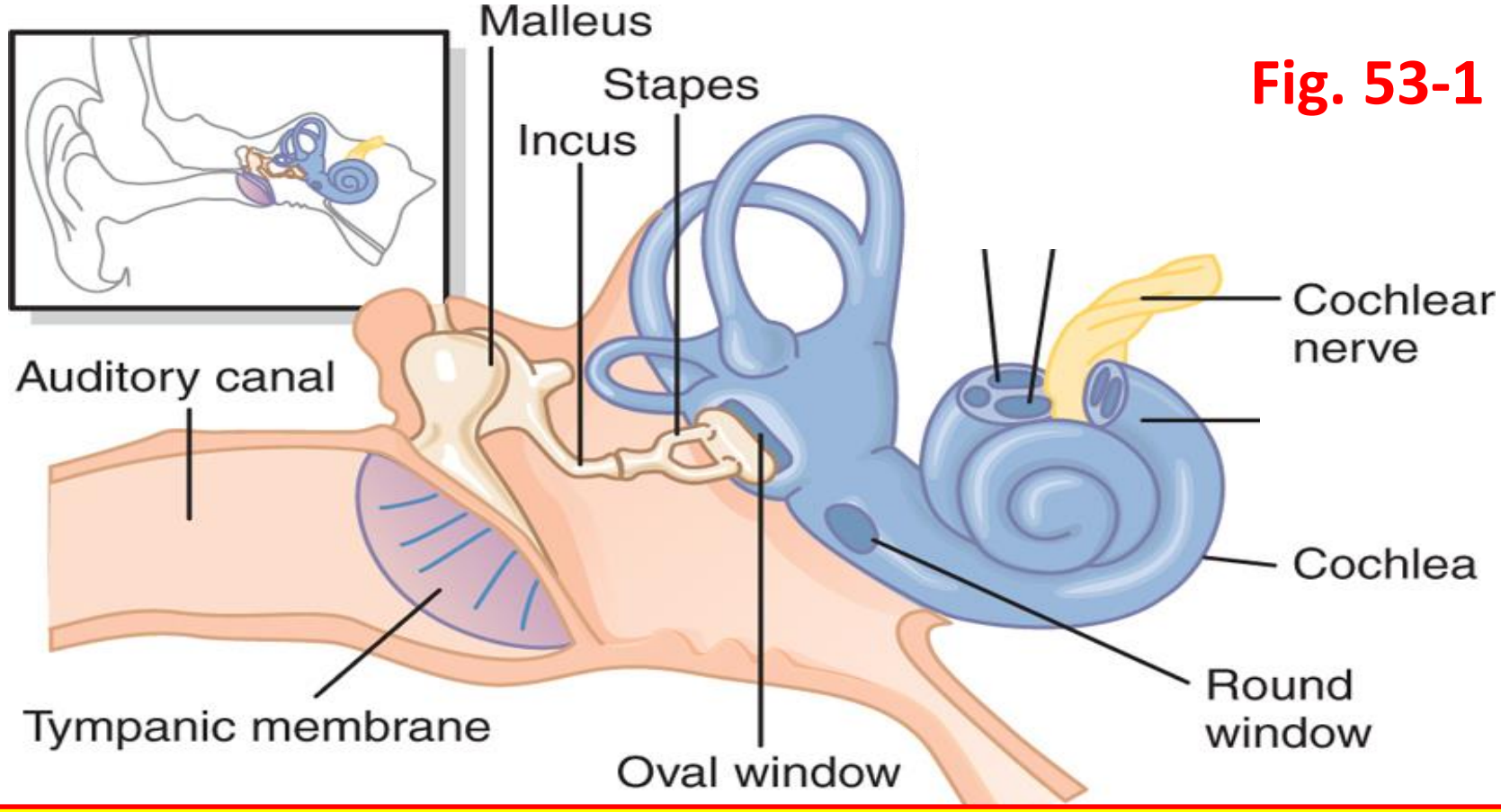
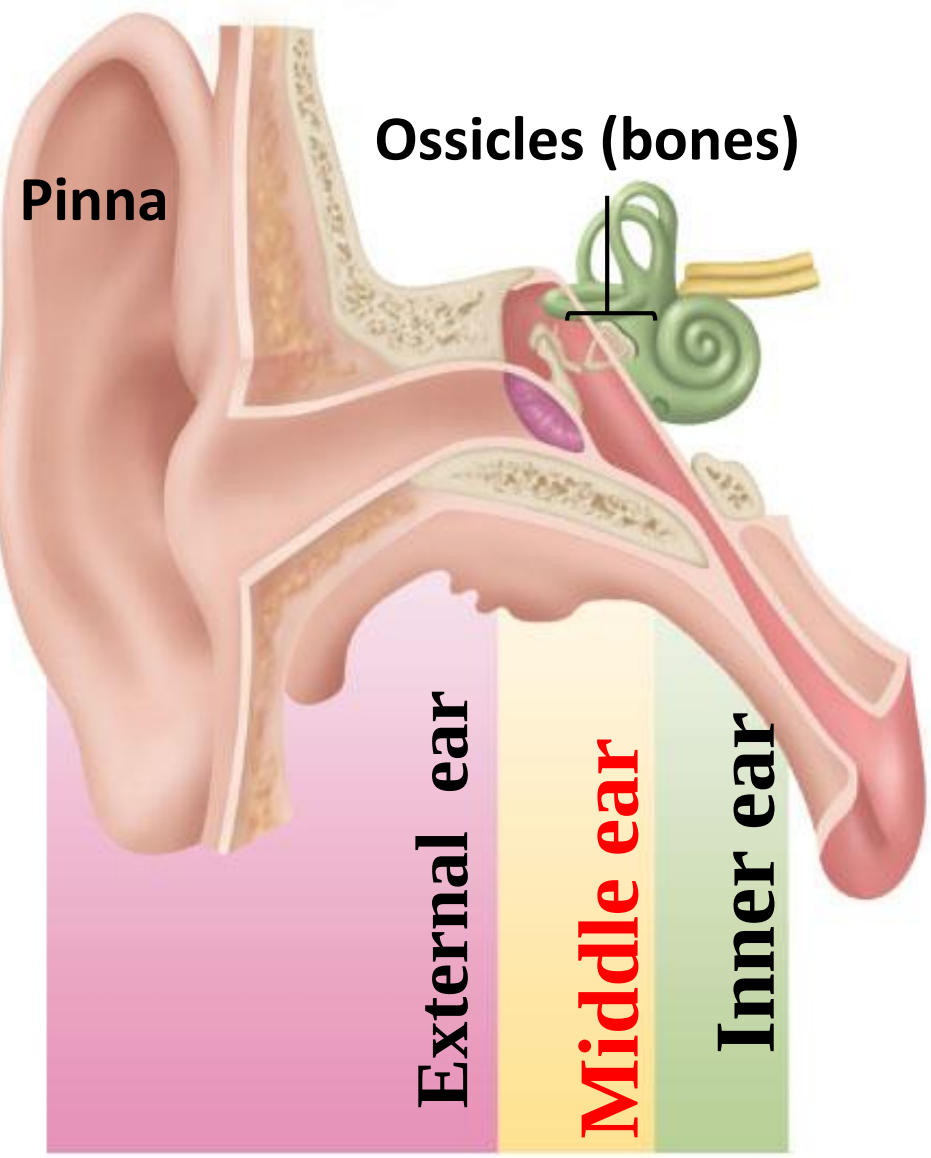


Fig. 53-1

- **Cochlea** is a **snail** like, coiled **fluid-filled** tubular system laying deep in the temporal bone
- Contains the hearing sensory organ (**organ of corti**)

Functions of External, Middle & Inner Ear-1



1 External Ear:

- Pinna provides clues about location of sound
- Gathers and focuses sound energy on tympanic membrane (**ear drum**)

2 Middle Ear

- Ossicles amplify vibrations of tympanic membrane to oval window
- This is needed for movement of sound waves in the **fluid** of the inner ear

3 Inner Ear

- Sound transduction & transmission

Functions of External, Middle & Inner Ear-2

External Ear

- **Sound collection**: Act as funnel to collect sound
- **Sound localisation** (front, back, high, low)
- **Protection**

Middle Ear

- The force from a large surface area (**drum**) is concentrated to a small (**oval window**) at a ratio of **17:1**
- **Lever action of ossicles**: increase the force of movement **1.3** times
- The total increase is 17 X 1.3 = **22** times

