I./3. : Ear: Anatomy and Physiology

dr. Szőnyi Magdolna

Peripheral parts of the ear: external middle and inner ear. These parts detect, conduct and transform auditory signals to electrical stimuli. Signals transmitted by the afferent auditory nerve fibers toward central nervous system.

I./3.1.: External ear

The auricle consists of elastic cartilage covered by skin, lying between the temporomandibular joint and the mastoid process. Blood supply of the cartilage arrives from the perichondrium.

**External ear canal** is about 3 cm long, consists of an outer cartilaginous and an inner bony part. The canal narrows and curves to protect the tympanic membrane against foreign bodies and direct trauma. To examine the tympanic membrane the cartilaginous part of the external meatus is stretched by pulling the auricle upward and backward. The skin of the cartilaginous part contains hair follicles and ceruminous glands which form wax. The structures are missing in the bony part. This second part is covered by a thin layer of skin which tightly adheres to the perichondrium.

Between the cartilaginous and bony meatus a stricture is found, so foreign bodies become impacted at this junction. Cartilage contains a number of dehiscences which provide a pathway for spread of bacterial infection the parotid gland, infratemporal fossa and base of the skull.

The external ear has a rich lymphatic drainage to the intraparotideal, retro and ifraauricular and superior deep cervical lymph nodes.

**Sensory innervation** is supplied by the auriculotemporal nerve (n. trigeminus), the great auricular nerve (cervicalis plexus), the vagus and the facial nerve. The branches of the vagus nerve generates the cough reflex when the posterior wall of the external ear canal is touched. In a patient with acoustic neurinoma the reflex is missing (Hitselberger’s sign).

The posterosuperior wall of the bony meatus forms a part of the attic wall the mastoid antrum and the pneumatic system of the mastoid process. Infections of the mastoid system can break through into the external ear canal causing sagging of the posterosuperior wall.

I./3.2.: Middle ear

Where is the border of the external ear?
Middle ear consists of the Eustachian tube, tympanic cavity and the pneumatic system of the temporal bone.

The tympanic cavity and the pneumatic system are aerated by the Eustachian tube, which opens in the nasopharynx.

External ear canal and tympanic cavity are separated by the eardrum lying at an angle to the bony part of the ear canal. Looking into the canal posterior part of the tympanic membrane seated closer, anterior part farther.

The cone shaped tympanic membrane is attached to the long process of the malleus, the bottommost point is the end of the long process. The tympanic membrane is divided into four quadrants by two direct. One is parallel and one is to square to the long process.

A typical characteristic sign, a light reflex is visible in the normal tympanic membrane caused by the reflection if the examining light. Two parts of the ear drum is pars tensa built up by a stiff fibrous layer and the pars flaccida, which lacks the radial-circular fibers. The external layer of the tympanic membrane is keratinizing squamous epithelium, the internal surface is mucosal layer of the tympanic cavity. The eardrum is attached to its bony groove by the annulus fibrosus which is a thickening of the edge of the tympanic membrane formed by fibrous fibers.

**The function the middle ear** is the transduction of the sounds to the fluid spaces of the inner ear. During the acoustic fitting a enhancement is developed by the length difference between the long process of the malleus and incus together with sound shading of the round window. The sound energy is not propagated to the oval and round window at same time.

**Important anatomic structures of the tympanic cavity.**

Posterior wall: bony canal of the facial nerve, pyramidal eminence with the tendon of the stapedius muscle and the chorda tympani. Inferior wall: bulb of the jugular vein. Superior wall: adjacent to the scala media by the tegmen tympani. Anterior wall: internal carotid artery and the opening of the Eustachian tube. Medial wall: behind the promontorium the cochlea is localized. The round and the oval window with the footplate of the stapes are also visible in this wall. Above the oval window runs the horizontal part of the facial nerve’s bony canal.

These anatomic structures are often involved in the inflammations of the
middle ear. Most frequent complications are facial nerve paresis, labirinthitis, meningitis, epidual or intracerebral abscesses. (see also in the diseases of the middle ear chapter).

**The middle ear cavity** is divided into three parts according to the level of the tympanic membrane.

Above the level of the tympanic membrane: epitympanic recess of attic with the head of the malleus, the body of the incus and lot of ligaments and mucosal folds and pockets together with the chorda tympani. In the level of the membrane: mesotympanum. Under its level: hypotympanic recess.

