

## Chapter 15 Hearing & Equilibrium

### **ANATOMY OF THE OUTER EAR**

EAR PINNA is the outer ear...it is thin skin covering elastic cartilage. It directs incoming sound waves to...

the EXTERNAL AUDITORY CANAL, which is skin-lined canal containing hair and sebaceous glands. The glands are actually the CERUMINOUS GLANDS, which secrete cerumen. Its purpose is to trap foreign particles. Next, the sound waves go to the...

TEMPANIC MEMBRANE (ear drum). It is a thick, flattened conical CT membrane. It is covered by skin externally and mucosa internally.

### **ANATOMY OF THE MIDDLE EAR**

The MIDDLE EAR is air-filled space inside the temporal bone. It is lined by mucosa that is *continuous with the pharynx* anteromedially via the *auditory tube*, which is collapsed most of the time. The auditory tube allows equalization of atmospheric pressure so the tympanic membrane can move freely (when the ear has a lot of pressure, the TM is taut and doesn't vibrate as much. This is why I'm always pretty deaf when I get off a plane.)

### **BONES OF MIDDLE EAR**

The bones of the middle ear are called OSSICLES. They transmit and amplify tympanic membrane vibrations to the inner ear.

- Malleus (hammer)
- Incus (anvil)
- Stapes (stirrup)

OVAL WINDOW is a foramen in medial wall of the middle ear. It is covered by the footplate of the stapes.

ROUND WINDOW is inferior to the oval window. It has a diaphragm, meaning it is covered by secondary tympanic membrane.

### **SKELETAL MUSCLES OF THE MIDDLE EAR**

The muscles of the middle ear reflexively contract to *dampen loud sounds*.

- The TENSOR TYMPANI contracts and tenses tympanic membrane
- The STAPEDIUS decreases the movement of the stapes

### **ANATOMY OF THE INNER EAR**

The divisions of the inner ear are the BONY LABYRINTH and the MEMBRANOUS LABYRINTH. The bony labyrinth is actually cavities in the temporal bone. It is filled with *perilymph*, which is similar to CSF.

Think of it as a fluid-filled sac floating in a fluid-filled space.

The membranous labyrinth is a tubular structure. Its continuous membrane sacs follow the path of the bony labyrinth. The sacs are filled with *endolymph*, similar to intracellular fluid.

## VESTIBULE

Bony labyrinth component: The VESTIBULE is a central, ovoid region of the *bony labyrinth*. It is medial to the middle ear.

Membranous labyrinth component: Organs of static equilibrium. These are the *sacculle* (smaller, anterior) and the *utricle* (larger, posterior)

Each of these contain *maculae*, which is a patch of columnar supporting cells. They are intermingled with hair cells. Each of the hair cells bears numerous *stereocilia* and a single *kinocilium*.

The SACCULE and UTRICLE are two membraneous labyrinth sacs in the vestibule. The smaller one, the SACCULE is continuous with the membranous labyrinth extending anteriorly into the cochlea, whereas the UTRICLE is continuous with the semicircular ducts extending into the semicircular canals posteriorly.

- Stereocilia and kinocilia are embedded in otolithic membrane... a gelatinous mat that sits on top of the macula).
- The membrane is weighted down by the otoliths. These are crystals embedded in superficial surface of the membrane. The weight makes the membrane move more due to inertia.

## SEMICURCULAR CANALS

These are three partial circles within the *bony labyrinth*. They are set at right angles to one another, two are vertical and one is horizontal. The *membranous labyrinth* component here is the organ of dynamic equilibrium...the SEMICIRCULAR DUCTS. They open from utricle and there is an enlarged ampulla at one end of each duct.

## AMPULLAE

Ampulla houses an equilibrium receptor called a CRISTA AMPULLARIS. These receptors respond to angular movements of the head. They are analogous to the vestibular maculae. Each CRISTA AMPULLARIS is composed of supporting cells and hair cells. The hair cells also have stereocilia plus one kinocilium that project into a cone-shaped, gel-like mass called a CUPULA.

## THE COCHLEA

The cochlea is a spiral, conical, bony chamber about the size of a split pea. It extends from the anterior part of the vestibule and coils for about 2.5x around a bony pillar, the MODIOLUS. If you think of the modiolus as a screw, then the threads on the screw are the SPIRAL LAMINA.

The *membranous labyrinth* in this area is the organ of hearing...the COCHLEAR DUCT. This is a wedge-shaped extension from the vestibule that winds through the cochlea and contains receptors.

The cochlear duct and the spiral lamina divide the cochlea into three regions.

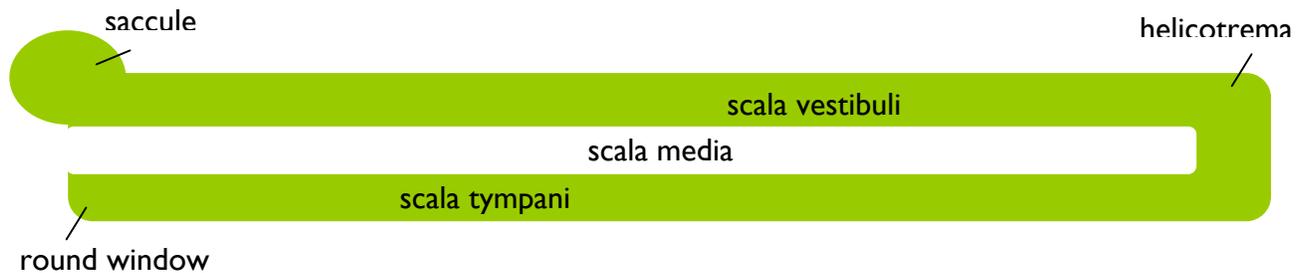
1. SCALA MEDIA (membranous labyrinth) is the interior of the cochlear duct. It is continuous with the saccule, so contains endolymph.
2. SCALA VESTIBULI (bony labyrinth) is superior to the scala media. It is continuous with the vestibule and contains perilymph.
3. SCALA TYMPANI (bony labyrinth) is inferior to the scala media. It ends at the round window. It contains perilymph.

