Special Senses: EAR

Sources:

- Stevens & Lowe's Human Histology Fourth Edition
- Wheater's functional histology: a text and colour atlas.
- OXFORD HANDBOOK OF CLINICAL SPECIALTIES-NINTH EDITION

Learning objectives:

1. Understand the bony and membranous labyrinths.
2. In the vestibule be able to recognize and describe the function of the sensory end organs.
3. Be able to recognize and describe the function of the components of the cochlea including the organ of Corti.
4. Be able to distinguish the auditory parts of the inner ear from those of the vestibular system. What are their roles in hearing and balance?
5. What are sensory hair cells?
6. What is presently the only known "cure" for deafness besides hearing aids?

Introduction

The ear has the dual sensory function of maintenance of *equilibrium* and *hearing.* Structurally, the ***Vestibulocochlear*** system may be divided into three parts, the ***external ear***, the ***middle ear*** (or **tympanic cavity**), and the ***internal ear*** (or **labyrinth**).

The specific sensory receptors for both movement and sound are situated within a membranous structure located in the internal ear, while the external and middle ear are concerned with reception, transmission and amplification of incoming sound waves.

The external ear:

Comprises the pinna and external auditory canal. Is responsible for reception of sound waves which are funneled onto the eardrum. **The pinna** is composed of elastic cartilage covered by hair-bearing skin.

External Auditory Meatus:

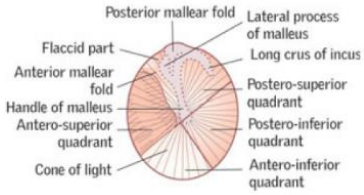
- It is a sinous tube that leads from the auricle to the tympanic membrane, conducting sound waves along its pathway.

- The outer third of the meatus is formed of elastic cartilage, and the inner two-thirds is bone (formed by the tympanic plate of the temporal bone).
- Is lined by thin skin which is closely bound to the underlying cartilage or bone by a dense collagenous dermis. The skin of the outer third has fine hairs which provide protection from foreign bodies.
- The dermis contains numerous coiled tubular ***ceruminous glands*** which secrete wax (cerumen). These glands open directly onto the skin surface or into the sebaceous glands associated with hair follicles.
- The accumulation of the secretions of the ceruminous glands together with sebaceous secretions, and desquamated cells produce a yellowish-brown waxy material called **cerumen** which protects the skin of the external auditory meatus from moisture and infection.

Tympanic Membrane (Eardrum):

Is pearly grey, thin fibrous membrane separating the external auditory canal from the cavity of the middle ear.

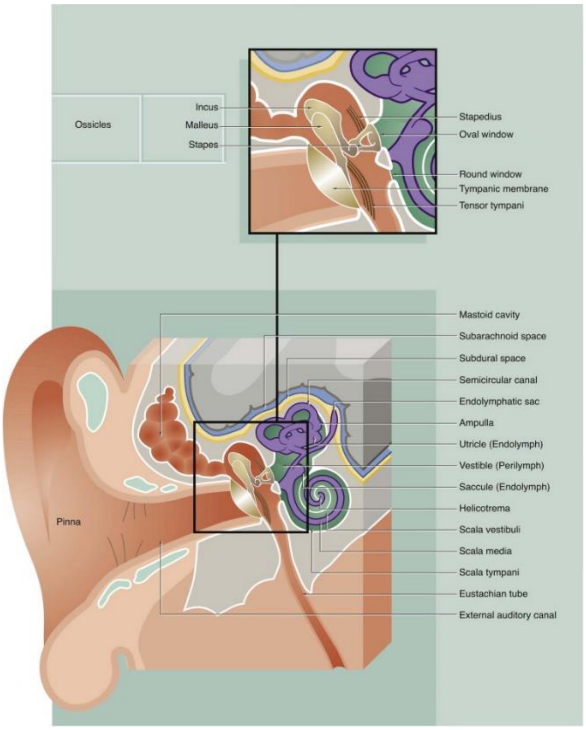
The anterior upper quadrant of the tympanic membrane ***(pars flaccida)*** is flaccid and more transparent***,*** since the connective tissue layer is much thinner there. This region is known as ***Shrapnell's membrane***. The remaining part of the membrane is tense ***(pars tensa)*** being firmly attached to the surrounding bone by a fibrocartilagenous ring. The ***handle*** of the ***malleus*** is attached to the centre of the membrane. Structurally, the tympanic membrane is made up of three layers:



