The Inner Ear

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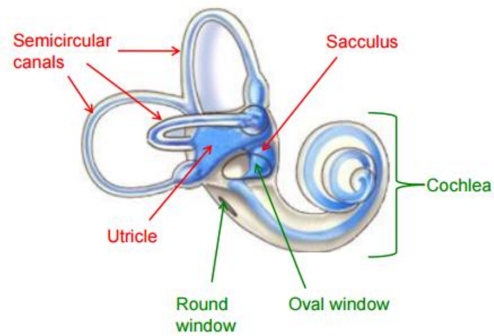
Learning outcomes

- Identify the anatomical landmarks of the inner-ear mechanism.
- Briefly describe the contributions of the inner ear to hearing and spatial orientation.
- List a variety of disorders that affect the inner-ear and give their causes, stating if they would be prenatal, perinatal, or postnatal in origin.

Inner Ear

- Vestibular apparatus: Balance
- Cochlea: Hearing



Anatomy and Physiology of the Inner Ear

- The footplate of the stapes fits into the oval window.
- The oval window is the separation between the middle ear and the inner ear.
- The immediate entryway is called the vestibule.
- The vestibule is filled with a fluid called perilymph.

The Vestibular Mechanism

- The human ability to maintain balance depends on information from three systems in the body, visual, proprioceptive and vestibular input.
- Interactions among these systems are controlled in the cerebellum.
- Within the vestibule, the membranous sacs the utricle and saccule are located which contain the endolymph.
- Arising from the utricle are the superior, lateral, and posterior semicircular canals.
- Osseous Labyrinths: Outer bony layer - Contains perilymph.
- Membranous Labyrinths: System of membranes inside osseous labyrinths - Contains endolymph.
- Any damage to the vestibular mechanism will cause vertigo

The auditory mechanism

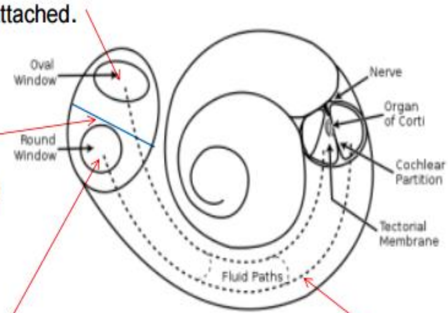
- Role of the cochlea

Mechanical vibration → Cochlea → Neural code

Cochlea

Oval window: membrane to which the stapes is attached.

Cochlea partition: membranes divide the cochlea into partitions all the way along its length

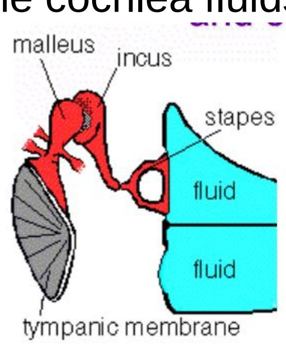


Round window

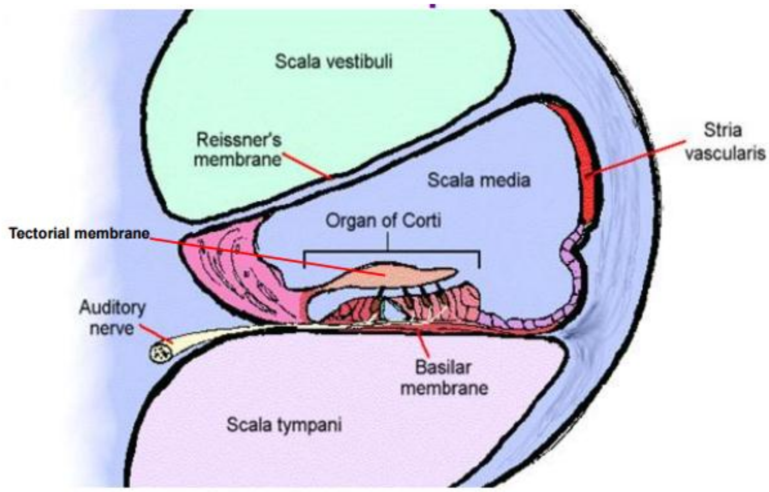
Filled with fluid

Interface between the middle ear and cochlea

The stapes is fused to the oval window of the cochlea. Movement of the stapes causes vibration of the cochlea fluids.