Inner Ear

- **Transduction:**

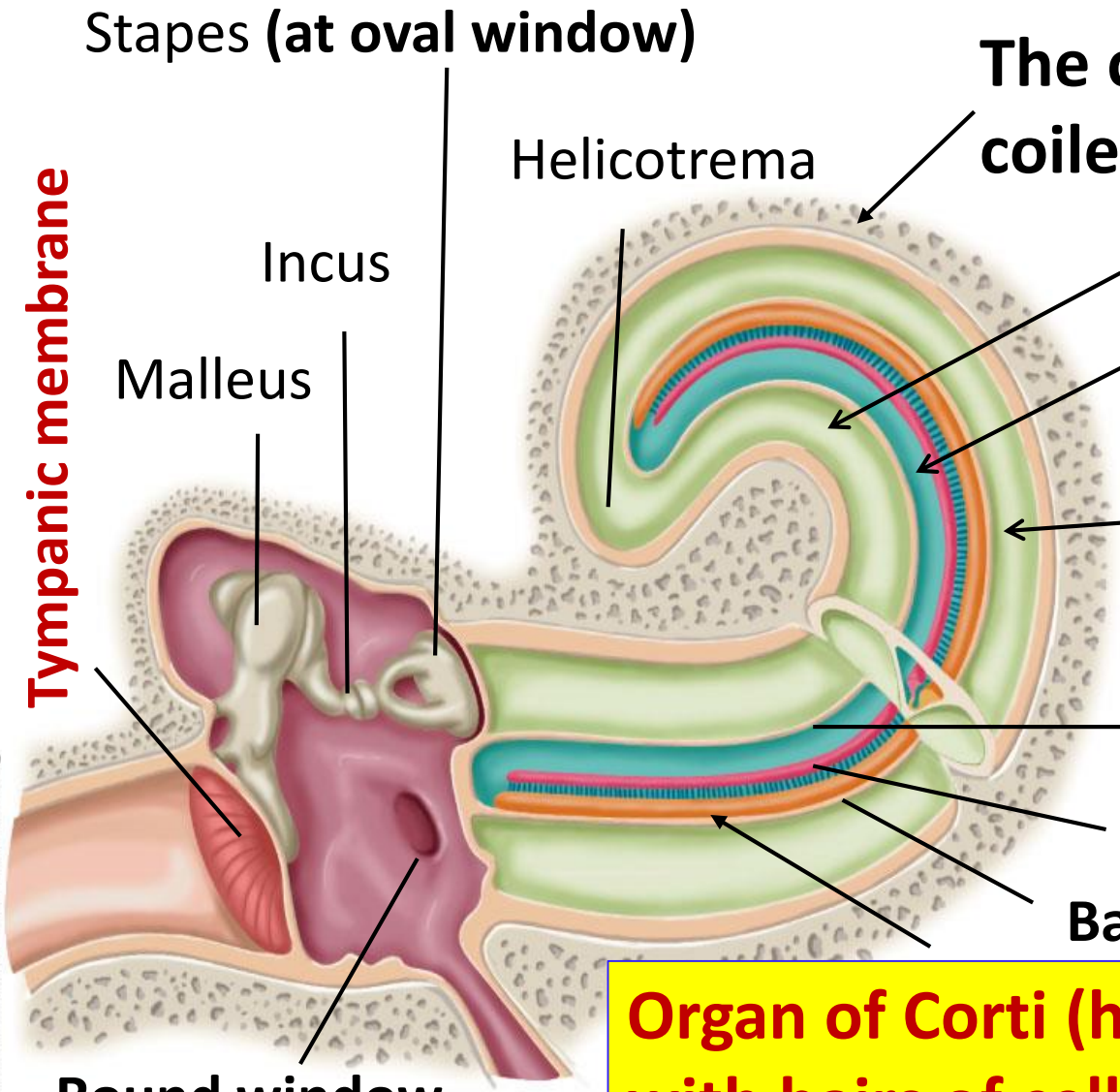
- Convert sound waves (mechanical) into nerve impulses

- **Transmission:**

- Send auditory signals to the CNS

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

Uncoiled Cochlea: Functional Components



The cochlea is a system of 3 coiled tubes filled with fluid:

- **Scala vestibuli**
- **Scala media** (cochlear duct)
- **Scala tympani**

Vestibular membrane

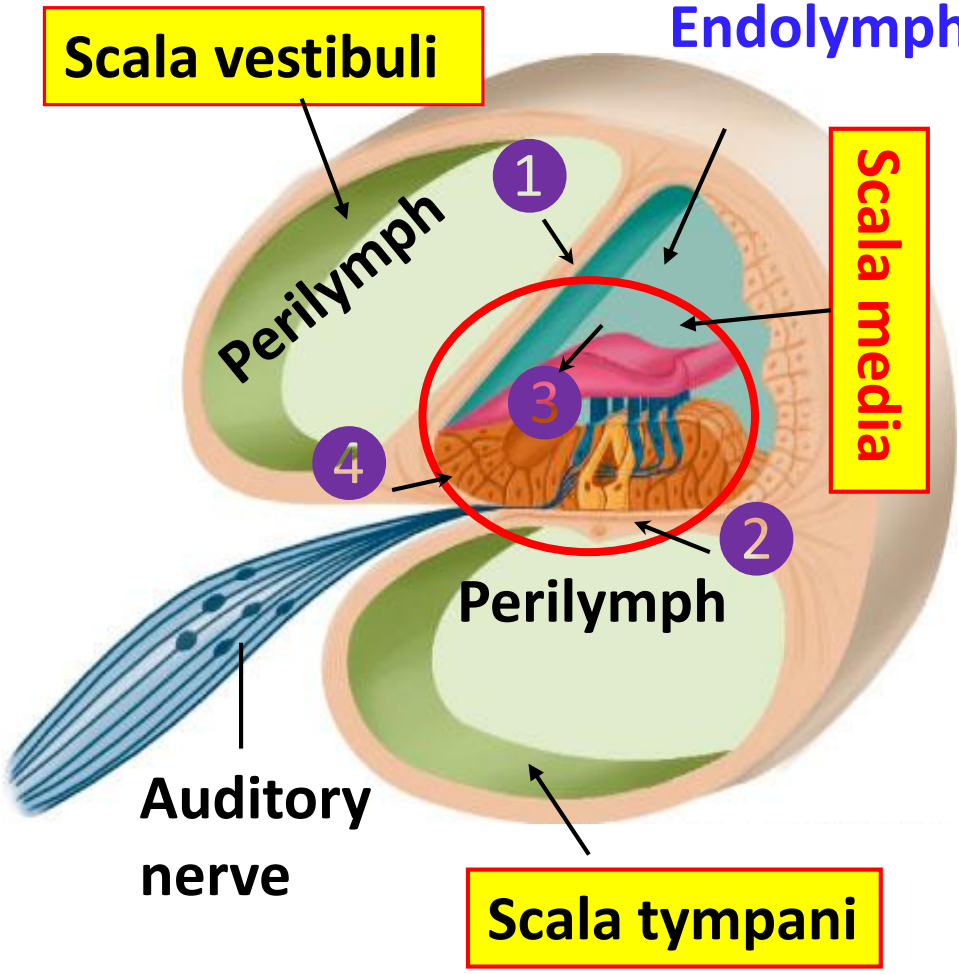
Tectorial membrane

Basilar membrane

Organ of Corti (hearing sense organ) with hairs of cells (stereocilia)

