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Anatomy of cochlea and round window

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One of the most important functions of the ear is sound reception, particularly the detection of amplitude and frequency of the sound waves by Corti's organ. The latter is a sensory structure located in the cochlear duct (middle scale), consisting of hair cells lying above the basilar membrane. The cochlear duct is surrounded by two cavities containing perilymph: the *scala vestibularis* and the *scala tympani*. The sound reception mechanism involves several other components of the ear such as malleus, incus and stapes, in the tympanic cavity, and the oval and round windows. The movement of the stapes on the oval window, that is adjacent to the *scala vestibularis*, generates pressure waves in the perilymph along the vestibular canal. The round window, that separates the *scala tympani* from the tympanic cavity, moves to compensate for oval window movements. The malfunction of the inner ear, due to specific diseases, could be corrected by use of the drugs such as gentamicin that reaches the cochlea through the round window. This brief paper reviews the main anatomical knowledge on the inner ear, with particular attention to the structures of interest for otolaryngologists treating ear disorders by inoculation of drugs into the tympanic cavity.

KEY WORDS: Inner ear – Cochlea - Organ of Corti - Round window.

Overview of the ear

The ear has three parts: external, middle and inner ear. The external ear transmits sound waves toward the middle ear in the tympanic cavity of the temporal bone. The external ear consists of the auricle and the external acoustic meatus. The auricle is a thin plate of elastic fibro-cartilage covered by skin. It is irregularly concave with eminences and depressions (*helix*, *antihelix*, *tragus* and *antitragus*, triangular *fossa*, scaphoid *fossa*, concha of auricle, intertragic notch, auricle tubercle and lobule) and is connected with surrounding tissues by means of ligaments and muscles, both extrinsic and intrinsic.[1]

The external acoustic meatus extends from the concha to the tympanic membrane, that separates the external ear from the middle ear (Figure 1). It consists of a lateral (cartilaginous) part and a medial (osseous) part. Along its route, it forms a S-shaped curve. The auricle and the external acoustic meatus develop as modifications of the first branchial groove and the branchial arches which bound it. The tympanic membrane is thin and semi-transparent. Its lateral surface is concave. The deepest point, the *umbo*, contacts the manubrium of malleus. It has a two parts, a *pars flaccida* and a *pars tensa*.[2]

The middle ear or tympanic cavity is a pneumatic chamber localized between the bottom of the external meatus and the internal ear. It consists of an upper part, the epitympanic recess, the proper tympa-

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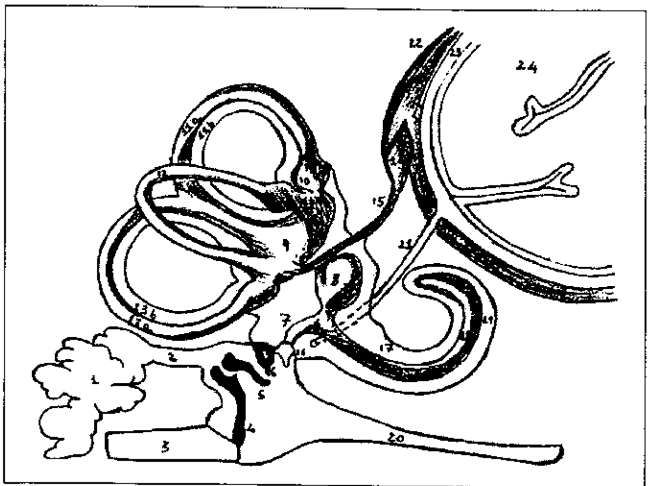

Figure 1.—Structures of inner, middle and external ear. 1. Mastoid air cells; 2. Tympanic antrum; 3. External acoustic meatus; 4. Malleus; 5. Incus; 6. Stapes; 7. Vestibule; 8. Saccule; 9. Utricle; 10. Ampullae; 11a. Sup. semic. duct; 11b. Sup. semic. canal; 12. Horizontal duct; 13a. Inf. semic. duct; 13b. Inf. semic. canal; 14. Endolymph sac; 15. Endolymph duct; 16. Fossula fenestrae cochlea; 17. Scala vestibularis; 18. Cochlear duct; 19. Scala tympani; 20. Auditory tube; 21. Perilymph duct; 22. Dura mater; 23. Arachn. Spaces; 24. Brain.