Cochlear partition



Tonotopic Organisation

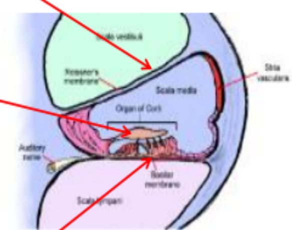
- Because of the structure of the BM/Organ of Corti, different sections mover up and down more easily to different frequencies of stimulation
- Apex moves easier for low frequencies
- Base moves easier for high frequencies
- The basilar membrane acts like a frequency analyser, splitting up sounds into their component frequencies.

Membranes

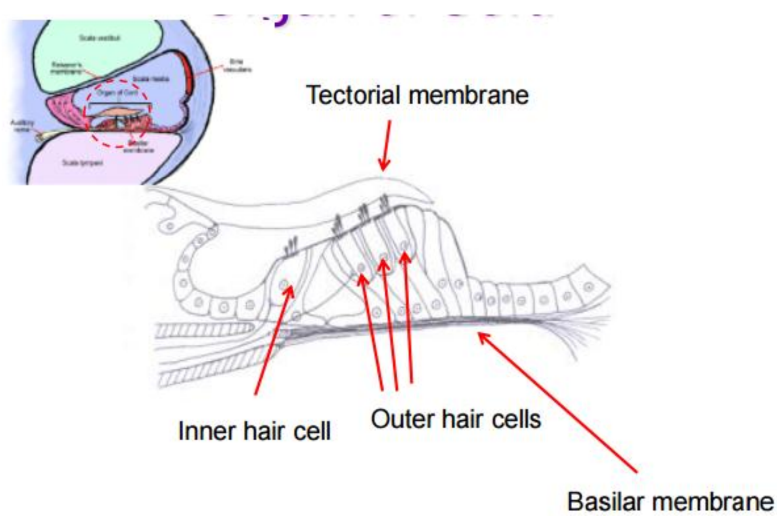
Reissner's membrane
Separates the fluid in the Scala media from that in the Scala vestibuli. Is very thin.

Tectorial membrane
Extends above the 'Organ of Corti'. It is made from gelatinous material, and does not contain any cells.

Basilar membrane
Vibrates in response to sound. The place of vibration depends on the frequency of the sound



Organ of Corti



Organ of Corti

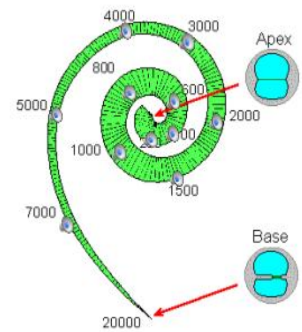
Basilar membrane motion causes the stereocilia on both the outer and inner hair cells to move from side to side.

Hair cell functions

- Inner hair cells
- Send electrical impulses to the brain via the auditory nerve. They are the site where mechanical vibrations are coded as electrical signals – known as mechanoelectric transduction.
- Outer hair cells
- Amplify basilar membrane motion. (more next time)

Basilar Membrane

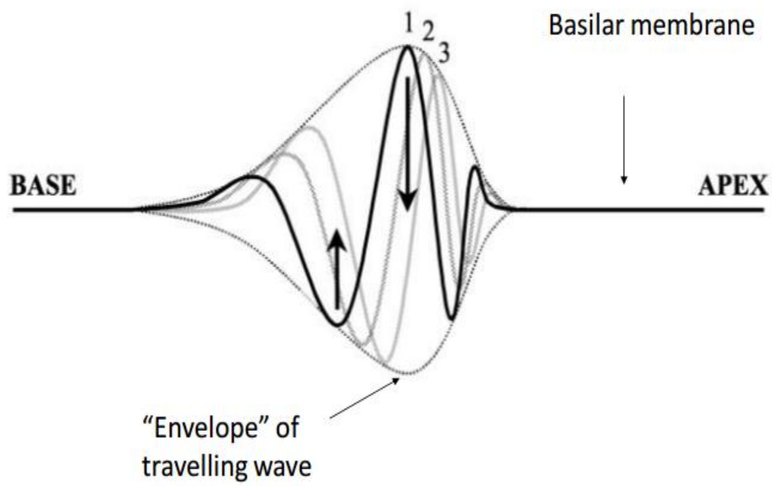
• Running the length of the cochlea is the basilar membrane.
• Each place on the membrane is tuned to a particular frequency
• Narrow and stiff at base = high freq.
• Broad and floppy at the apex = low freq.