- An external ***cuticular layer:*** consists of thin hairless skin, the epidermis being only about 10 cells thick and the basal layer being flat and devoid of the usual epidermal ridges.
- An intermediate ***fibrous layer*** consists of an outer layer of fibres radiating from the centre of the membrane towards the circumference and an inner layer of fibres disposed circumferentially at the periphery.
- An inner ***mucous layer*** represents a continuation of the modified respiratory-type mucous membrane lining the middle ear cavity, but in this situation it is merely a single layer of cuboidal cells devoid of cilia and goblet cells. The underlying lamina propria is thin with a blood supply separate from that of the dermis of the cuticular layer. A similar modified respiratory-type mucosa invests the ossicles, small muscles and nerves exposed to the middle ear cavity.

The Middle Ear (Tympanic Cavity):

- Is an air-containing cavity in the petrous part of the temporal bone and is separated from the external auditory canal by the tympanic membrane.
- It contains the auditory ossicles, 3 small compact bones, articulated by synovial joints and covered externally by the same low cuboidal epithelium that lines the inner ear. These ossicles transmit the vibrations of the tympanic membrane (eardrum) to the perilymph of the internal ear through the oval window.
- Two small skeletal muscles, the ***tensor tympani*** and ***stapedius***, pass to the midpoint of the tympanic membrane and stapes bone, respectively, and damp down excessive vibrations which might otherwise damage the delicate auditory apparatus.
- The tympanic cavity communicates in front (anteriorly) with the nasopharynx through the auditory (Eustachian) tube which is lined by ciliated epithelium similar to that of the respiratory tract. Its function is to equilibrate pressure between the middle ear cavity and the atmosphere. Normally, the auditory tube is collapsed, but it is opened by movement of muscles in the nasopharynx, such as occurs with swallowing or yawning.
- From behind (posteriorly), the middle ear cavity communicates directly with air-filled spaces in the mastoid bone (**mastoid sinuses**), which are lined by low cuboidal or flattened squamous epithelium.



The Inner Ear:

Is situated in the petrous part of the temporal bone, medial to the middle ear and it consists of:

1. A series of bony cavities in the temporal bone of the skull called the ***bony labyrinth***.
2. An interconnected fluid-filled sacs that are contained within the bony labyrinth called the ***membranous labyrinth***.

The bony labyrinth is divided into three main areas:

- **The vestibule.** The central part of the osseous labyrinth; it gives rise to three ***semicircular canals*** posteriorly and to the ***cochlea*** anteriorly. The vestibule contains two components of the membranous labyrinth, the ***utricle*** and the ***saccule***, which are connected by a short Y-shaped duct from which arises the ***endolymphatic duct***.
  Laterally, the vestibule is separated from the middle ear cavity by a thin bony plate containing two fenestrations or windows. The ***oval window*** is occluded by the base of the stapes bone and its surrounding ***annular ligament*** whereby vibrations are transmitted to the perilymph from the tympanic membrane via the ossicle chain. The ***round window*** is closed by a membrane similar to the tympanic membrane **(**and is thus sometimes described as the ***secondary tympanic membrane)***. This membrane permits vibrations, which have passed the sensory receptors for sound, to be dissipated.

- **The semicircular canals.** Three semicircular canals arise from the posterior aspect of the vestibule, two being disposed in vertical planes at right angles to one another and the other in a near-horizontal plane. Within each semicircular canal is a semicircular duct filled with endolymph and continuous at both ends with the utricle; near one end of each semicircular membranous duct is a dilated area called the ***ampulla*** . In each ampulla, there is a ridge called the ***crista ampullaris*** containing sensory receptors with axons converging on the vestibular nerve. Together with the receptors of the maculae of the utricle and saccule, these receptors help maintain balance and equilibrium.

