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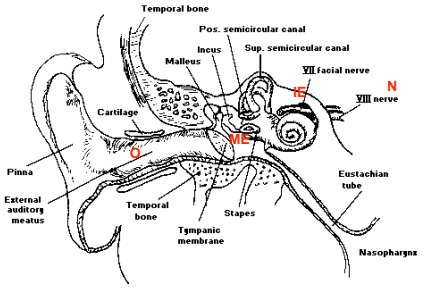
Gross Anatomy



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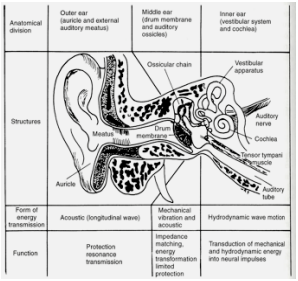
Structure, Energy Transmission and Function



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Structure, Function & Process

	External ear	Middle ear	Internal ear		Acoustic nervous system		
STRUCTURE			Basilar membrane	Receptor cells	Auditory nerve	Brainstem	Cortex
FUNCTION	Gather sound, protection	Transmission, transformer, protection	Filtering	Transduction	Simple coding	Complex coding, feature abstraction	Feature abstraction, perception
PROCESS	Mechanical vibration	Mechanical vibration	Mechanical hydro-dynamics	Mechanical to electrochemical	Electrochemical		

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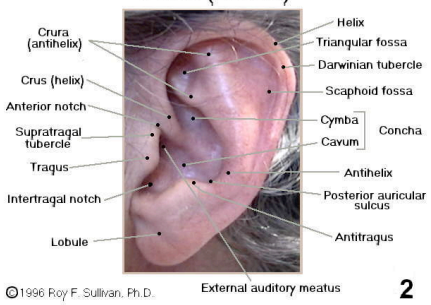
Pinna (Auricle)



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External Auditory Meatus or Canal (EAM, EAC)

- Outer third is cartilaginous
- Inner 2/3 is osseous
- Junction = Isthmus
- About 1" long
- 1/4" diameter
- Bends medially, anteriorly, & down
- Tightly lined with
  - Migratory skin
  - In cartilaginous portion:
    - Hair follicles
    - Earwax glands

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Outer Ear

- Pinna (auricle) + External auditory meatus or canal (EAM, EAC)
- Function
  - Collects sound and directs it towards eardrum
  - Protects deeper auditory structures
  - Localization (?in man?)
  - Resonance ≈ 20 dB boost to high speech frequencies

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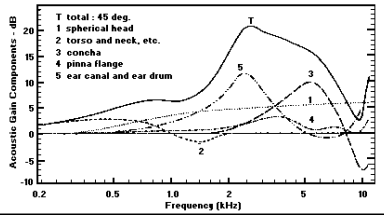
Outer Ear Resonance

- **EAC + concha + other structures boosts high frequencies ~ 20 dB SPL at eardrum**
- **Peaks at 2700 Hz in average adult ear**



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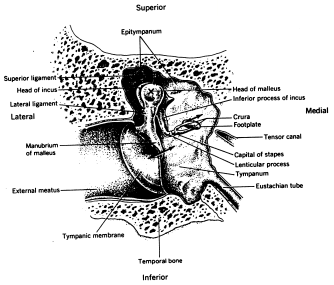
Middle Ear Structures

- Eardrum
- Ossicular chain
- Eustachian tube
- Middle ear muscles



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Middle Ear

- **Air space ventilated by the Eustachian tube**
- **Lateral boundary = tympanic membrane (TM) or eardrum**
- **Ossicles = chain of 3 bones suspended in tympanic space**
- **2 muscles**
  - **Tensor tympani (anterior wall to malleus)**
  - **Stapedius (posterior wall to stapes)**

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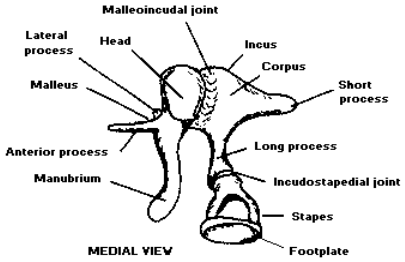
Ossicles



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Ossicles

- **Malleus**
  - **embedded in TM**
  - **Head to head joint with incus**
  - **Three ligaments**
- **Incus**
  - **Lentiform process - incudo-stapedial joint**
  - **One ligament**
- **Stapes**
  - **Fixed to oval window by an annular ligament**