Definitions – cochlear mechanics

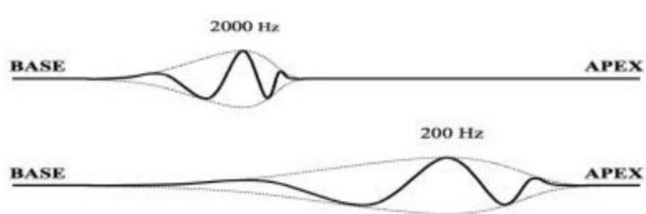
- Frequency tuning: Degree to which different frequency components are separated along the length of the basilar membrane. Also known as ‘frequency selectivity’.
- Characteristic frequency: Each place along the basilar membrane responds best to sounds of a particular frequency. This frequency is known as the ‘characteristic frequency’.

Travelling Wave



Travelling Wave

- When pressure waves enter the cochlea, the basilar membrane starts vibrate.
- The vibration takes the form of a "travelling wave", that appears to travel from the base of the cochlea to the apex.
- The wave peaks at the place tuned to the frequency of the sound, then dies away rapidly.



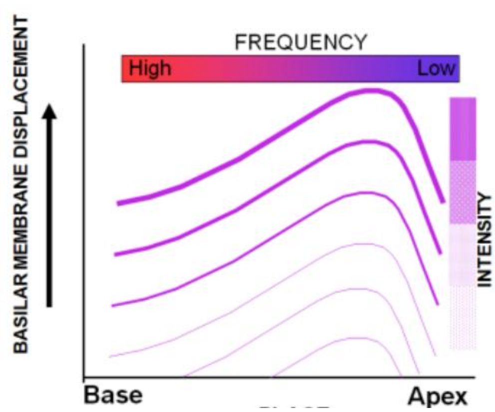
Passive Mechanism

- By studying corpse ears, we know that the passive mechanism results in the following basilar membrane properties:

1. Broad tuning and therefore poor frequency selectivity.
2. Insensitivity to low-level sounds.
3. Linear response growth.

Passive Mechanism - Linear Growth

Each curve shows the response for a different intensity tone.
• Increases the intensity of the tone in equal steps causes an increase in basilar membrane motion that is also in equal steps.
• 10dB increase in intensity results in a 10dB increase in displacement – linear system

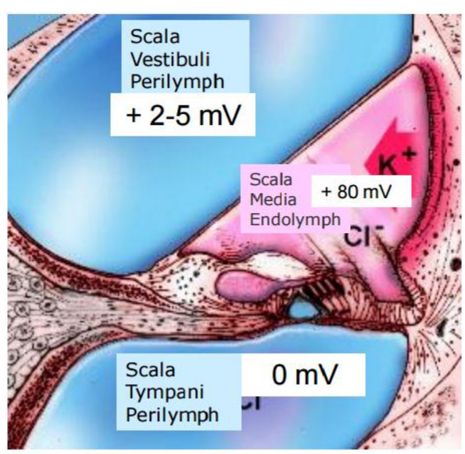


Measurements from healthy ears

- Basilar membrane responses from healthy ears look different: – Sharper frequency tuning (especially at low levels) – Better sensitivity to low level sounds – Compressive growth
- This is because in healthy ears, there is an additional 'active' mechanism that operates. This mechanism is a result of the activity of outer hair cells.

The fluids of the Cochlea

- Perilymph
  - HIGH Na+
  - low K+
  - Found in the scala vestibuli and scala tympani
  - Similar composition to most extracellular fluid.
- Endolymph
  - High K+
  - Low Na+
  - Found in the scala media
  - Similar composition to intracellular fluid.

