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Review Article

The human cochlea - anatomical aspect: a brief review

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ABSTRACT

The inner ear or the labyrinth performs the function of hearing and balance. It consists of a bony and a membranous labyrinth. Bony labyrinth consists of three parts – the vestibule, cochlea and the semicircular canals. Membranous labyrinth consists of the cochlear duct, the utricle and saccule, the three semicircular ducts, and the endolymphatic duct and the sac. The membranous labyrinth contains fluids which are in a state of dynamic equilibrium with the intracranial cerebrospinal fluid. Basilar membrane displacements result in electrolyte alterations and thus generate nerve impulses. Scala media is filled with endolymph that can be distinguished by its ion composition that is much like an intracellular character with respect to its potassium content. Scala tympani and scala vestibuli are filled with perilymph containing an extracellular-like ion composition and communicate at the apex of the cochlea via the helicotrema. The fluid contained within the tunnel of Corti and Nuel's spaces within the sensory epithelium resembles composition of the perilymph. The disturbance in the milieu interior is consequent to auditory and vestibular impairments. The unique anatomy of the membranous labyrinth shall be elaborated.

Keywords: Bony labyrinth, Membranous labyrinth, Reissner's membrane, Osseous spiral lamina, Organ of Corti

INTRODUCTION

The bony labyrinth lodges the membranous labyrinth with its fluids namely the perilymph, endolymph and the cortilymph with varied electrolytic compositions. Displacements of the tympanic membrane, oval window and the basilar membrane convert the mechanical sound energy to electrical nerve impulses that are finally perceived by the cerebral cortex. The anatomy of the cochlea needs introspection.

REVIEW OF LITERATURE

The human cochlea initially described by Eustachi in 1564 and pictorially depicted by Albini as early as 1744. Anatomist Cotugno elaborated the cochlear anatomy with corrosion casts in the treatise "Deaqueductibus Auris Humana Interna". Ninety years later, Corti in the year 1851, discovered the "organ of corti" that bears his name.[1]

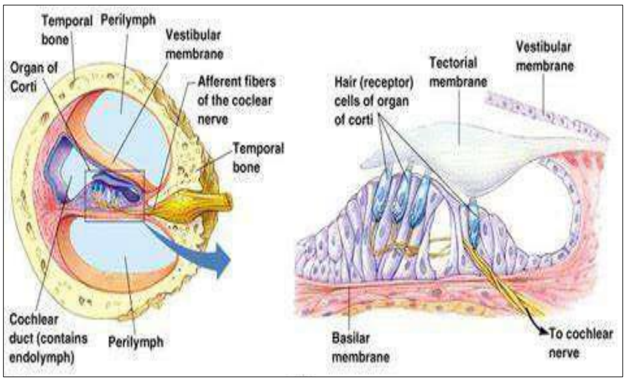

Figure 1: Cross section of cochlea.[2]

Anatomical aspect

The ear is composed of three parts: the outer ear, the middle ear and the inner ear.

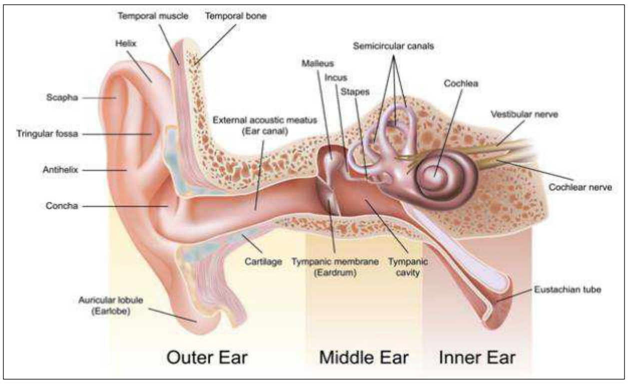

Figure 2: Anatomy of ear.[3]

The inner ear or the labyrinth performs the function of hearing and balance. It consists of a bony and a membranous labyrinth. The membranous labyrinth is filled with a clear fluid called endolymph while the space between membranous and bony labyrinth is filled with the perilymph. Bony labyrinth consists of three parts – the vestibule, cochlea and the semicircular canals. Vestibule is the central chamber of the labyrinth and in its lateral wall lies the oval window. The inside of its medial wall presents two recesses, a spherical recess, which lodges the saccule and the elliptical, the utricle. In the posterosuperior part of vestibule are the five openings of semicircular canals.[4]