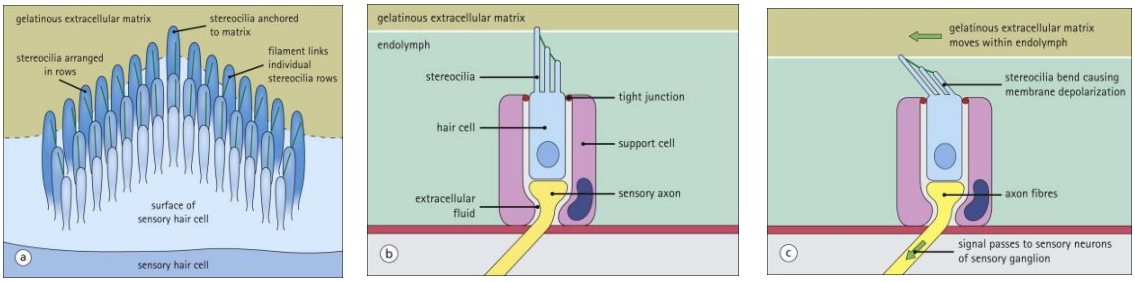
- **The cochlea.** The cochlea occupies a conical spiral-shaped space in the temporal bone, extending from the anterior aspect of the vestibule. The membranous component of the cochlea arises from the saccule and spirals upwards, with its blind end attached at the apex of the osseous space.

Hair Cells:

Within the inner ear, movement of endolymph is detected by specialized epithelial cells **(hair cells**). Hair cells are arranged in different patterns in the cochlea and vestibular apparatus to detect acceleration (movement), gravity (position) or sound (hearing).

The apical surface of each hair cell bears a highly organized system of microvilli (stereocilia), which are arranged as three parallel rows in a V- or W-shaped pattern. The height of the microvilli progressively decreases from the back to the front of the hair cell. Fine filaments link individual microvilli from each row, with the tips of the shorter microvilli behind. Each hair cell is rigidly fixed in place by support cells, however, the tips of the tallest row of microvilli are embedded in a gelatinous extracellular matrix, which is free to move within the fluid cavities of the inner ear or vestibular system. Deflection of the microvilli causes electrical depolarization of the hair cell membrane, which is transmitted to the central nervous system by the connecting axons of sensory nerve cells.

Support cells surround the hair cells and are anchored to them at their apex by occluding junctions. These junctions maintain ionic gradients between the endolymph and the extracellular fluid around the cells, the gradients being reversed on depolarization.



Patches of hair cells are located in three sites:

- Within the vestibular apparatus in the ampullae of the semicircular canals to detect acceleration
- Within the macula of the utricle and saccule to perceive the direction of gravity and static position
- Within the organ of Corti of the cochlea to detect sound vibration.

The Cochlea:

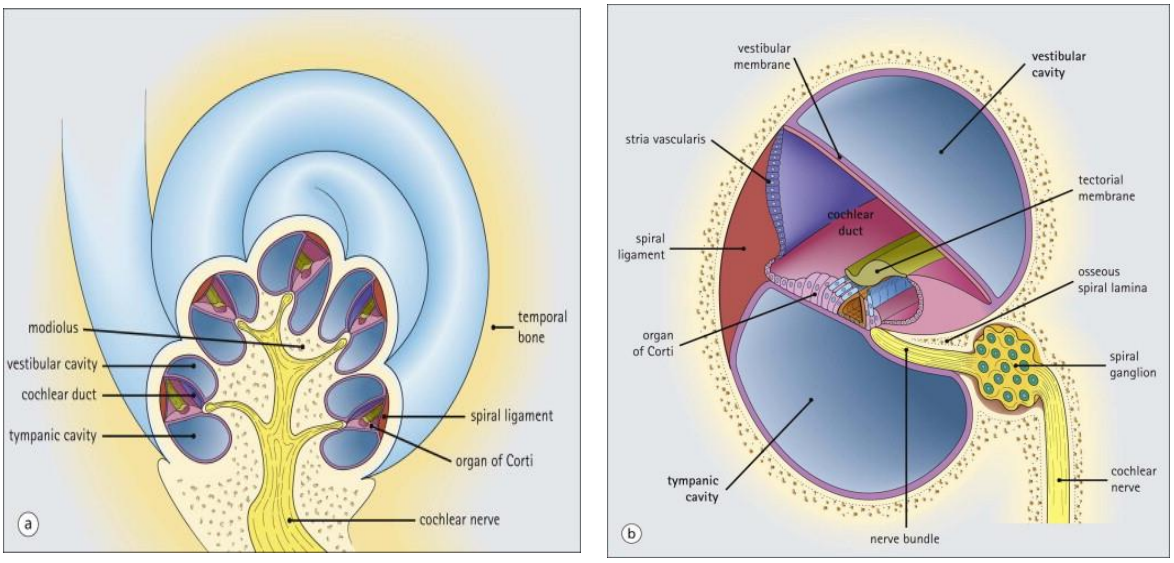
Is the part of inner ear concerned with perception of sound. The cochlea (about 35mm in length) makes two-and-half spiral turns around a bony core known as the **modiolus.** The modiolus has spaces containing blood vessels and contain the cell bodies and processes of the acoustic branch of the eighth cranial nerve ***(spiral ganglion)***. Extending laterally from the modiolus is a thin bony ridge, the ***osseous spiral lamina,*** which extends further across the cochlea in the basal region than it does at the apex.

The Cochlear duct (Scala media):

Is a spirally arranged tube lying within the bony cochlea. It is triangular in cross section and is connected to the saccule by the ***ductus reuniens.*** The cochlear duct is attached to the bony walls of the cochlea in such a manner as to divide the osseous space into three spiral compartments. The middle compartment, the ***scala media***, contains endolymph and the upper (***scala vestibule)*** and lower (***scala tympani***) compartments contain perilymph.

At the base of the cochlea, the *scala vestibule* is directly continuous with the perilymph of the vestibule and via this space, vibrations pass through the perilymph towards the apex of the cochlea. At the apex, the scala vestibuli becomes continuous with the *scala tympan*i of the cochlear spiral via a minute hole called the ***helicotrema***. the *scala tympan*i terminates at the secondary tympanic membrane covering the round window.

The sensory receptors for sound are located in a spiral-shaped structure known as the ***organ of Corti.***



The sides of the triangular cross section of the cochlear duct are made up of the following structures: **(1) *the basilar membrane*** (forming the floor of the triangular space) ***(2) the stria vascularis*** (forming the lateral wall) ***and (3) the vestibular membrane*** (forming the roof the space). The Cochlear duct ends as a blind sac at the apex of the cochlea.

The ***basilar membrane*** consists of a thin sheet of fibrous tissue that is attached medially to the osseous spiral lamina and laterally to the ***spiral ligament*** **(**which consists of a marked thickening of the endosteum of the lateral wall of the cochlear canal).The membrane is thinnest at the base of the cochlea and becomes progressively thicker as it spirals towards the apex. A highly

specialized epithelium lies on the upper surface of the membrane to form the ***spiral organ of Corti;*** the undersurface exposed to the scala tympani, is lined by simple epithelium.

The ***stria vascularis*** forms the outer wall of the cochlear duct. It is a specialized area of epithelium with a rich vascular supply in the lateral wall of the cochlear duct. Many of the cells here have ultrastructural features indicating an ion transport function, and it is thought that they secrete endolymph.

The ***vestibular membrane (Reissner's membrane)*** consists of two layers of flattened epithelium separated by a basement membrane, one cell layer being in continuity with the cells lining the vestibular cavity and the other in continuity with the cells lining the cochlear duct. The cells are held together by well-developed occluding junctions to maintain different electrolyte concentrations between the endolymph and the perilymph.