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Impedance-Matching Function

- If airborne sound tried to enter the fluid-filled chamber of the IE directly, the mismatched impedances of air and fluid would cause 99.9% of sound energy to be reflected at the boundary

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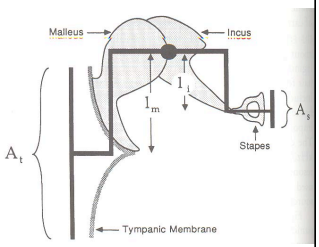
Impedance Matching

- Area ratio
  - 20-25 dB gain
- Leverage
  - 2-3 dB
- TM "Buckling"?
  - A few dB



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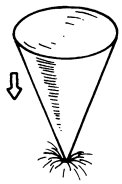
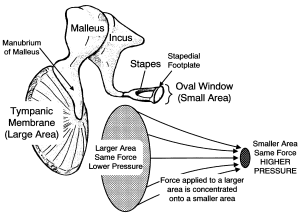
Area Differences Cause Pressure Changes

- As the area decreases, the pressure increases





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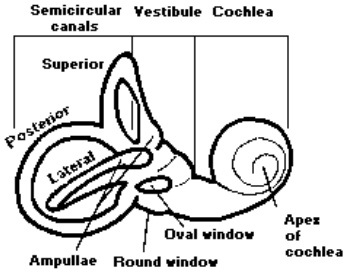
Osseous (Bony) Labyrinth



- **System of channels in petrous portion of temporal bone which house the vestibular and auditory end organs.**

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Osseous (Bony) Labyrinth

- **Vestibule**
- **Three Semicircular Canals**
- **Bony Cochlea**
  - **approx. 35 mm in length**
  - **2 ¾ turns in humans**
  - **Inner (modiolar) wall**
    - **Modiolus = honey combed inner core of cochlea**
    - **Spiral osseous lamina**
      - **Bony shelf forms inner attachment for basilar membrane**

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Internal Auditory Meatus or Canal (IAM, or IAC)

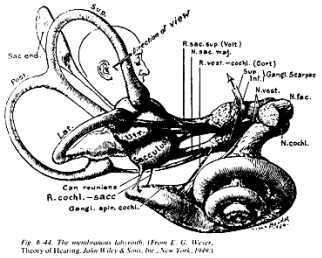

Fig. 8-44. The membranous labyrinth. (From E. G. Wever, Theory of Hearing, John Wiley & Sons, Inc., New York, 1949.)

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Internal Auditory Meatus or Canal (IAM, or IAC)

- **Junction of vestibular & cochlear branches of VIII n. and VII n.**
- **Pathology in region can cause**
  - **Unilateral hearing loss**
  - **Vertigo**
  - **Tinnitus**
  - **Facial paresis**

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Membranous Labyrinth

- Series of communicating endolymphatic sacs and ducts of similar structure
- Small strands of connective tissue fix membranous labyrinth in osseous channels

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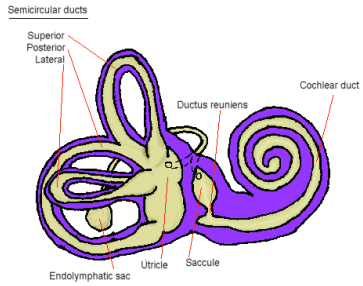
Membranous Labyrinth



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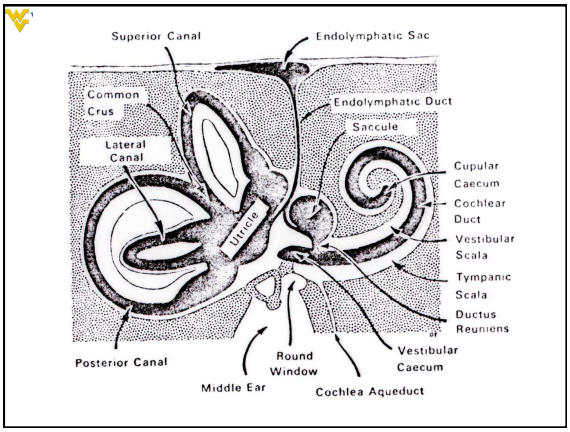