Between epi and mesotympanum there is an anatomic constriction which can lead to retention of secretions in inflammation and deficient aeration of the attic. This results the development of chronic epitympanitis and the cholesteatoma (an important form of the chronic middle ear inflammation).

Further narrow zone is the junction of the attic and mastoid antrum which may be closed by swollen mucosa or granulation tissue blocking the aeration and drainage of the mastoid cell system.

The pneumatization of the temporal bone shows great variability. Pneumatic system can be well developed and extended involving the occipital region and the zygomatic arch, but it also may be composed of compact bone. In the latter case air containing cells are restricted near by the antrum. The mastoid process begins to develop after birth, consist of spongy bone. Between the 2nd and 5th years of life pneumatization proceeds and completes between 6th and 12th years of life. Obstruction of the aeration of this region in childhood due to regular middle ear inflammations interferes the formation of pneumatized cells. In these cases inflammatory process may be concealed in the depth and lead to unexpected complications.

Pneumatization of the petrous pyramid may result petrositis. Very rarely purulent liquefaction set up in the cells of the petrous apex accompanied by osteomyelitis. Due to the close relationship to the trigeminal and abducens nerve Gradenigo’s triad may occur: otorrhoea, ipsilateral, trigeminal neuralgia, abducens paresis). VII., IX., and X. cranial nerves may also be involved.

**I/3.3.: Inner Ear**

**Inner ear** is divided into two parts: the acoustic and vestibular organ. The acoustic part consists of the cochlea, the vestibular part consists of the vestibule and semicircular canals, utricle and saccule. Ductus and saccus endolymphaticus joined to the vestibular system end in a blind sac lying in the epidural space on the posterior surface of the petrous pyramid. The perilymphatic system communicates directly with the subarachnoid space via the cochlear aqueduct.
3. picture: Structure of the inner ear

Blood supply arises from labyrinthine artery (art. cerebelli anterior inferior) via rich collateral branches.

In the cochlea scala vestibuli and tympani filled with perilymph, which potassium concentration is low but sodium concentration is high compose a common fluid space in the apex of the cochlea (helicotrema).

Reissner’s membrane and lamina basilaris separates ductus cochlearis (scala media) from scala vestibuli and tympani. Ductus cochlearis is filled with endolymph, a high potassium and low sodium content fluid, communicates with the endolymph of utricle, saccule and semicircular canals.

Movements of the stapes produce a traveling wave on the basilar membrane (Békésy’s traveling wave theory). The wave length becomes shorter as the wave approaches the helicotrema, but amplitude becomes greater. The amplitude reaches a maximum at one specific point and then immediately ceases. This frequency dependent mechanism determined by the physical build-up of the cochlea. High frequency sounds at the base of the cochlea, low frequency sounds at the apex are detected. This traveling wave is frequency specific way augmented by the active movements of outer hair cells.

4. picture: The function of the organ of Corti

Displacement between the tectorial membrane and the basilar membrane generates the movements of the hair cells cilia. Lateral connections between cilia construct solid rigid bundle, and cilia bend as a uniform structure. Apical connection join to potassium channels and can follow the basilar membrane movements at a high speed. Due to this mechanism receptor cell is depolarized by the opening of the potassium channels.
SV scala vestibuli, SM scala media, ST scala tympani, MB basilar membrane, RM Reissner’s membrane, SV* stria vascularis, TM tectorialis membrane, IHC Inner hair cell, OHC outer hair cell, PS pillar cells, DS Deiter’s cells, CS Claudius cells, SG spiral ganglion cells and fibers.

Receptor cells, the inner and outer hair cells are surrounded by supporting cells. Corti’s tunnel is framed by inner and outer pillar cells. Outer hair cell are not located on the basilar membrane but hold by Deiter’s cells. Laterally Hensen, Claudius and outer sulcus cells farther stria vascularis rank. Apical pole of hair cells and processes of supporting cells construct the reticular lamina which is a gap free membrane. This and the Reissner’s membrane have chemical separating function, these are the border of endolymph space. Only the apical pole of the hair cells, only cilia are connected with the endolymph, outer hair cells lateral wall belongs to the perilymph space.

Endolymph is a filtrate of perilymph, but the high potassium concentration is kept constant by stria vascularis’s active transport pumps. Endolymph’s potential (endocochlear potential) is high, +80mV. Intracellular receptor potential is -80mV. The voltage difference between the two side of the receptor cell apical membrane is significant (160mV) and potassium concentration difference is also important.