Cross Section of the Cochlea

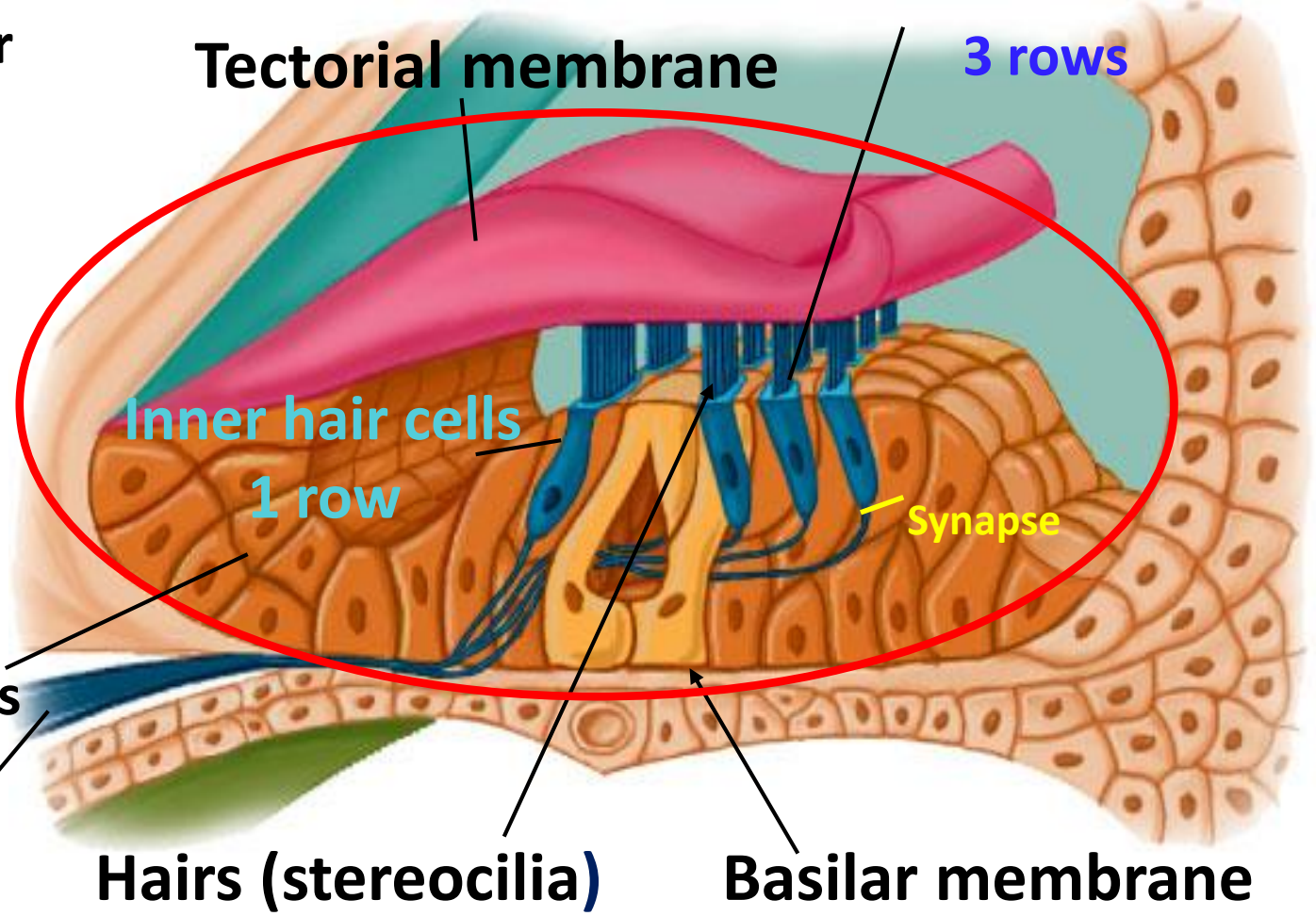
1. **Vestibular membrane**
   - Separates scala media from scala vestibule (**very thin**)
2. **Basilar membrane**
   - Separates scala media from scala tympani
3. **Tectorial membrane**
   - Attached to the sterocelia of hair cells
4. **Organ of Corti**
   - Located in scala media on top of basilar membrane
   - Contains 2 types of receptor cells called ***hair cells***
   - Supporting cells



Enlargement of Organ of Corti

Organ of Corti:

- Rests on basilar membrane
- Contains inner & outer hair cells
- These are attached to tectorial membrane
- Supporting cells



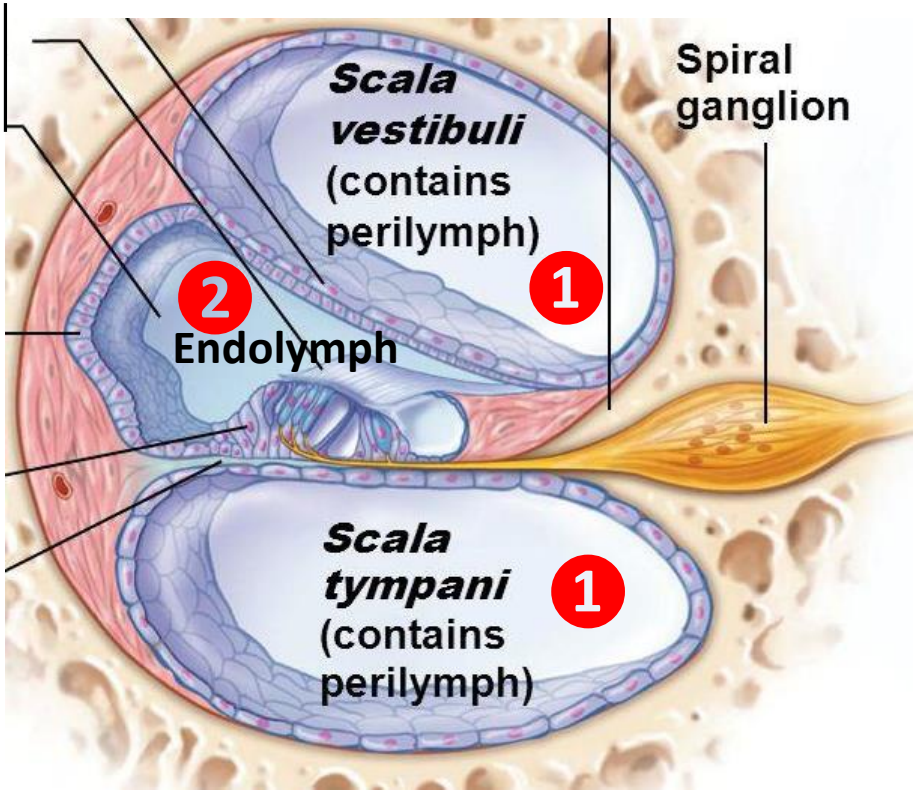
Hair cells (receptors) act as neurons but are not neurons themselves!

Composition of the Cochlear Fluids-1

The cochlear canals contain two types of fluid:

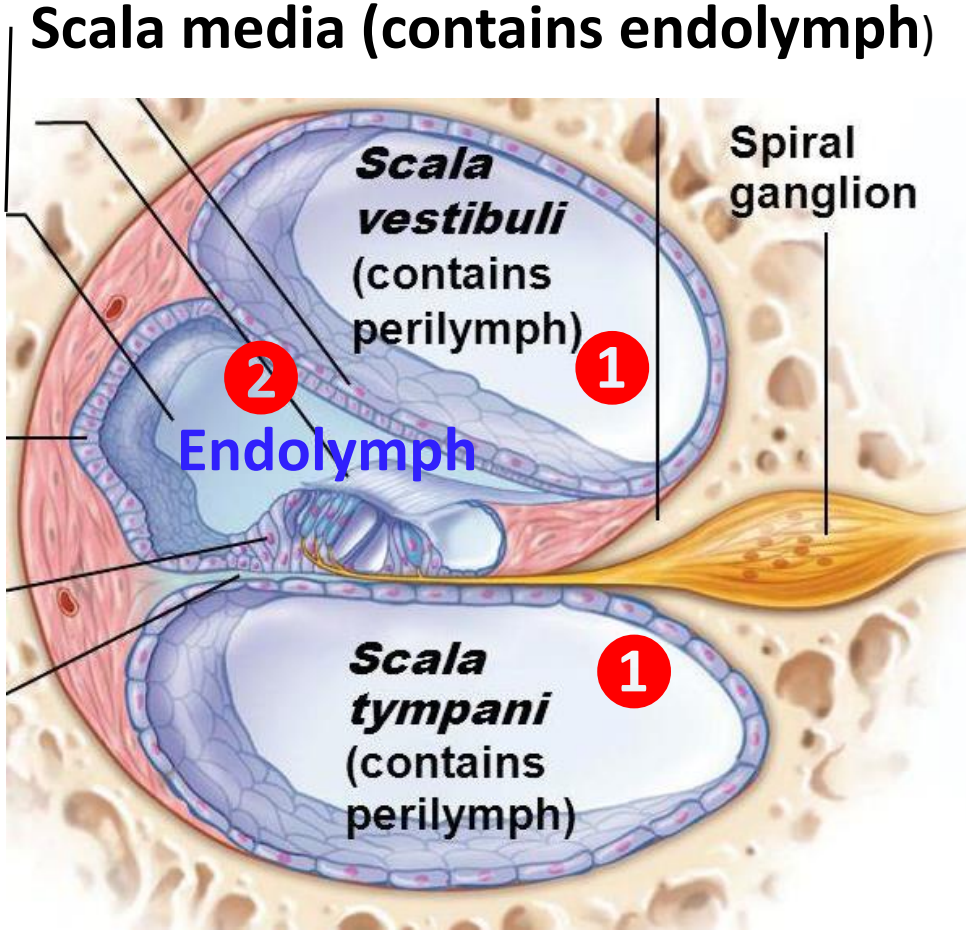
1. **Perilymph** : found in scala vestibuli & and scala tympani
   - It has a similar ionic composition as extracellular fluid found elsewhere
2. **Endolymph**: found inside the cochlear duct (scala media)
   - Has **a unique composition** not found elsewhere in the body!!
   - Is very rich in **K^+** (150**mM**), very poor in **Na^+** (1mM) and almost completely lacking in **Ca^{2+}** (20-30 **µM**).