Organ Of Corti:

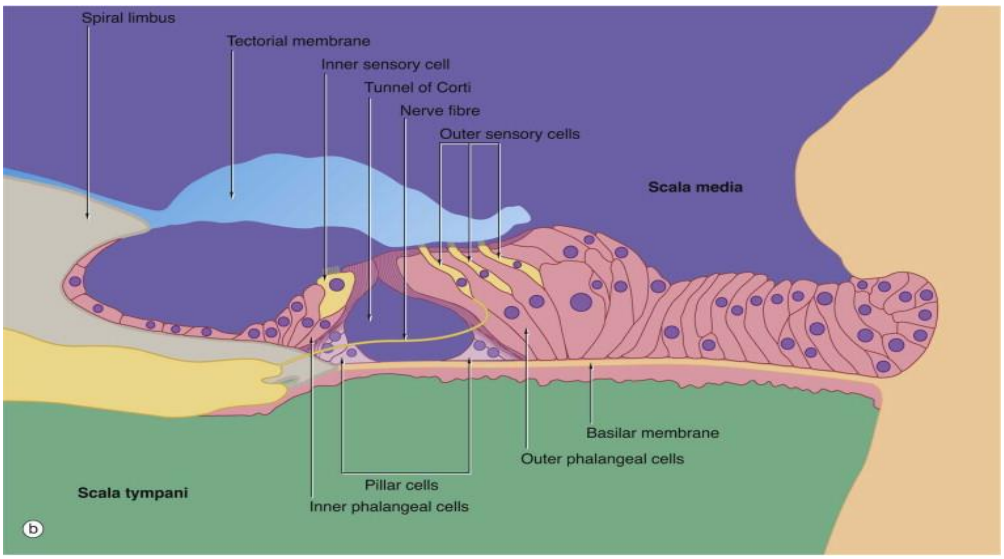
The ***organ of Corti*** is a highly specialised epithelial structure containing receptor cells which convert (transduce) mechanical energy in the form of vibrations into electrochemical energy, resulting in excitation of auditory sensory receptors.

The organ of Corti lies in the scala media, supported on the basilar membrane.

The ***organ of Corti*** consists of two types of cells, ***sensory (hair) cells*** and ***support cells*** of several different types, including among others the ***pillar cells*** and ***phalangeal cells***. The hair cells and supportive cells are arranged as two groups, an inner group and an outer group, which are separated by a small opening at the end of the osseous spiral lamina termed tunnel of Corti. The inner group of cells are smaller and rounder and are arranged as a single row along the cochlea. The outer group are tall and thin and arranged in three to five parallel rows, depending on the position in the length of the cochlea.

The sensory cells are known as hair cells because numerous stereocilia project from their free ends. These stereocilia are embedded in a sheet of gelatinous extracellular matrix (the ***tectorial membrane).*** Axons of the bipolar neurons of the spiral ganglion of the cochlea make synaptic contact with the hair cells and run to the spiral ganglion.

There are several classes of support cell in the organ of Corti. Inner and outer Pillar cells contain abundant scaffolding microtubules, and surround and support the triangular cavity (tunnel of corti). In contrast, phalangeal cells support the hair cells and are attached to them by occluding junctions at their apices, thus isolating the basal membrane of hair cells from the endolymph and maintaining electrochemical gradients.



Detection of Sound in the Inner Ear

- Sound waves are funnelled into the external auditory meatus and impinge on the tympanic membrane, which vibrates at the appropriate frequency. These vibrations are transmitted to the stapes bone via the malleus and incus and, in the process, their amplitude is enhanced about 10-fold.
- The base of the stapes, which lies in the oval window, conducts the vibrations into the perilymph of the vestibule of the inner ear and pressure waves pass from here into the scala vestibuli of the cochlea. These pressure waves are probably conducted directly to the endolymph of the scala media across the delicate vestibular membrane, from which vibrations are induced in the basilar membrane upon which rests the organ of Corti. From here, spent vibrations are transmitted into the perilymph of the scala tympani and dissipated at the secondary tympanic membrane over the round window.
- Role of the basilar membrane: the basilar membrane is thinnest at the base of the cochlea and thickest at the apex. At every point on the spiral, the membrane is 'tuned' to respond (vibrate) to a particular frequency of sound waves reaching the ear, with the highest frequencies (pitch) being sensed towards the base of the cochlea and lower frequencies being sensed along the spiral towards the apex. For any given sound frequency, only one specific point of the basilar membrane and organ of Corti is thought to vibrate and thereby activate the appropriate hair cells to initiate afferent sensory impulses which then pass to the auditory cortex of the brain. Bending of the stereocilia of the hair cells results in depolarisation of the cell membrane which, in turn, excites the sensory nerves which synapse with them.
- The sensory input from the cochlea is integrated in the brainstem and auditory cortex, from which efferent suppressor pathways can modulate receptor activity to enhance auditory acuity.