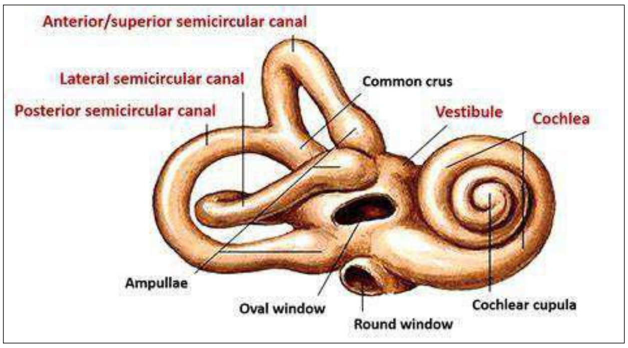

Figure 3: The right bony labyrinth.[4]

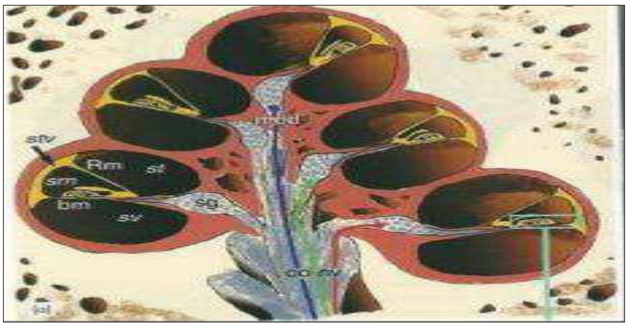

Figure 4: The modiolus.[5]

The semicircular canals are three in number, lateral, posterior and superior, and lie at right angle to each other. Each canal has an ampullated end which opens independently into vestibule. The non ampullated end of posterior and superior canals unite to form the crus commune. Thus, the three canals open into vestibule by five openings. The cochlea is a bony coiled tube making 2.5 to 2.75 turns round a central pyramid of bone called modiolus. The osseous spiral lamina divides the bony cochlea incompletely; thus, it gives attachment to the basilar membrane. The bony bulge on the medial wall of middle ear, the promontory, reflects the basal coil of cochlea.

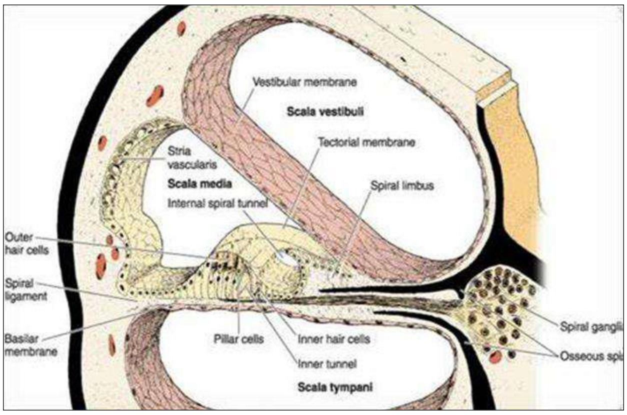

Figure 5: Osseous spiral lamina.[6]

The bony cochlea is divided into: scala vestibule, scala media or the membranous cochlea, and scala tympani.

The perilymph is the fluid inside the scala vestibuli and tympani communicates with the cerebro spinal fluid via the cochlear aqueduct. Scala tympani and scala vestibuli communicate with each other at the apex of cochlea through an opening, called the helicotrema. Scala vestibuli is separated by the footplate of stapes and scala tympani by the secondary tympanic membrane from the middle ear.[6]

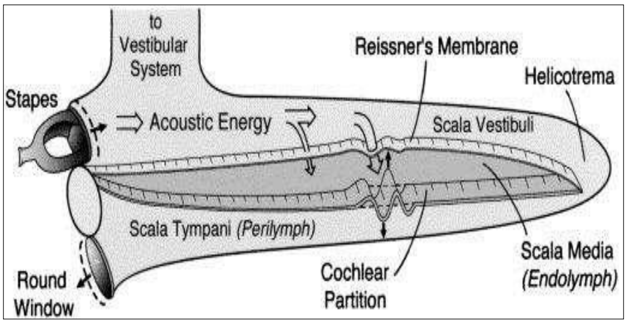

Figure 6: Helicotrema - communication between scala tympani and scala vestibule.[7]

Membranous labyrinth consists of the cochlear duct, the utricle and saccule, the three semicircular ducts, and the endolymphatic duct and the sac.