Scala media (contains endolymph)



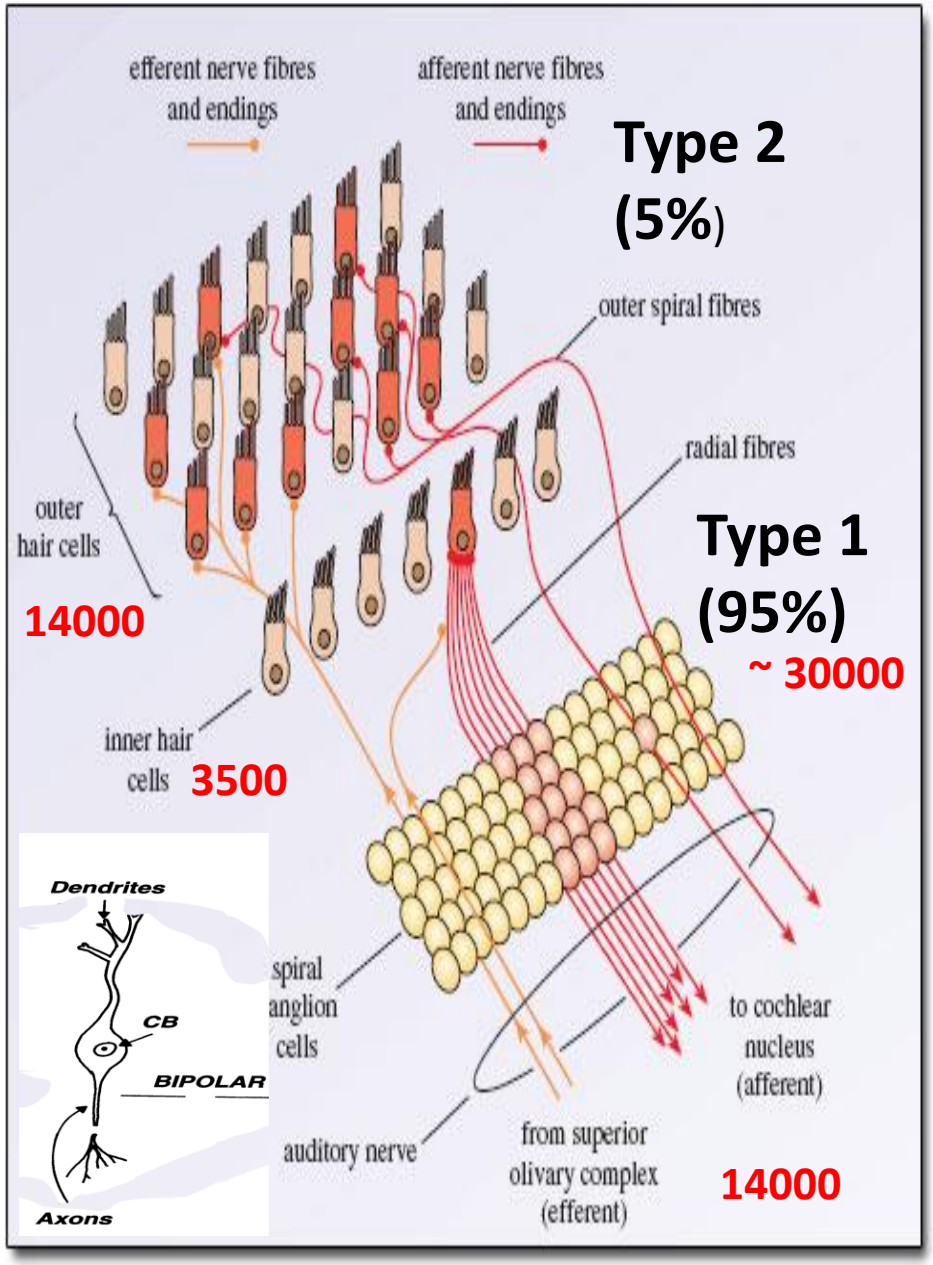
Composition of the Cochlear Fluids-2

- Only the stereocilia of the hair cells are bathed in **endolymph**
- The main body of hair cells and support cells are bathed in **perilymph**.
- The hair cells have a resting potential of ~-60mV, which favours an influx of $\mathbf{K^+}$.
- The driving force for K^+ will cause **K^+ influx**



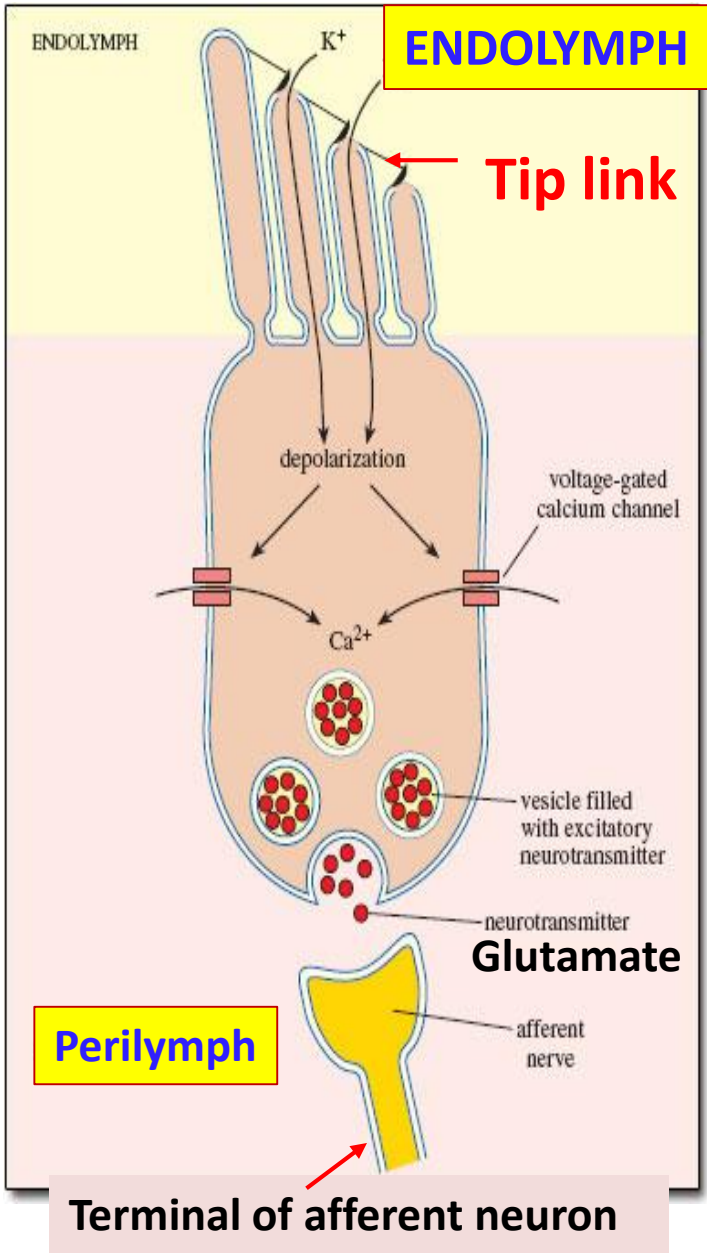
Organization of Hair Cells

- ~17500 hair cells within each cochlea
- Arranged in 4 parallel rows
- One row of **inner hair cells** innervated by **A-fiber afferents** (Type 1)
- About 95% (30000) of afferents are type 1
- Three rows of outer hair cells innervated by **C-fiber afferents** (Type 2; only ~5% of afferents)
- Protruding from surface of each hair cell are up to 100 hairs (stereocilia)
- Stereocilia move collectively as a unit



Inner Hair Cells: What are they?