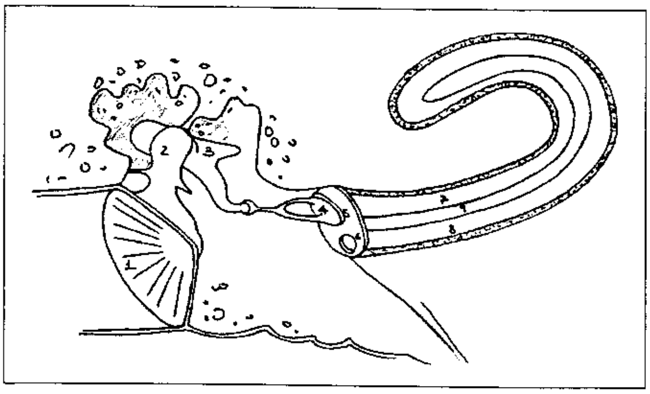

Figure 2.—Middle and inner ear and round window. 1. Tympanic membrane; 2. Malleus; 3. Incus; 4. Stapes; 5. Oval window; 6. Round window; 7. Scala vestibularis; 8. Scala tympani; 9. Middle scale.

num, that posteriorly communicates with tympanic antrum, and the mastoid air-cells, and continuing anteriorly with the auditory tube (Figure 1). The medial wall has eminences and depressions; particularly, the anterior part forms the promontory.[2]

The tympanic cavity is crossed by a chain of three small bones, *malleus*, *incus* and *stapes*, that harvest and amplify the sound waves to retransmit them to the hearing organs of the internal ear. The footplate of the *stapes* is connected to an oval orifice, the vestibular window. Below, there is the cochlear – or round – window [3] (Figure 2).

The cochlea and the round window

The inner ear has a bony labyrinth whose outer wall is merged with the surrounding temporal bone. The otic capsule is that portion of the petrous part of the temporal bone which surrounds the internal ear. It derives from the mesenchyma, turned into precartilage and cartilage to change into bone. The bony labyrinth surrounds and protects the membranous labyrinth, a complex of canals and cavities filled with endolymph. The perilymph runs between the bony labyrinth and the membranous labyrinth. The sensory receptors responsible for the equilibrium and hearing sensitivity are located in the membranous labyrinth.[4]

The bony labyrinth consists of three parts: the vestibule, periotic semicircular canals and a cochlear portion. The vestibule has two membranous sacs: the saccule and the utricle, whose receptors provide information about gravity and linear acceleration. The semicircular canals have ducts whose receptors are stimulated by the rotation of the head. The cochlea lies in front of the vestibule (Figure 1). The cochlea is shaped like a snail and contains the cochlear duct (middle scale), surrounded by two cavities containing perilymph: the *scala vestibularis* and the *scala tympani* (Figure 3). The *scala tympani* is separated from the tympanic cavity by the round window (Figure 2). It lies under the overhanging edge of the promontory in a niche and it is oblique. It is closed by a membrane called the secondary membrane of the tympanum. The complex (middle scale, *scala vestibularis* and *scala tympani*) is coiled to spiral around a central spool of bone, the *modiolus*[2]. The cochlear duct is blind and ends at the apex of the cochlea and communicates with the other channels at the modiolar apex, the *helicotrema* (Figure 2). The cochlear duct forms three turns: basal, middle and apical turns. The external wall of the cochlear duct is merged with the periosteum, with a spiral prominence to the cochlear duct and above the vascular stria, that secretes the endolymph. The regulation of inner-ear fluid homeostasis, regarding volume, concentration, osmolarity and pressure, is induced by structures such as the