Cochlear duct is also called scala media. In organ of Corti reside the mechano-sensory cells arranged in one row of inner hair cells (IHCs) and three to four (sometimes as many as five) rows of outer hair cells (OHCs). Bundles of sensory hairs (stereocilia) emerge from the apical poles of the sensory receptor cells. Hair cells are surrounded by several types of supporting cells, and these support cells have contact with the basement membrane. Because hair-cell stereocilia are coupled to the overlying cellular tectorial membrane, oscillations of the basement membrane cause back-and-forth deflection of the hair bundles. This motion is not uniform along the cochlear spiral, because the basement membrane is narrow and rather stiff at its base but is wider and more compliant near the apex of the cochlear duct. Von Bekesy was the first to show that sound sets up a travelling wave and its peak amplitude varying with respect to location on the basement membrane with frequency. High frequencies are mapped near the base while low frequencies cause maximal vibrations closer to the apex. This leads to a tonotopical organization of the sensory cells where the location of excited hair cells along the basement membrane determines the perceived frequencies. Basement membrane and the thin Reissner's membrane subdivide the spiral canal into its three compartments. Scala media is filled with endolymph that can be distinguished by its ion composition that is much like an intracellular character with respect to its potassium content.

Scala tympani and scala vestibuli are filled with perilymph containing an extracellular-like ion composition and communicated at the apex of the cochlea via the helicotrema. The fluid contained within the tunnel of Corti and Nuel's spaces within the sensory epithelium resembles perilymph'scomposition.[8]

The Reissner's membrane consists of an epithelial-cell layer facing the endolymph compartment of the scala media and a mesothelial facing the perilymph compartment of the scala vestibuli. These cell layers are separated by a basement membrane and form a vital barrier between these two fluids that possesses completely different ion compositions. Reissner's membrane is involved in homoeostasis and fluid transport. Integrity of this membrane is essential for hearing to maintain the endocochlear potential (EP; +80 mV) in the cochlear duct.[9]

The basilar membrane forms the boundary between the scala media and the scala tympani and includes Claudius' cells, Boecttcher's cells; the organ of Corti, which contains Hensen's cells, Deiter's cells, pillar cells, inner border cells, outer hair cells, and the inner hair cells, inner sulcus; spiral limbus, which contains the interdental cells and overlying tectorial membrane.[10]

The lateral wall includes spiral ligament, stria vascularis and the external sulcus). The spiral ligament anchors the basement membrane at the lateral aspect of the otic capsule. This attachment to the organ of Corti is characterized through the presence of tension fibroblasts that contain actin, myosin, and tropomyosin. This may generate a certain active tension that can be modulated. Besides its mechanical function, the spiral ligament plays an important role for the supply and drainage of perilymph.[11]

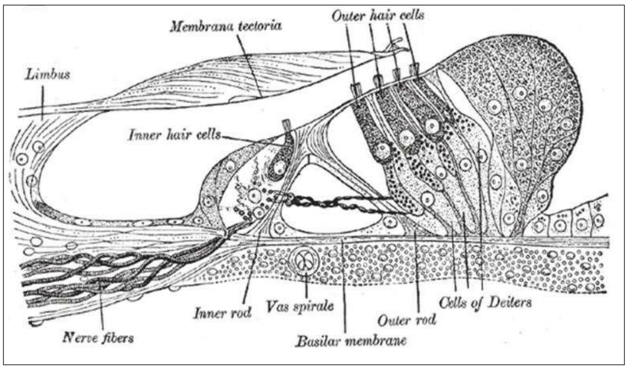

Figure 7: Organ of corti.[12]

Table 1: The difference between outer and inner hair cells.[13]

Characteristics	Outer hair cells (OHC)	Inner hair cells (IHC)
Number (human)	9000 to 12,500	3000 to 3500
Arrangement of cells	Three staggered rows	A single row
Form	Cylindrical	Pear-shaped
Structure	Cytoskeleton containing motor protein (prestin, actin) that enables the cell to change its size.	Conventional cytoskeleton
Arrangement of stereocilia	Three rows of Ws	Three aligned rows
Cellular organelles	Nucleus situated at the base of the cell (basal nuclei). Abundant mitochondria aligned along the cell body and below the basal nucleus.	Nucleus situated medially in the cell. Less abundant mitochondria than in the OHC and more uniformly organized in the cell body.
Neural network	Afferent system: synapses with small endings from non- myelinated type II spiral ganglia link the cochlea to cochlear nuclei (approximately 5% of auditory nerve fibres). Approximately	Afferent system: synapse with large myelinated type I spiral ganglion neurons, which link the cochlea to the cochlear nuclei (95% of auditory nerve fibres). 10 to 20 type I neurons per IHC.