- Are **mechanoreceptors**
- Are disturbed by vibrations of basilar membrane caused by sound waves.
- Vibration of the basilar membrane causes stereocilia to move toward the tallest hair
- This causes stretching of tip links which causes opening of mechanically gated **K^+ channels**
- Influx of **K^+** results in membrane depolarization



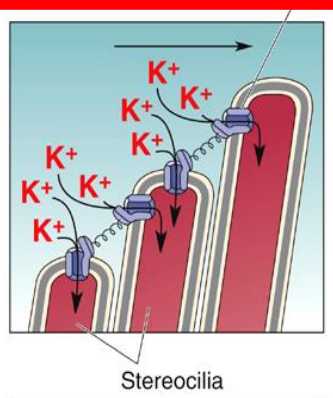
How Are Sound Waves Transuded into Neuronal Impulses? -1

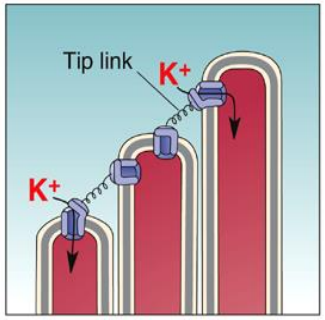
- Depolarization causes influx of **Ca^{2+}** needed for neurotransmitter release

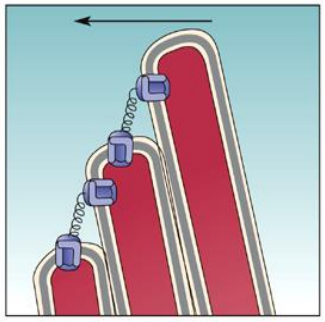
- Cilia return to original position- **K^+** ion channels close causing **hyperpolarization**

- Generate **receptor potential** (**Not action potential**) when their hairs are deformed by fluid movement

- They synapse with afferent **spiral ganglion neurons**







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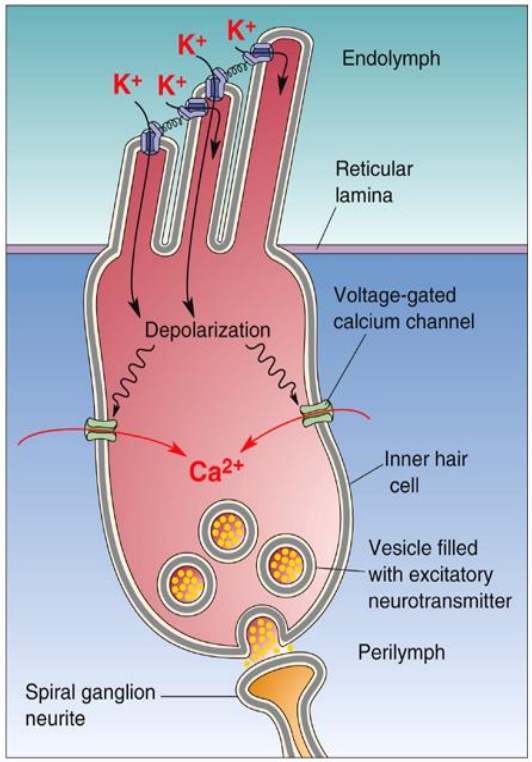

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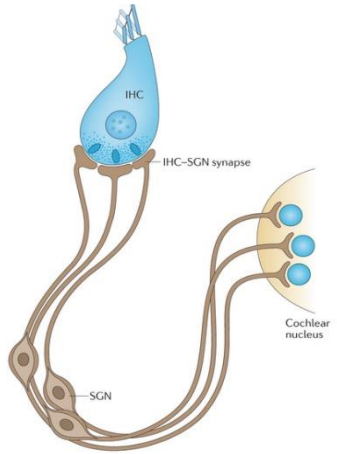
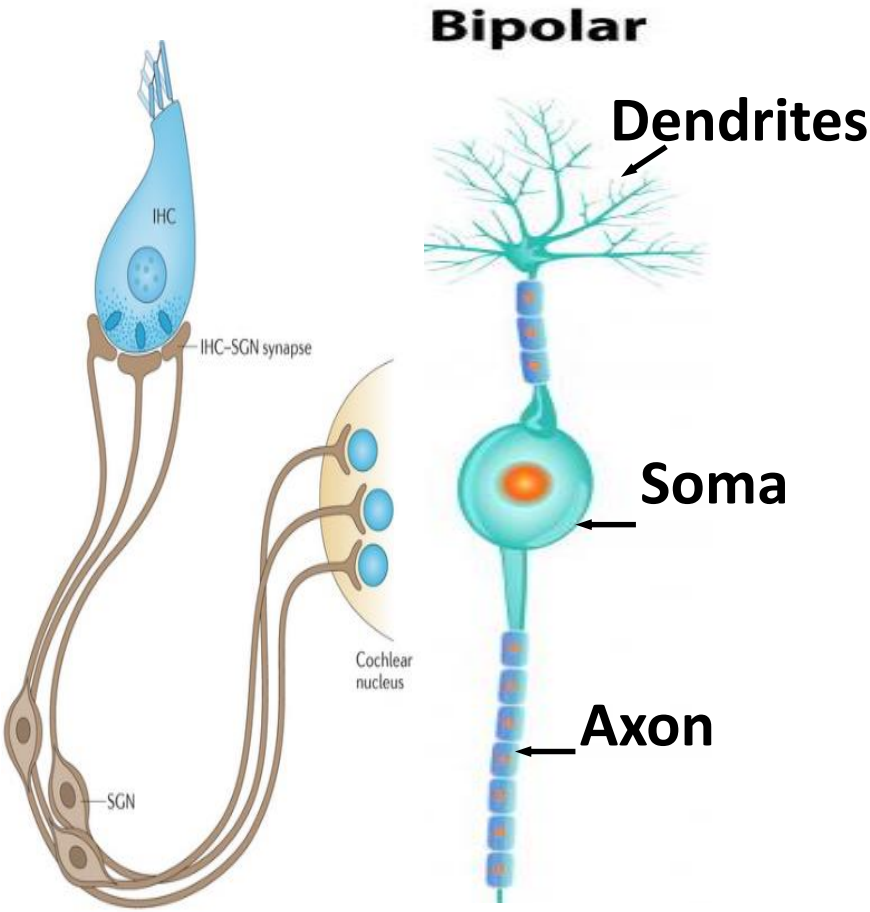


How Are Sound Waves Transuded into Neuronal Impulses?-2

- Inner hair cells communicate via a chemical synapse **(Glutamate)** with the terminals (**dendrites)** of **spiral ganglion neurons**
- These **1st order (type 1) neurons** are **bipolar.** The collection of their cell bodies form the **spiral ganglion.**
- Their axons (central) (form the **auditory nerve;** cranial nerve **VIII**) make their way and synapse on the **cochlear nucleus** in the medulla.

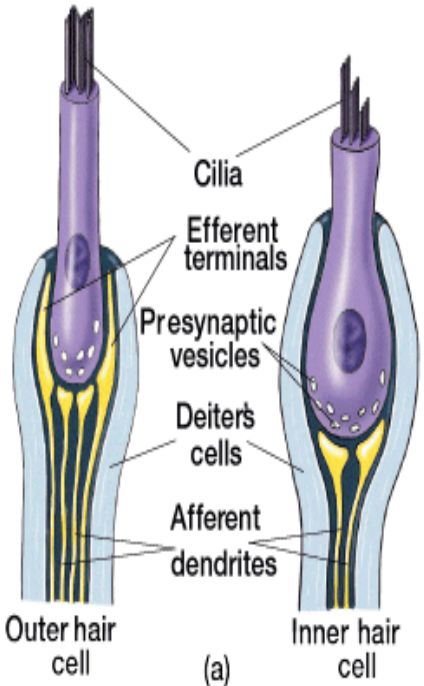


Spiral ganglion neuron

n= ~ 30000 neurons

Role of Outer Hair Cells

- Do not signal the brain about incoming sounds
- They rapidly alter their length in response to changes in membrane potential caused by incoming sound vibrations,
- Shorten on depolarization and lengthen on hyperpolarization



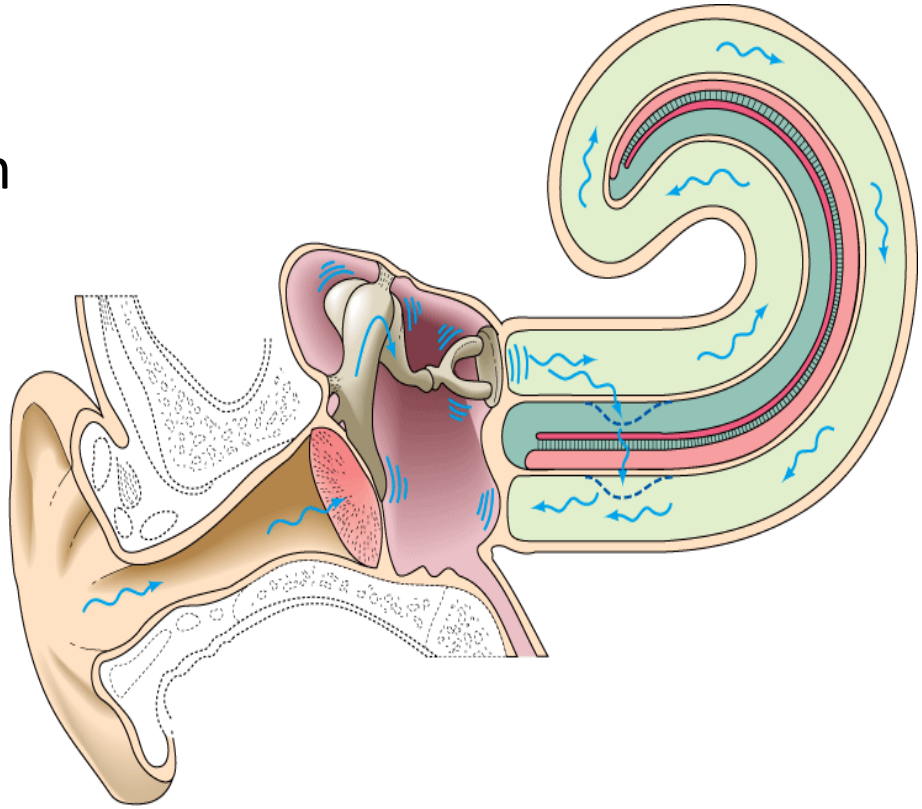
(a)