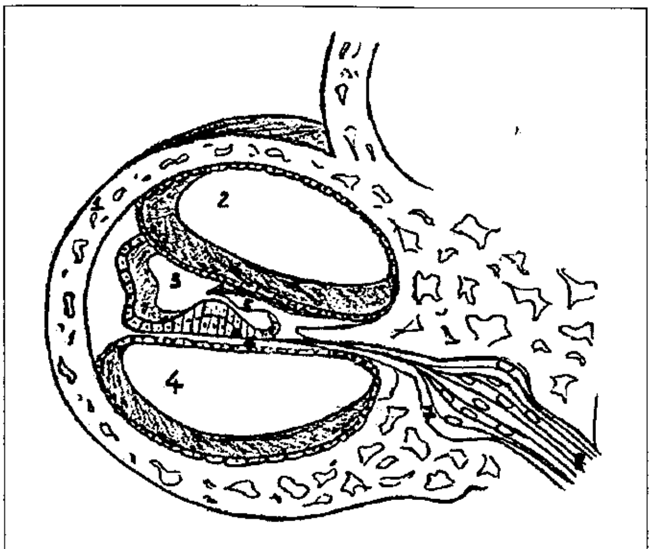

Figure 3.—Cross section of the cochlea and organ of Corti. 1. Bone wall; 2. Scala vestibularis; 3. Cochlear duct; 4. Scala tympani; 5. Tectorial membrane; 6. Basilar membrane; 7. Spiral ganglion; 8. VIII encephalic nerve, cochlear branch.

stria vascularis and vestibular dark cells, responsible for endolymph secretion.[5, 6] The vestibular wall, or Reissner membrane, extends obliquely from the spiral ligament to the spiral strip of the tympanic wall. It converts the movements of the perilymph (induced by movement of the stapes) in movements of the endolymph. The tympanic wall extends straight from the osseous spiral lamina to the spiral ligament. It has two parts, an internal spiral strip and an external basilar membrane. The latter contains an internal arcuate zone and an external combed area. The organ of Corti is located in the cochlear duct (Figure 3). It is a sensory structure above the basilar membrane that separates the cochlear duct from the tympanic duct below. The organ of Corti contains hair cell receptors arranged in longitudinal rows contacting the overlying tectorial membrane.[7] These cells collectively detect the amplitude and frequency of the sound waves that enter the cochlea.[8-10]

Functional anatomy

Sound reception takes place through various steps. The sound waves reach the tympanic membrane causing vibration of the membrane. This causes the displacement of malleus, incus and stapes. The movement of the stapes on the oval window generates pressure waves in the perilymph in the vestibular canal. The round window moves to compensate. When the stapes moves toward the internal of cochlea, the window protrudes outward. The pressure waves induced by the stapes cause distortion and vibration of the basilar membrane, determining vibration of the hair cells. This triggers solicitation of the tectorial membrane, implying the activation of sensory nerves within the cell bodies in the spiral ganglion of the central part of the cochlea (Figure 3). From there the axons (afferent fibres of the VIII encephalic nerve, cochlear branch) reach the bulbar nuclei (cochlear nuclei) to be sorted to other encephalic centres.[11] The cochlear nuclei sends fibres that cross the midline and ascend on the opposite side until the midbrain (inferior colliculus), the coordination centres that respond to acoustic stimuli, like auditive reflexes, involving skeletal muscles of the head, face and trunk. The fibres make synapses with the neurons of the thalamus to reach the acoustic cortex in the temporal lobe. The stimulus becomes conscious.