Spiral Ganglion:

- The spiral ganglion is a spiral-shaped mass of nerve cell bodies lying in a canal at the extremity of the osseous spiral lamina of the modiolus.
- The efferent nerve fibers from the spiral organ of Corti enter the spiral lamina and converge on the spiral ganglion cells in the modiolus.
- The spiral ganglion consists of bipolar neurons whose central processes converge to form the cochlear division of the eighth cranial nerve.
- The vestibular division of the eighth cranial nerve, which receives sensory information from the maculae of the utricle and saccule and from the ampullae of the semicircular canals, has a vestibular ganglion situated in the internal auditory meatus.

***Vestibule*:**

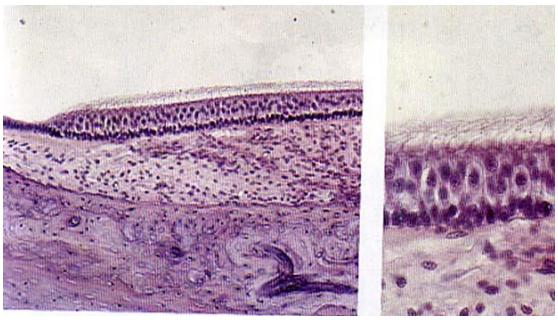
Is the central part of the bony labyrinth and lies posterior to the cochlea and anterior to the semicircular canals. In its lateral wall are the *fenestra vestibuli* (oval window), which is closed by the base of the stapes and its annular ligament, and the *fenestra cochleae* (round window), which is closed by the *secondary tympanic membrane*. Lodged within the vestibule are the saccule and utricle of the membranous labyrinth**.**

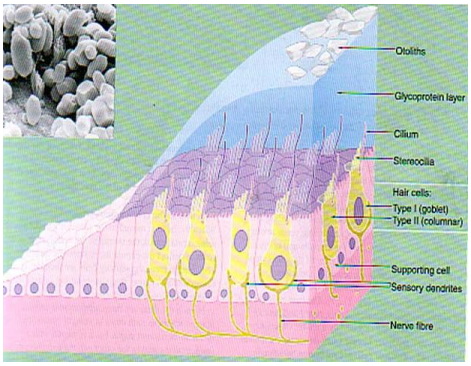
Utricle and Saccule:

- The *utricle* and *saccule* are two dilated regions of the membranous labyrinth lying within the vestibule of the inner ear and are joined by the short *utriculosaccular duct*, which leads into the slender *endolymphatic duct*.
- Both the utricle and the saccule are filled with *endolymph* and are suspended in the perilymph of the vestibule. The walls of each are composed of a fibrous membrane which is bound down in places to the periosteum of the vestibule and, in other areas, is attached to the periosteum by fibrous strands, the intervening space being filled with ***perilymph*** .
- The utricle and saccule are composed of a thin sheath of connective tissue lined with simple cuboidal epithelium but in each there is a small region of highly specialized epithelium called the ***macula****.*
- These receptors are sensitive to the orientation of the head in relation to gravity or other acceleration forces.
- *Maculae* in both locations have the same basic histologic structure and consist of a thickening of the wall and possess two types of *receptor cells (type I and type II hair*

cells), some *supporting cells,* and the afferent and efferent nerve endings.