(b)

- They **amplify** motion of the basilar membrane
- Improve and tune stimulation of **inner hair cells**

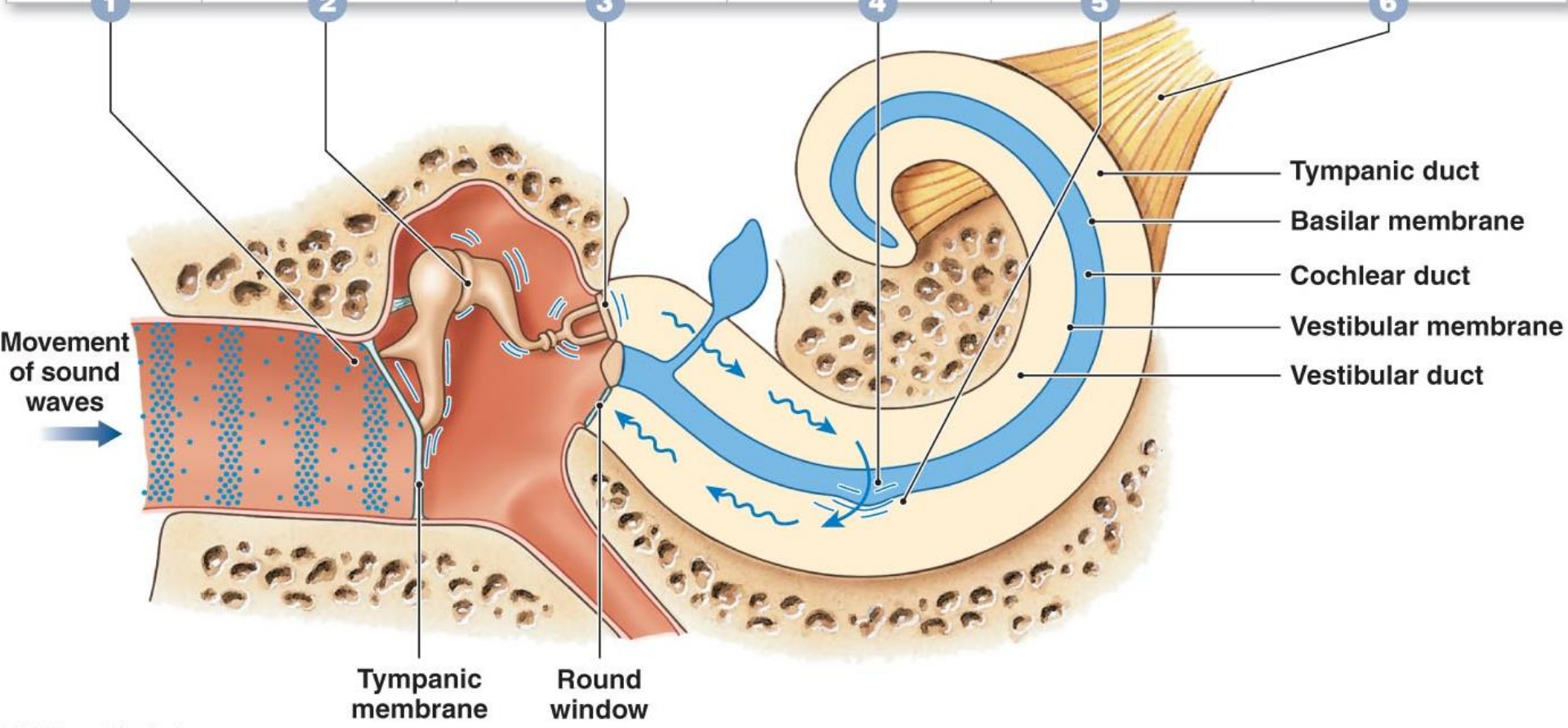
Transduction of Sound: Overview

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)



Events Involved in Activating Hair Cells

1. Sound waves arrive at the tympanic membrane.
2. Movement of the tympanic membrane causes displacement of the auditory ossicles.
3. Movement of the stapes at the oval window establishes pressure waves in the perilymph of the vestibular duct.
4. The pressure waves distort the basilar membrane on their way to the round window of the tympanic duct.
5. Vibration of the basilar membrane causes vibration of hair cells against the tectorial membrane.
6. Information about the region and the intensity of stimulation is relayed to the CNS over the cochlear branch of cranial nerve VIII.



Fluid Movement Within Cochlea Tubes

- The vestibular (Reisnner`s) membrane is so thin (is removed) and does not obstruct passage of sound vibrations
- The scala vestibuli and scala media are considered as one chamber, as far as fluid movement is concerned.