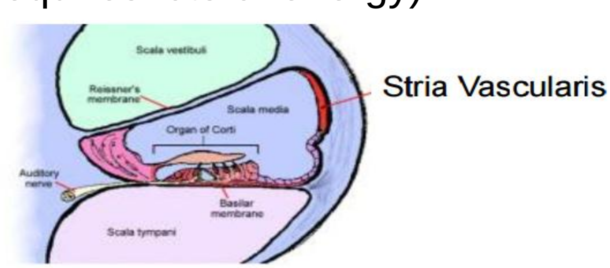


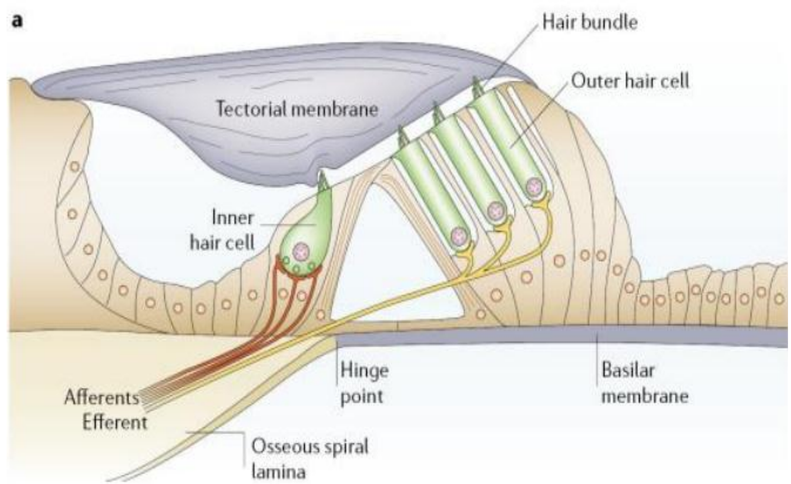
The fluids of the Cochlea

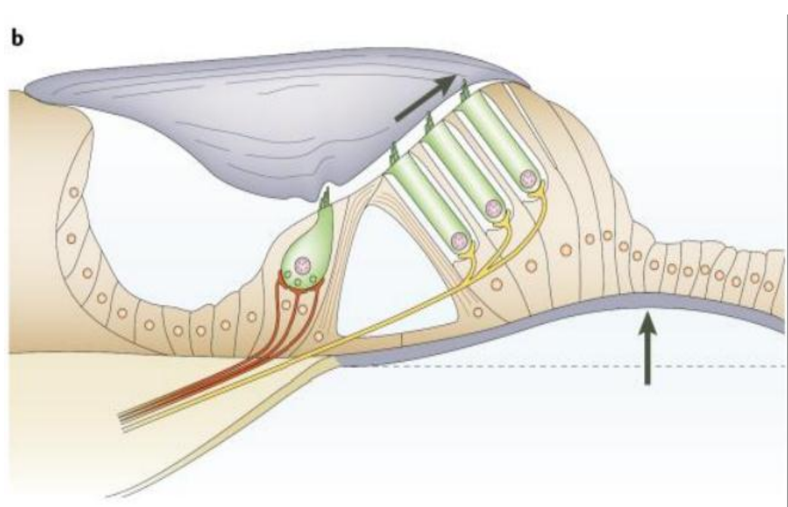
- A large +80 mV endocochlear potential is recorded between the scala media and scala vestibuli.
- The endocochlear potential is the driving force that is responsible for moving positively charged ions through the transduction channels of the hair cell stereocilia.
- The endocochlear potential is generated by active metabolic processes in cells within the stria vascularis.

Stria Vascularis

- Pumps K+ ions into the Scala media to form the endolymph Highly vascular (large blood supply) Metabolically active (pumping K+ ions out of cells requires lots of energy)




a
Hair bundle
Outer hair cell
Tectorial membrane
Inner
hair cell
Afferents
Efferent
Hinge
point
Basilar
membrane
Osseous spiral
lamina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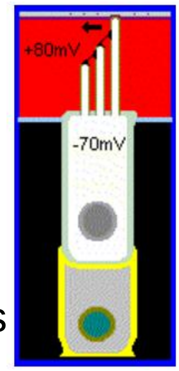
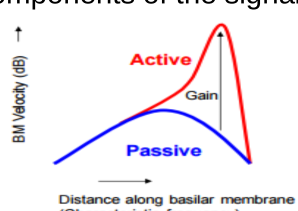
Outer Hair Cells

- When the stereocilia move, this causes potassium ions (from the endolymph in the scala media) to enter the cell.
- This leads to a shortening of the cell body in a process called 'electromotility'.