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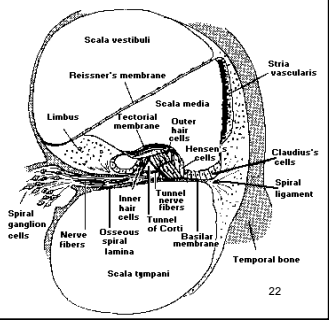
Cochlea Cross Section

- **2 membranes partition cochlea into 3 scala or ducts**
  - **Reissners Membrane**
  - **Basilar Membrane**



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Cochlear Fluids

- **Perilymph**
  - **Like extracellular fluids (CSF)**
  - **High sodium**
  - **Low potassium**
  - **No electrical potential**
- **Endolymph**
  - **High potassium**
  - **Low sodium**
  - **Like intracellular fluids**
  - **Except for positive electrical potential (approx. + 100 mV)**

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Cochlear Compartments

- **Perilymphatic**
  - **Upper**
    - **Scala vestibuli**
    - **Origin = vestibule, in region of oval window**
  - **Lower**
    - **Scala Tympani**
    - **Origin - round window**
  - **Communicate @ apex - "Helicotrema"**
- **Endolymphatic**
  - **Scala Media or cochlear duct**
    - **Hearing structures**
    - **Stria Vascularis**
      - **Lines outer surface**
      - **Highly vascular**
      - **Maintains endolymph**

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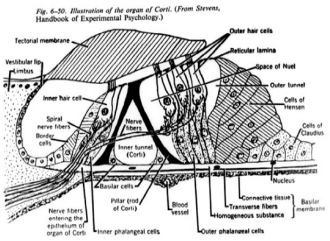
Organ of Corti



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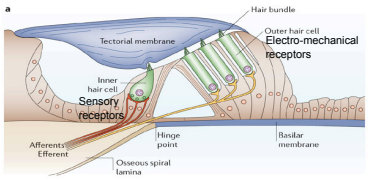
Hair Cells

- Inner Hair Cells – primary sensory receptors
- Outer hair cells – electro-mechanical receptors



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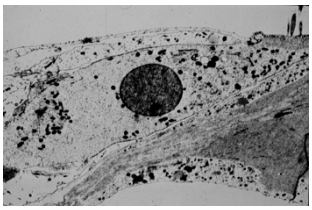
Inner Hair Cells (IHCs)

- **~ 3,500**
- **Single row along modiolar boundary**
- **Flask shaped**
- **Surrounded by supporting cells**
- **≥ 95% of afferent nerve fibers**



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Outer Hair Cells (OHCs)

- **15-20 k**
- **3-5 rows**
- **Cylindrical**
- **Anchored only at apex and base, while rest of cell body is surrounded by fluid in organ of Corti**
- **≤ 5% of afferent nerve fibers**

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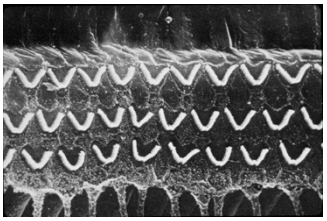
Outer Hair Cells

- **100 - 200 stereocilia**
- **3-5 rows in W pattern**
- **Top of W faces modiolus**



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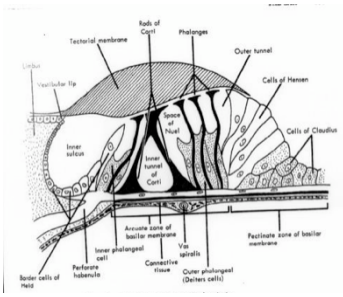
Supporting Cells



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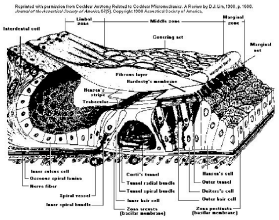
Tectorial Membrane

- **Gelatinous structure**
- **Attachments**
  - **Limbus**
  - **Loose connections to supporting cells of other extreme**



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Mechanical-Hydraulic Transduction

- Stapes motion alters the hydraulic pressure in vestibule
- Transmitted instantly through SV
- Velocity of sound in the cochlear fluids ≈160,000 cm/sec
- Cochlear fluids are incompressible
- Relieved by action of round window
  - Reciprocal movement of oval and round windows has been directly observed