The VESTIBULAR MEMBRANE separates the scala vestibuli from the scala media. It is located at the roof of the cochlear duct.

The BASILAR MEMBRANE separates the scala media from the scala tympani. It is located at the floor of the cochlear duct.

The COCHLEAR NERVE branches arise from the cochlear duct and they converge in the center of the modiolus.

The HELICOTROMA is the apex of the cochlea. This is where the cochlear duct ends, and also where the scala media ends. The scala vestibuli and the scala tympani meet each other around the end of the cochlear duct.



The ORGAN OF CORTI is the sensory receptor in the organ of hearing, and is located in the COCHLEAR. It rests on the *basilar membrane*. The supporting cells surround cochlear hair cells that include one row of inner hair cells and three rows of outer hair cells. Both types of hair have the typical stereocilia and one kinocilia. All these cilia are imbedded in gelatinous material called the TECTORIAL MEMBRANE (longest stereocilia are embedded within.)

## **HEARING**

SOUND PRODUCTION involves the rapid compression and rarefaction of air or other substance. Sound energy is funneled down the external auditory canal by the ear pinna. The sound waves strike the tympanic membrane and the tympanic membrane vibrates in response. The ossicles transmit amplified volume through the middle ear to the oval window

Next, the OVAL WINDOW vibrates, which creates a fluid wave of the perilymph of the scala vestibuli. The wave is transmitted down the scala vestibuli through the cochlear duct at the scala media. The ROUND WINDOW vibrates as the fluid reaches it.

### **BASILAR MEMBRANE RESONANCE**

The basilar membrane fibers span width of the membrane. The fibers are short and stiff near the oval window end (vestible). They increase in length and decrease in stiffness the further you go along the cochlear duct. The fibers are long and loose at the helicotrema.

The basilar membrane resonates spatially with different frequencies.

- Higher pitches near oval window
- Lower pitches near helicotrema

### **BASILAR MEMBRANE VIBRATION**

The vibration creates a deflection of the inner hair cells stereocilia (they bend, so they stimulate the nerve).

- Bends **toward kilocilium** cause depolarization
- Bends **away from the kilocilium** cause hyperpolarization

This causes bursts of impulses traveling along cochlear nerve (signal is transmitted)

The outer hair cells (the rows of three) transmit little information to the brain. Their role is to alter the mobility of the basal membrane, which **amplifies the inner hair cell response**.

### **AUDITORY PATHWAY**

Impulses generated in the cochlea pass through the SPIRAL GANGLION (in modiolus) where the auditory bipolar neurons reside, and along the afferent fibers of the cochlear nerve to the cochlear nuclei of the medulla.

From there, impulses are sent on to the SUPERIOR OLIVARY NUCLEUS and then the INFERIOR COLLICULI, which is the auditory reflex center in the midbrain), and then on to the THALAMUS, then out to the AUDITORY CORTEX in the temporal lobe. The cortex receives bilateral input, which is necessary for localization of sound.

### **AUDITORY PROCESSING**

- PITCH
  - processed at the cochlear level
  - spatial mapping of pitch to auditory cortex
- VOLUME
  - Louder sound creates a larger fluid wave, which results in larger vibrations and deflections, and larger graded potentials on the hair cells.
  - This causes the release of more neurotransmitter (CN VIII)
  - Action potentials generated more frequently
  - More bipolar spiral ganglion neurons are recruited with bigger stimulus
- LOCALIZATION
  - Off-center sounds activate one ear sooner and more intensely
  - Mid-line sounds...can't tell if front, back or above

## **EQUILIBRIUM**

STATIC EQUILIBRIUM is the position of the head in space, relative to gravity. It also refers to linear acceleration, which is straight-line changes in speed and direction (velocity). It is perceived in the VESTIBULE.

- Maculae of utricles is horizontal and detect horizontal movement...forward, backward, side to side
- Maculae of saccule is vertical and detects up and down movement.

### HOW DOES THIS EQUILIBRIUM THING WORK?

Inertia of otolithic membrane to movement causes it to lag behind. When this happens, the embedded stereocilia get bent (deflection). If bent toward the kinocilia then it's a depolarization (NT release and impulse generation increases). If they get bent away from the kinocilia, then it's hyperpolarization (NT release and impulse generation decline).

The mechanism adapts quickly and only detects changes in movement.

DYNAMIC EQUILIBRIUM relates to the sense of rotational acceleration (turning movements). It is perceived by the semi-circular canals, namely the crista ampularis. Rotation of the head causes inertial fluid movement in the semicircular ducts. The fluid moves past the cupula and deflects the stereocilia. Remember that the mechanism is bilateral. The cupula goes in the opposite direction on the opposite side. Again, bending of the cilia in the opposite direction causes hyperpolarization...so there is increased firing on one side, and decreased firing on the other side.

## **EQUILIBRIUM PATHWAYS**

Equilibrium is not a conscious sense as there are no cortical connections. The reflex pathways activate first. Signals are sent to the...

- cerebellum
- vestibular nuclear complex in the brainstem
- both regions also receive input from
  - visual pathway
  - somatic sensory (primarily cervical proprioceptors)

Output is sent to the extrinsic eye muscles as well as neck, trunk, and limb musculature. This allows for reflexive adjustments of head position and posture.

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