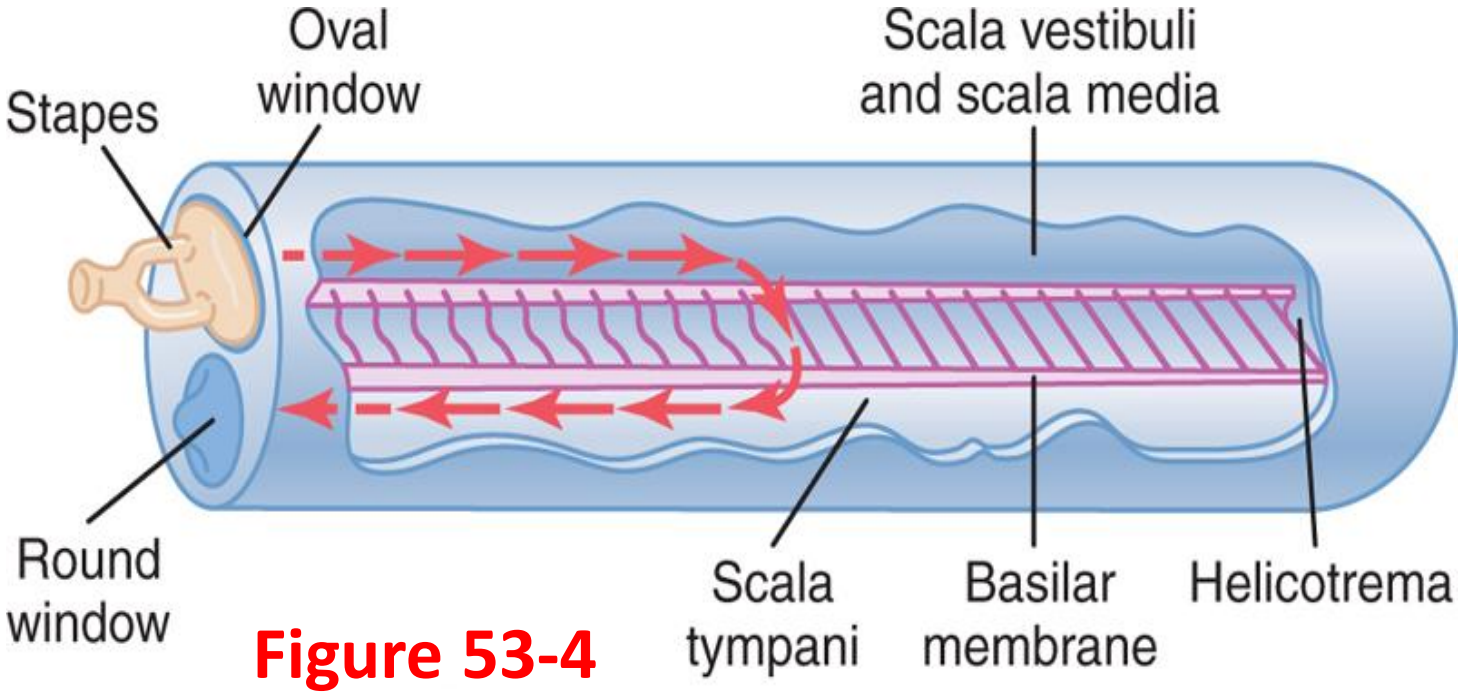


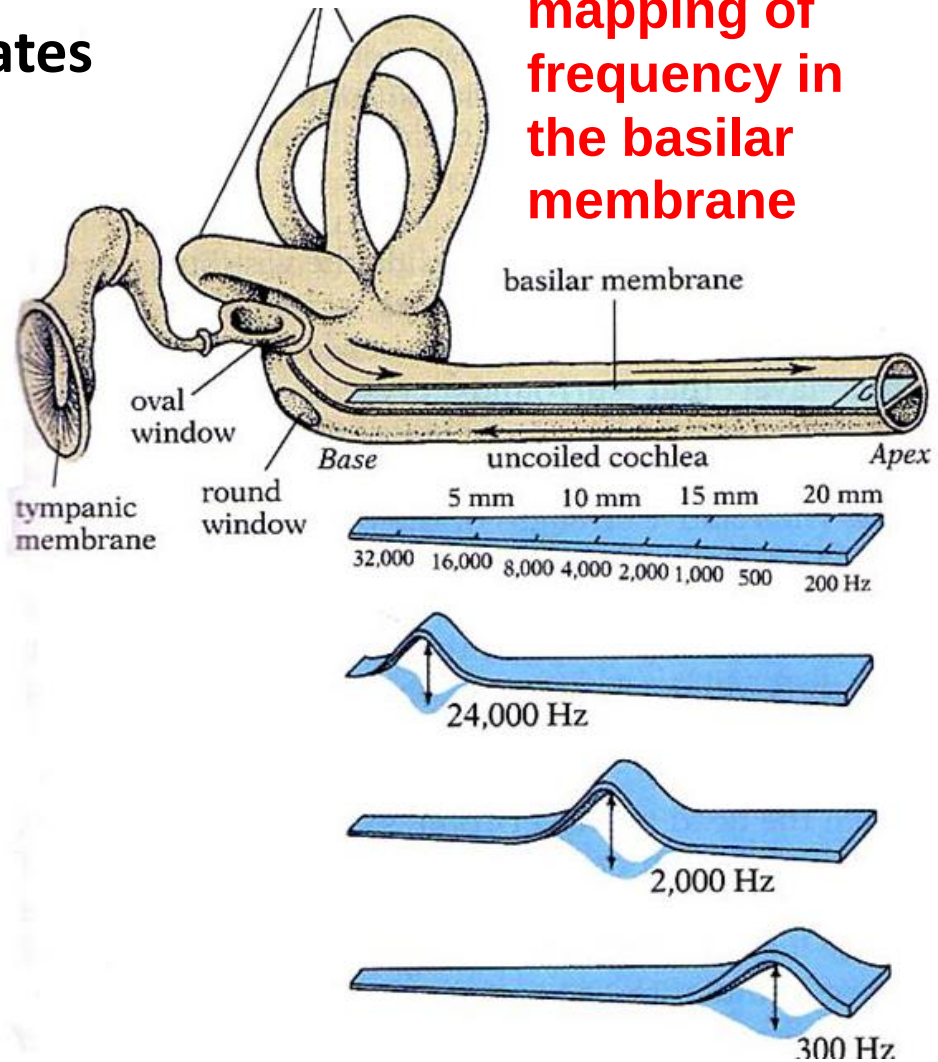
Figure 53-4

Pitch Discrimination

- ✓ **Distinguishing between different frequencies depends on the region of the basilar membrane that vibrates**

- Different regions of the basilar membrane vibrate maximally at different frequencies.
- **Base: narrower & stiffer**
  - Vibrates at higher frequencies
- **Apex: wider & more flexible**
  - Vibrates at lower frequencies
- **Maximal firing of afferent fibers depends on location along basilar membrane**

Tonotopic mapping of frequency in the basilar membrane



Loudness Discrimination

- **Loud sounds** cause the eardrum to vibrate more vigorously (bulge in and out to greater extent), but at the same frequency as a softer sound of the same pitch
- The great tympanic membrane deflection is translated into grater basilar membrane movement
- This causes greater bending of hair cells
- The CNS interprets greater hair bending as a loud sound

- **Pitch discrimination** depends on "**where**" the basilar membrane is maximally vibrating
- **Loudness discrimination** depends on "**how much**" that place vibrates

The Auditory Pathway

1. Spiral ganglion neurons (**Cochlea**)
2. Cochlear nerve **(VIII)**
3. Cochlear nuclei **(Medulla)**
4. Superior olivary complex **(Pons)** (**bilateral**)
5. Lateral lemniscus
6. Inferior colliculus **(Midbrain)**
7. Medial geniculate nucleus **(Thalamus).** ***NOT mid-brain, mistake in Fig. 53-10 Gyton & Hall Text book***)
8. Primary auditory cortex **(Temporal lobe).**

There are 4 relay stations in CNS for sound signals!

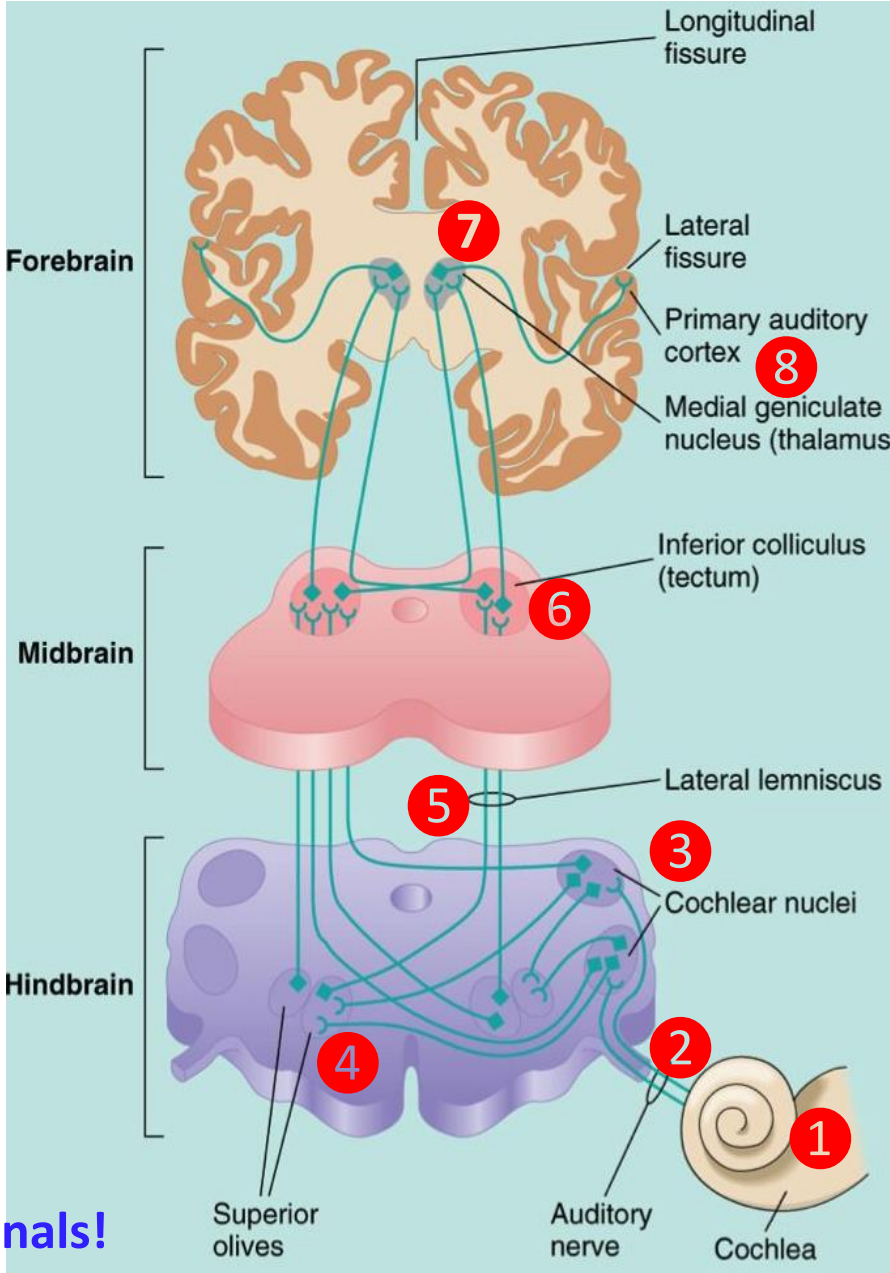
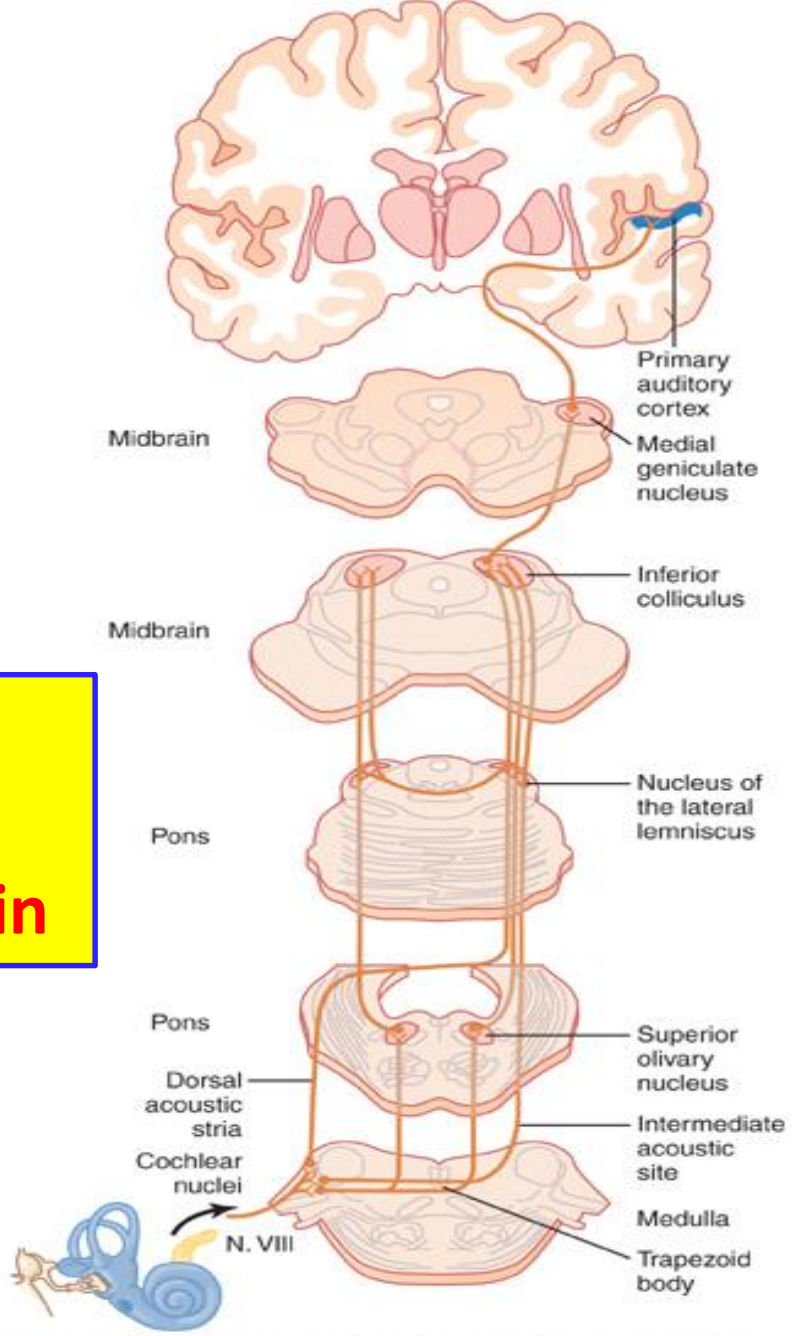