In normal position cilia are in upright position, about 15% of the ion channels are in open state, so potassium flows through the apical pole of the receptor cells into the intracellular space and leave though the lateral membrane toward the strain vascularis via the supporting cells. Bending of the cilium bundle toward the highest cilium generate a greater potassium influx and depolarize the cell, in the opposite direction channels’ open probability is reduced and hyperpolarization is evoked. Permanently
flowing potassium current is modulated by bending of cilia, and this process can follow the basilar membrane’s movements at a high velocity.

**Depolarization** liberates neurotransmitters at the basal pole of the inner hair cells and action potential is evoked in the fibers of the acoustic nerve so information is transmitted to the central nervous system (brainstem nuclei - lateral lemniscus - inferior colliculus - medial geniculate body - auditory cortex).

Depolarization of outer hair cells create the voltage dependent conformation changes of the motor protein localized in the lateral membrane. This means the voltage dependent contraction and elongation of the cell, which develop at the incoming sound’s frequency. Since outer hair cells cilia are embedded in the tectorial membrane their movements supply positive energy feedback against the system’s high incapacity, viscous damping. Outer hair cells giving an augmentation to the information arriving to the inner hair cells are responsible for the great sensitivity and frequency selectivity of the inner ear.

Functional damage of outer hair cells causes the elevation of the hearing threshold and deterioration of the nerve fibers sharp tuning curves

**Innervations of Inner hair cells** is mainly afferent, several nerve fibers end on each cell, while outer hair cell innervations is mostly efferent.

All afferent fibers has a spontaneous activity without acoustic stimulation and their stimulus threshold is different. The stimulus threshold of high activity fibers is lower. All fibers are most sensitive to one special frequency (characteristic frequency), for this stimulus threshold is lowest.

Frequency analysis begins at the development of the travelling wave, amplitude maximum arises at a frequency specific place and the appropriate inner hair cells and nerve fibers will come to operation. With increasing sound intensity the action potential rate in the nerve fibers will be elevated and the number of stimulated afferent neurons also increases.

Central nervous system also analyses the temporal pattern and the periodicity of action potentials

**Vestibular organ** consists of the utricle, saccule and semicircular canals which are located three different directions spatially.

Utricle and saccule enclosing the static maculae are the end organs of linear accelerator stimulation. Hair cells cilia are embedded in gelatinous mass, with otoliths (statoconia) on its surface. Linear acceleration changes the otolith pressure and deflects cilia. This stimulates the sensory cells by modulation of the resting potential.

Semicircular canals have a pear shaped expansion, the pars ampullaris, where cilia of the sensory cells extend to the cupula which reaches the roof of the ampulla. The cupula is a mobile structure, closes the pars ampullaris.

The central nervous system analyses the information from the vestibular system, muscle tone and position and visual information, establishes and sustain the position of the body, walking and movement coordination.

Similarly to the hearing action potentials arrive permanently from the vestibular system even in resting position. Bending cilia of the receptor cells elevate action potential frequency, in the opposite direction decreases.

Accordingly we can detect the movement in two different directions by the
modulation of action potential originated from one receptor cell.

Semicircular canals in the two inner ears react to a movement opposite way.

In one canal angular acceleration generates ampullopetal (toward the utricle) depolarizing, while in the other ear ampullofugal hyperpolarizing reaction evoked.

Vestibuloocular reflexes operate eye movements according to the head movements, spinal reflexes keep the position of the body by operating the muscles. Movement of the head in one direction will provoke a slow conjugated movement of the eyes in the opposite direction, so we can fix the field of vision on the retina. This is the slow component of nystagmus. The fast component in the opposite direction is also regulated by reflexes.

The connection between the fluid movement in the semicircular canals and the eye movements is described by the Ewald laws.

1.) The eye movement tracks the head movement in the stimulated semicircular canal’s plane and the slow phase of nystagmus shows to the endolymph flow’s direction.

2.) The movement of the endolymph toward the ampulla –ampullopetal endolymph flow- has a stimulating effect in the lateral semicircular canal.

3.) The ampullofugal endolymph flow in the anterior and posterior semicircular canal also has stimulating effect

Diseases of the vestibular system will be discussed in details in the vestibular chapter.