Active Mechanism

- The frequency selectivity of the basilar membrane is enhanced by the active amplification at places that are tuned (have a 'characteristic frequency' equal to) to the frequency components of the signal.



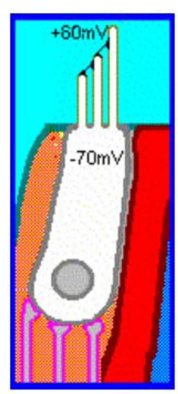
- The diagram shows the basilar membrane velocity along its length in response to a pure tone at a signal level, with and without active amplification.

Outer Hair cells Function

- Outer-hair cell damage, which occurs in many cochlear hearing losses, reduces this sharpening with a resultant decrease in speech-recognition abilities, especially in background noise.
- The outer-hair cells also enhance the reception of sound by the inner hair cells by shortening themselves thereby bringing the inner hair cells into contact with the tectorial membrane.
- Without this assistance from the outer hair cells, the inner hair cells are limited to stimulation from the motion of the endolymphatic fluid within the scala media responding only to sounds above about 40 to 60 dB SPL.

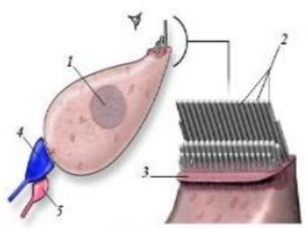
Inner Hair Cells

- When the stereocilia move, this causes potassium ions (from the endolymph in the scala media) to enter the cell.
- This electrical signal is transmitted to the auditory nerve fibres, and then to the brain.



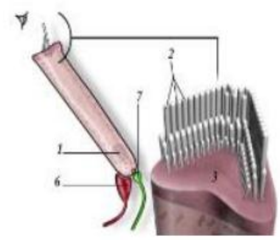
Inner Hair Cells

1. 3,500 IHCs
2. One row
3. There is no contact between stereocilia and tectorial membrane
4. Mechano-electric transduction



Outer Hair Cells

1. 12,000 OHCs
2. Three rows
3. The tips of the tallest raw of stereocilia are in contact with tectorial membrane
4. Active mechanism

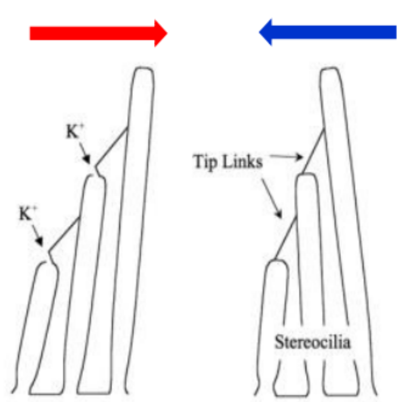


Mechanoelectric Transduction

When the stereocilia are bent in one direction, tip links stretch and open ion channels.

Positively-charged potassium ions enter the cell causing it to become "depolarised"

Stereocilia bent in other direction, tip-links close



The Cochlear Microphonic (CM)

1. Stereocilia bend
2. K+ flows into the IHC
3. IHC depolarised
4. Voltage-gated Ca2+ channels open; Ca2+ flows into the IHC
5. Neurotransmitter – glutamate – is released into the synaptic clefts at the base of the IHC
6. The neurotransmitter causes depolarisation of the dendrite of the auditory nerve.
7. Action potentials are generated in the auditory nerve fibre.

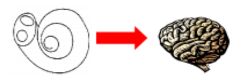
- The size of the cochear microphonic has been measured by placing pickup electrodes over the round window and, in some cases, within the cochlea.

The Action Potential (AP)

- At the moment that the auditory neurons are stimulated by the hair cells that rest on them, a change in the electrical potential occurs on the surface of each neuron. This is called the action potential (AP). Increases in the intensity of the auditory input signals to the cochlea result in increased electrical output from the hair cells. This stimulation causes increased electrical activity in the neuron.

Auditory neurones

- Two types of neurone have connections in the cochlea:
- Afferent neurons:



Transmit information from the cochlea to the brainstem.

- Efferent neurons: Transmit information from the brain to the cochlea.