- Type I hair cells are polygonal in shape and surrounded by a network of afferent and efferent nerve endings while Type II hair cells are cylindrical in shape, with basal synaptic afferent and efferent nerve endings.
- Each hair cell possesses on its free surface 40-80 elongated highly specialized microvilli, or stereocilia, and a single *kinocilium* which are embedded in a gelatinous membrane called the *otolithic membrane.* Within the membrane are numerous crystalline bodies called *otoliths*, composed of calcium carbonate crystals.
- The *supporting cells* are tall and columnar, lie on the basal lamina between the hair cells, Each possesses small microvilli on its free surface and basally located nucleus.
- The function of the supporting cells is not known with certainty. The cells may assist in the nutrition of the hair cells or modify the composition of the endolymph.





Function of the maculae

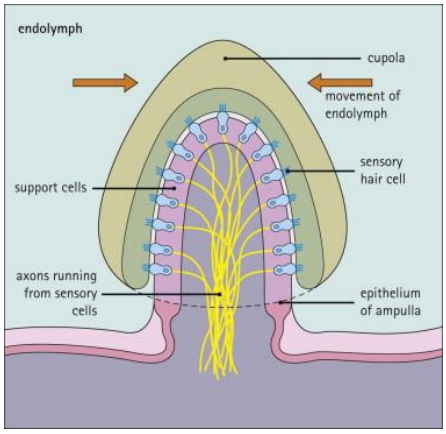
The function of the maculae relates mainly to the maintenance of balance by providing sensory information about the static position of the head in space. This is of particular importance when the eyes are closed or in the dark or under water.

When the head is moved from a position of equilibrium, the otolithic membrane tends to move with respect to the receptor cells, causing bending of their stereocilia. When the stereocilia are bent in the direction of the cilium, the receptor cell undergoes excitation and, when the relative movement is in the opposite direction, excitation is inhibited. The orientation of the hair cells in different directions in the maculae causes different hair cells to be stimulated with different positions of the head. The pattern of hair cell stimulation allows the central nervous system to determine the position of the head very accurately with respect to gravity. The sensory input from the maculae is integrated with that of other proprioceptors, such as muscle spindles, to elicit reflex responses directed towards the maintenance of postural equilibrium.

Semicircular Canals:

The three semicircular canals the *superior (anterior), posterior, & lateral* open into the posterior part of the vestibule. Lodged within the canals are the semicircular ducts. Each canal has a swelling at one end called the ampulla (a 1 mm long dilated region of the membranous labyrinth).

Within the ampullae of the semicircular canals, hair cells are arranged over a finger-like ridge called the 'crista ampullaris'. Structurally, the cristae ampullaris bear many similarities to the maculae of the utricle and saccule. The hair cells are of the same two morphological forms, ***type I*** and ***type II cells***. The hair cells are supported by a single layer of columnar cells which is continuous with the simple cuboidal epithelium lining the rest of the membranous labyrinth.



Like those of the maculae, the hair cells of the cristae have numerous ***stereocilia*** and a single ***kinocilium.*** The stereocilia and the kinocilia of the hair cells are embedded in a ridge of gelatinous glycoprotein which is tall and cone shaped in cross-section, giving rise to the term ***cupula***. In contrast to the macula, the cupula does not contain otolithic crystals.

Function of the crista ampullaris

When the head is moved in the plane of a particular semicircular canal, the cupula is deflected in the opposite direction. The stereocilia of the sensory cells are then deflected towards or away from the cilia, resulting in excitation or inhibition, respectively. The sensory input from the cristae ampullaris mainly concerns changes in the direction and rate of movement of the head. Afferent fibres pass via the vestibular part of the eighth cranial nerve to the brainstem, cerebellum and cerebral cortex, where sensory information from various other sources is integrated for the maintenance of balance, position sense and equilibrium.

Discussion points:

The width of the basilar membrane changes such that it is shorter at the base and longer toward the apex of the cochlea. What is the significance of this change in length?

Is there a difference in the innervation and function of the inner vs. outer hair cells?

The hair cells within the organ of Corti sense sound vibration. Is there any clinical significance to this other than hearing?

What are the 2 main types of deafness? Where is the lesion in each one?

How do you think cochlear implant is performed?

The vestibular system is important estimate body position. Signals from other parts of the body also contribute. What are these parts?

Websites:

https://blausen.com/en/topic/ear/

Watch all videos they are very useful.