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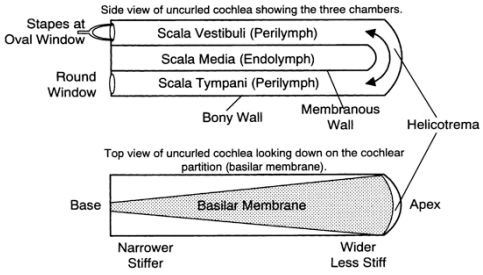
Cochlear Partition



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Hydraulic – Mechanical Transduction

- Perilymphatic compression creates a differential pressure across the S.M.
- S.M. acts as “cochlear partition”
- Slow pressure changes
  - Transmitted to ST (& round window) via helicotrema
- As cochlear partition is driven by more rapid motion of stapes, mechanical vibrations are produced in the form of “traveling waves”

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Traveling Waves

- No matter what, displacement of partition appears to move base >> apex
- Abrupt stimulus = decaying oscillation

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Traveling Waves

- If the cochlear partition is driven by sinusoidal motion of stapes
  - Each point on partition moves with a freq. identical to the acoustic stimulus
  - Not all points move in the same way at the same time

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Traveling Waves

- **Stiffness vs. frequency**
  - **Stiff structures respond best to high freq.**
  - **Flaccid structures = low frequencies**
- **Basilar membrane**
  - **Narrow and stiff in base**
  - **Wide and flaccid (floppy) in apex**
  - **Hence, point where amplitude of vibration is maximal shifts from base to apex as frequency is changed from high to low**

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Traveling Wave: 4000 Hz

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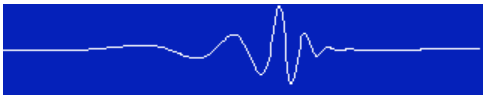
Traveling Wave: 1000 Hz



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Traveling Wave: 250 Hz

- < 50 Hz, traveling waves never reach maxima

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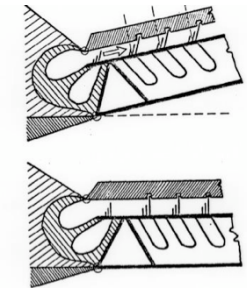
Hair Cell Activation

- **BM and tectorial membrane pivot around different points**
- **Causes a relative shift between tectorial mem. and organ of Corti**
- **Results in shearing of hairs in radial direction**



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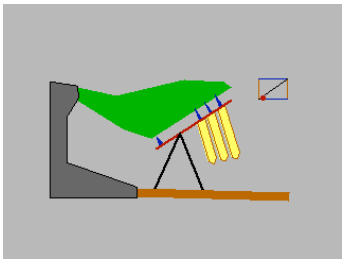
Radial Shearing



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The "Biological Battery"

- **Endocochlear potential**
  + 60-100 mV in Scala Media
- **Organ of Corti potential**
  -60 to -100 mV inside hair cells
- **Combined effect ≈ 140 mV differential across hair cell surface**

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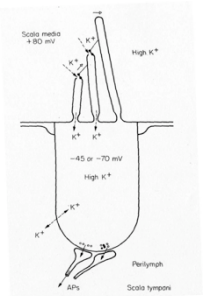
Mechanical - Electrochemical Transduction Control



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Mechanical - Electrochemical Transduction Control

- Tips of shorter stereocilia have ion channels for transporting K+ ions from endolymph into the cell
- Channels are capped by proteins which act like trap-doors
- When the cilia are moved outward, microfilaments pull open the "trap-doors" and K+ ions flow into the hair cell

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Mechanical - Electrochemical Transduction

- The flow of charged ions triggers
- In IHCs:
  - Release of neurotransmitter chemicals which activate auditory nerve fiber responses
- In OHCs
  - Electromotile response (shape changes)

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IHC - OHC Interaction

- Hair cells = mechanoelectrical transducers
  - Input = mechanical (ciliary deflection)
  - Output = electrical signal (receptor potential)
- OHCs = also electromechanical transducers
  - Input = electrical signal (receptor potential)
  - Output = mechanical (change in shape)

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OHC Motor Function

- Enhances sensitivity (threshold)
- Sharpens traveling wave tuning
- Generates otoacoustic emissions
  - Acoustic energy produced in the cochlea (by OHCs) and recorded in the ear canal

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OHC Motor Function

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