Continued.

Characteristics	Outer hair cells (OHC)	Inner hair cells (IHC)
	ten OHC per type II neuron. Efferent system: very large descending endings from both sides of the medial superior olivary complex. The endings form axo-somatic synapses with the OHC cell body.	Efferent system: arising from small neurons in the ipsilateral lateral superior olivary complex bring feedback (post- synaptic) control to the type I afferent fibre
Type of synapse	Postsynaptic cistern	Presynaptic ribbon
Neurotransmitter	Aceylcholine, GABA, neuropeptide (descending fibres)	Glutamate (ascending fibres)
Functional role	Enables local amplification of the movements of the basilar membrane. Increases the sensitivity of the internal hair cells.	Enables transduction of mechanical energy into electrical energy. Actual sensory receptors.

The tectorial membrane (TM) is an extracellular matrix that causes a shearing motion to stereocilia bundles when vibration enters the cochlea partition. This auxiliary mass is required to present movement to the "light weight" and therefore rather vibration-insensitive hair cells. The tympanic membrane is composed of radially running unbranched fibrils of type II and type IX collagen (type A) and highly branched fibers of type V collagen (type B) in which the thick fibers are embedded. The jelly-like matrix is composed of various glycoproteins, the tectorins and otogelin.[14]

Supporting cells provide tight and buckling resistant connections of hair cells with the basement membrane. Deiter cells sustain the bases of outer hair cells forming a "seat" for the basal portions of these sensory cells and send a phalangeal process to the reticular lamina completing their structural support. Hensen, Claudius, and Boettcher cells shape the lateral segment of the organ of Corti.[15]

Human spiral ganglion

The human cochlea from normal hearing individuals contains approximately 35,000 afferent neurons that are bipolar with soma located in the helical Rosenthal's canal (in the modiolus along the 1¾ turns of the cochlea. The spiral ganglion terminates in a bulge containing the cell bodies of neurons innervating hair cells of the third turn. Peripheral processes run within a bilamellar bony space of the osseous spiral lamina to the habenula perforata to exit this bony canal and innervate the hair cells.[15]

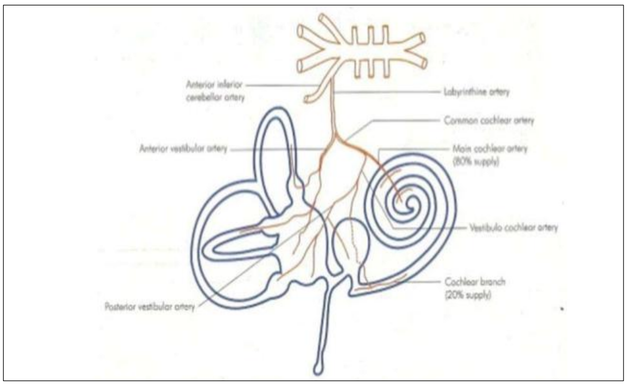

Figure 8: Blood supply of cochlea.[16]

DISCUSSION

Retzius, precisely elaborated the micro-anatomy of the human cochlea.[17] The human cochlea is in fact one of the most intricate tissues to analyze, Vis a Vis its bony capsule and delicate architecture. Preparations are affected due to post-mortem changes due to the between demise and slide fixation. Human inner-ear tissue intraoperatively is assessed by transmission electron microscopy, scanning electron microscopy, *in vitro* culture, and immune-histochemistry. Fine structural and molecular analysis can be undertaken by these modalities. Modern cochlear implant surgery necessitates that otologist to be conversant with the intricate anatomy of the human cochlea and its variations. The classical technique to insert electrode arrays through a drilled cochleostomy has been abandoned by some surgeons today. Instead, a round-window approach can be used as originally implemented by William House for short electrodes.

The 'hook' region of the cochlea exhibits extensive anatomical variations that are difficult to foresee on pre-implantation computed tomography. Implantation depends on the functional status of residual spiral ganglion neurons. These cells are more or less preserved in CI patients but how the conservation influences the outcome of CI is controversial. Therefore, their preservation is crucial and more information should be attained about their deterioration and how it can be prevented. Better understanding of structure, function, and regenerative capability is needed to comprehend the nature of electrical stimulation of the peripheral and central nervous system to improve the design of future implant systems.

CONCLUSION

The cochlea with its unique architecture is concerned with the special sense of hearing and balance. The orientation of receptors is such that sounds over a wide range of frequencies can be perceived and transmitted to the auditory cerebral cortex for integration and interpretation.

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