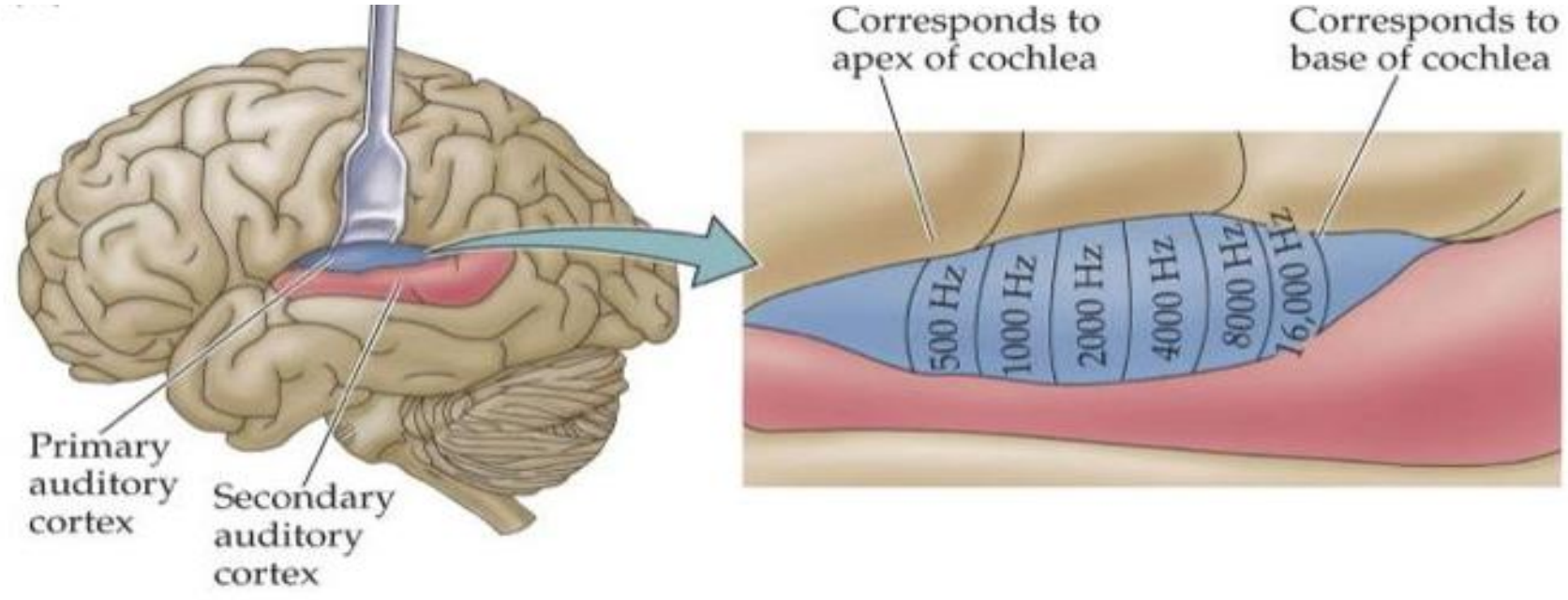
Figure. 53-10 (Gyton & Hall Text book)

Mistake: Medial geniculate nucleus is locate din the thalamus NOT in the midbrain



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



Typical Hearing Disorders-1

Conductive hearing loss: - inadequate transmission of sound **through external or middle ear due to**:

- Blocked auditory canal (wax, fluid)
- Rupture or perforation of tympanic membrane
- Otitis media - middle ear infection /inflammation
- Restriction of ossicular movements (e.g. by fibrosis or calicification)
- Osteosclerosis (pathological fixation of stapes on the oval window)
- Bone conduction is better than air conduction

- **Rinne`s hearing test: bone conduction is better than air conduction (abnormal)**
- **Normally:** air conduction is better than bone conduction

Typical Hearing Disorders-2

Sensorineural (nerve) deafness – hearing loss caused by disruption anywhere in pathway from hair cells to the auditory cortex due to:

- Loss of hair cells (explosion, chronic loud noise)
- Damage to vestibulocochlear nerve (VIII)
- Damage to nuclei / tracts to the cortex.
- **Weber`s hearing test:** (lateralization to better ear)

Neuronal presbycusis*:* degenerative age related process occurs as hair cells wear out with use (**loss of ~ 40% of hair cells by age 65**)

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

Hearing Tests

Rinne`s test

- The base of a vibrating tuning fork is placed on mastoid process until the sound is not heard
- Then the prongs of the fork held in air near the ear
- The difference in time is noted

Rinne`s Test Results

- Normally **AC > BC**
- If a patient has conductive hearing loss, **BC ≥ AC** .

Weber`s Test

- A vibrating tuning fork is placed on the middle of the head.
- The patient answers where the sound is coming from: the left ear, the right ear, or both.

Weber Test Results

- Normal hearing will indicate sound in both ears.
- **Conductive loss**: sound travels towards the **poor ear** (**lateralization to bad ear**).
- **Nerve loss**: sound travels towards the **good ear**

AC = air conduction

BC = bone conduction

Audiometer: air phone connected to electronic device emitting tones of low & high frequencies


Thank You
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