Therapeutic modalities that block pro-cell-death pathways are being developed and evaluated for hearing preservation. Because they have both anti-inflammatory and anti-apoptotic actions, corticosteroids have long been used to protect against several types of acute sensory-neural hearing loss.[12] Areas of research covered include hair cell protection, hair cell regeneration and spiral ganglion cell regeneration.[13] The hair cells can be easily damaged by excessive stimulation by ototoxic drugs and by the effects of aging. In mammals, auditory hair cells are never replaced, causing damage to the ear with progressive and permanent deafness. In contrast, non-mammalian vertebrates are capable of replacing lost hair cells.[4, 14] Studies in both lower vertebrates and mammals have suggested that the sensory epithelia could be manipulated to achieve hair cell regeneration. These approaches include the use of inner ear stem cells, trans-differentiation of non-sensory cells, and induction of a proliferative response in the cells that can become hair cells.[15-17] Oto-acoustic emissions (OAEs) differ between sexes. Prenatal exposure to high levels of androgens can weaken the cochlear amplifiers, thereby weakening oto-acoustic emissions (OAEs).[18] During the perinatal period, the brainstem reaches a mature state, and brainstem activity is reflected in behavioral responses to sound (phonetic discrimination).[19]

Vascularization of inner ear

The inner ear is vascularised by the labyrinthine artery. This artery passes through the internal auditory meatus, dividing into three branches: the vestibular artery, the vestibule-cochlear artery and the cochlear artery. The first supplies the vestibular nerve, the utricle, the saccule and the semicircular ducts. The second supplies the basal turn of the cochlea, most of the saccule, the body of the utricle, the posterior semicircular duct and parts of the lateral and superior semicircular ducts. The third, at the level of the modiolus, gives rise to spiral arteries.[2]

The venous drainage occurs through three main veins. The internal auditory vein drains the apical and the middle turns of the cochlea. The vein of the cochlear aqueduct arises from the capillaries of the basal turn, saccule and part of the utricle. It passes in the otic capsule to enter into the inferior petrosal sinus. The vein of the vestibular aqueduct drains blood from the semicircular ducts and part of the utricle. It opens into the lateral sinus receiving small veins from the plexus around the endolymphatic sac.[1]

Conclusions

From the current anatomical knowledge provided above, we can determine the effect of drugs in the treatment of pathologies of the inner ear. In general, chemical perfusion therapy of inner ear disease is safe, inexpensive and easy to perform. High inner ear medication concentrations can be achieved while minimizing systemic side effects.[20] For example, the intratympanic gentamicin or the transtympanic steroids are an effective procedure for the control of cochleo-vestibular disorders, such as Ménière's disease and sudden deafness, acting on the cochleo-vestibular system. These drugs probably passes through the round window, reaching the complex, middle scale, *scala vestibularis* and *scala tympani* of the inner ear. Future research could increase the indications for steroids and gentamicin treatment, as well as introducing new drugs and gene therapy.[21]

Riassunto

Anatomia della coclea e della finestra rotonda

Una delle più importanti funzioni dell'orecchio è la ricezione del suono, particolarmente il rilevamento dell'ampiezza e della frequenza delle onde sonore da parte dell'organo di Corti. Quest'ultimo è una struttura sensoriale localizzata nel dotto cocleare (scala media), costituito da cellule ciliate disposte sulla membrana basilare. Il dotto cocleare è circondato da due cavità conteneti perilinfa: la *scala vestibularis* e la *scala tympani*. Il meccanismo di ricezione del suono coinvolge diverse altre componenti dell'orecchio, come il martello, l'incudine e la staffa, nella cavità timpanica e le finestre ovale e rotonda. Il movimento della staffa sulla finestra ovale, che è adiacente alla *scala vestibularis*, genera onde pressorie nella perilinfa lungo il canale vestibolare. La finestra rotonda, che separa la *scala tympani* dalla cavità timpanica, si muove a compensare i movimenti della finestra ovale. Il malfunzionamento dell'orecchio interno, a causa di particolari patologie, può essere corretto dall'impiego di farmaci come la gentamicina che raggiunge la coclea attraverso la finestra rotonda. Questo breve articolo propone una revisione delle principali conoscenze anatomiche dell'orecchio interno, con particolare attenzione alle strutture di interesse otorinolaringoiatrico per il trattamento di disordini dell'orecchio attraverso l'instillazione di farmaci nella cavità timpanica.

Parole chiave: Orecchio interno - Coclea - Organo di Corti - Finestra rotonda.

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